MANAGEMENT AND REHABILITATION OF THE SILVERMINES AREA

PHASE II REPORT:
MANAGEMENT OPTIONS

Prepared for:

DEPARTMENT OF MARINE AND NATURAL RESOURCES

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Report U1606/2 **MARCH 2002**

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SUMMARY

MANAGEMENT & REHABILITATION OF THE SILVERMINES AREA
PHASE II REPORT: MANAGEMENT OPTIONS

This report covers the second phase of the study for the management and rehabilitation of the Silvermines area, and is concerned with the available management and rehabilitation options.

INTRODUCTION

The Silvermines area of County Tipperary has been mined for over a thousand years for lead, zinc, copper, silver, baryte and sulphur. The last mine, Magcobar, closed in September 1992. 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. Figure 1 is an annotated orthophoto showing the main features of the study area. The yellow outline represents the extent of the study area.

The waste products contain heavy metals, which are mobilised after heavy rain, entering the streams. In the past, the tailings impoundments have also produced dust blows, with the wind-blown particles containing heavy metals. The metal of most concern has been lead, and there have been cattle deaths caused by lead poisoning. It is primarily these deaths and the dust blows which have alerted the authorities to the need to undertake closure and rehabilitation measures to reduce the risk to human and livestock 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. These have been included in the present investigation.

A number of studies have been carried out to investigate the problems and, in 2001, the Department of Marine and Natural Resources (DMNR) appointed SRK Consulting to prepare conceptual designs for the management and rehabilitation of the Silvermines region, over an area of about 2,300 ha. This design was to include five specific sites identified as requiring treatment:

- *Gortmore tailings management facility (TMF);*
- *Tailings at Shallee;*
- *Lagoon and settlement pond at Garryard;*
- *Ballygown area and ground to the south of Silvermines village; and*
- *Magcobar pit and waste dumps.*

The work was to include any other sites within the study area requiring remediation. Although particular problem areas were identified, the problems are linked and it was recognised by all concerned with the study that the Silvermines area must be dealt with as a whole. It was required to present separately the subset of those work plans which correspond to works which Mogul of Ireland might be asked to carry out under Clause K of their State Mining Lease.

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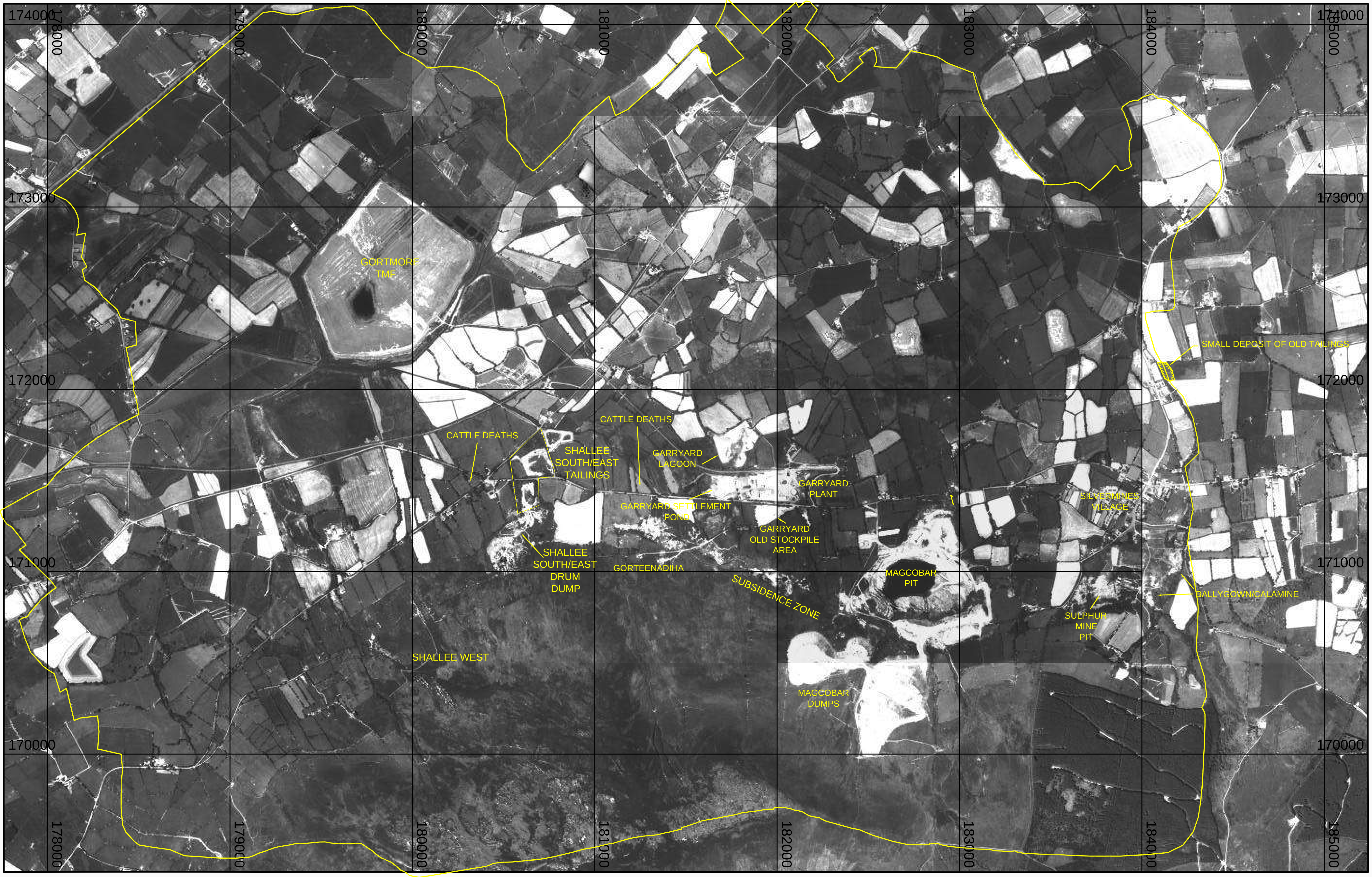

April 2001	PROJ. No: U1606	SILVERMINES	1:20,000
SRK Consulting Engineers and Scientists		THE STUDY AREA	Fig 1

THE STUDY

The study was to be carried out in three stages:

- *Phase I, review of available information,;*
- *Phase II, management options; and*
- *Phase III, conceptual design of selected options.*

The report on the Phase I study was concerned with the review of the large amount of documentary information, the identification of gaps in the data, the identification of potential remedial measures, and the definition of the work required for Phase II.

THE SITE WORK

The study was undertaken on the basis that the available information would be sufficient for the preparation of the conceptual design for management of the site. It was appreciated that the Phase I review of available information might identify minor gaps in the data, and the intention was that, during Phase II, these gaps would be filled.

During Phase I, the need for a limited amount of additional sampling and testing of water and soils was identified, and this was carried out during Phase II. It was also found that there was very little groundwater information and, as a result, DMNR authorised additional drilling and testing. In addition, Phase II included the completion of observational work on the site, comprising the photographic record, the surface inventory and the assessment of the mining heritage. This work was limited and delayed during Phase I by the foot and mouth restrictions.

The ecology of the area, both habitats and vegetation, was reviewed, with site inspections and the examination of the available data and publications. This information was used in the assessment of re-vegetation options and sustainability in Phase II.

As a result of the foot and mouth restrictions and the additional groundwater study, the programme was extended, with the reports to be submitted at the end of December 2001.

INDUSTRIAL HERITAGE

The Shallee Mine is considered to be a unique survival, worthy of preservation, conservation and utilisation. Major archaeological sites have also been identified at Ballygown, Gorteenadiha, and the old copper mining at Magcobar. These sites should be protected.

Detailed recording of structures on all these sites should be carried out, and public consultation should take place before finalising the programme for conservation and usage. This usage may include the establishment of a centre for Mining Heritage and a walking trail linking the sites.

RIVER AND STREAM CONTAMINATION

During the Phase II study, sampling of surface water and soils was carried out to supplement the data already available. The main purposes were to identify the significant sources of elevated metals in the water courses, and to quantify the elevated metals from each sub-catchment. This information has been used in the design of *the remedial measures to reduce the heavy metal content of the water courses, and as baseline data for the monitoring of the results of the remedial works.*

The results confirmed that surface water in all parts of the study area contains elevated metals. Most of this loading is particulate material. The metals include lead, barium, cadmium, zinc, iron and manganese.

GROUNDWATER

A drilling investigation was carried out to supplement the available information on geology, groundwater levels, groundwater aquifer properties and groundwater quality. Thirteen holes were drilled and sampled at Ballygown, Garryard, Shallee and Gortmore, to determine the effect of the mining works and waste deposits on the groundwater. Pump tests were carried out in two boreholes, and double piezometers were installed in four.

The results showed a low permeability in the limestone aquifer matrix, with higher permeabilities associated with fracture features. The overlying alluvial aquifers are more susceptible to potential contamination, but there is no evidence of significant effects of mining on groundwater levels or quality. No active remedial measures for groundwater are considered necessary.

Mercury was detected in two boreholes near the Gortmore TMF and one at Garryard in November 2001. Further sampling and analyses in January 2002 revealed levels of mercury below the detection limit, confirming that mercury levels in the groundwater are insignificant.

DUST

No dust investigation has been carried out in the Phase II study, but the available monitoring information has been reviewed. There have been no significant dust blows from Gortmore TMF since the dust blows of the 1980s, because of the vegetation cover on the impoundment. The remedial design for Gortmore TMF will include measures for the improvement and maintenance of the vegetation.

MINE STABILITY

The available plans and reports have been reviewed, and it has been concluded that future subsidence of the Mogul underground workings will be confined to the present subsidence zone with some possible expansion to the north.

WASTE DUMP STABILITY

The Magcobar dumps are granular and relatively free-draining. With continued maintenance of the surface water drainage system, these dumps will remain stable. No problems are anticipated with the Shallee South/East tailings dumps, or with the old tailings deposits at Ballygown.

The Gortmore TMF contains silt-sized waste, which is not free-draining and, as a result, the TMF has a high water table. There has been no deposition on the TMF for many years, however, so the tailings have consolidated, and are therefore more stable than they were during the operating life of the mine. No stability problems will occur under present conditions, and the proposed works including the waste disposal facility on the upper surface will not cause instability. The stability should be confirmed during the detailed design and if there is any future change in geometry or water management.

HAZARD IDENTIFICATION

The list of key hazards is as follows:

HAZARD	***KEY SOURCE***
Stream water contamination and sediment loads	*Garryard Old Stockpile*
	Garryard Tailings Lagoon
	Shallee South/East Drum Dump
	Ballygown old tailings
	Ballygown waste dumps
Dust potential	*Gortmore TMF poorly-vegetated sections*
Risk to human life	*Open shafts and surface workings*

There are numerous other minor problems requiring remediation, but the six items listed above are the most significant. All problems, both major and minor, are considered in the Phase II report.

DISPOSAL OF WASTE MATERIAL

The remediation of the study area will result in the disposal of quantities of contaminated soil and waste materials:

- *Ballygown – disposal of asbestos roofing and possible concrete;*
- *Ballygown – about 100m^3 of mine waste from vicinity of Silvermines Stream;*
- *Magcobar – about 200m^3 of sulphide waste from dump area;*
- *Magcobar – disposal of scrapped crushing plant and associated structures;*
- *Garryard – about 14,000m^3 of ore and process waste from Old Stockpile;*
- *Garryard – about 22,000m^3 of process waste from Tailings Lagoon;*
- *Garryard – disposal of general scrap and waste from the site and old hostel building;*
- *Dredging of stream sediments, annual or biennial, quantities unknown; and*
- *Shallee – segregation and disposal of ore, process waste and scrap metal, about 4,000m^3.*

These estimated quantities are not based on measurements and actual quantities must be confirmed during the detailed design.

This material will be disposed of at a remote site or at a suitable location within the study area, which could be the surface of the Gortmore TMF. The options are under review. The waste materials at Shallee include large quantities of metal drums, cables and other mine debris, and would require separate disposal off-site, probably at a designated site in Shannon.

REMEDIATION OPTIONS

A detailed risk assessment has been carried out for the study area and the remediation options have been considered. The main features of the preferred options are:

- *general upgrading and maintenance of surface water system;*
- *conservation of mining heritage features of Ballygown and Gorteenadiha;*

- *conservation of Shallee South/East as mining heritage site with visitor facilities;*
- *possible establishment of a heritage trail linking the mining features of the Silvermines area;*
- *removal of contaminated materials from areas as listed above, and deposition on a designated disposal site, which may be the Gortmore TMF;*
- *construction of temporary silt retention structures for discharges from Gorteenadiha area and Ballygown;*
- *segregation of drums and other waste from Shallee South/East and disposal on a designated licensed site outside the study area or on site;*
- *clearing of the Garryard tailings lagoon and redevelopment as a wetland treatment pond;*
- *establishment of a wetland treatment pond for water discharged from Shallee South/East;*
- *minor earthworks at the Gortmore TMF, upgrading of pool decant and retention ponds; and*
- *application of a growth medium to parts of the Gortmore TMF and re-establishment of vegetation.*

PHASE III

The Phase II report, giving the options and proposing preferred options, provides the information on which the Phase III Conceptual Design will be prepared and costed. A programme will be prepared for implementation.

APPENDIX D

GEOPHYSICS

GEOPHYSICAL SURVEY REPORT

PROJECT

INVESTIGATION OF THE SHALLOW GEOLOGICAL STRUCTURE

LOCATION

SILVERMINES
COUNTY TIPPERARY, IRELAND

CLIENT

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November 2001
Version 1

1. INTRODUCTION

This report describes a geophysical survey carried out on behalf of SRK Consulting at Silvermines, County Tipperary, Ireland. The aim of the geophysical survey was to provide information on the underlying geological structure and identify suspected zones of mine-waste contamination.

2. SURVEY DESCRIPTION

The geophysical investigation was carried out using two geophysical survey techniques, namely, *Resistivity Tomography* and *Ground Conductivity.*

2.1 Resistivity Tomography

Survey Description

An ABEM LUND resistivity system configured with a Wenner-Schlumberger electrode array was used to acquire resistivity data along a series pre-selected profile lines (Figure 1). The position of the profile lines reflects the proposed distribution of new boreholes, field boundaries and general access constraints. As an optimal compromise between resolution and depth of penetration, a minimum electrode spacing of 5m was adopted for the survey. However, in order to improve the resolution of the shallow sub-surface, the minimum electrode spacing was decreased to 2.5m for line Res-2.

Background

Acquisition of resistivity tomography data involves the deployment of regularly spaced electrodes along a survey line, which in turn are connected to a central control unit via multi-core cables. Resistivity data are then recorded via complex combinations of current and potential electrode pairs to build up a pseudo cross-section of apparent resistivity beneath the survey line. The depth of investigation primarily depends on the electrode spacing, with greater electrode separations yielding bulk resistivity measurements to greater depths.

Electrical properties are among the most useful geophysical parameters in characterising Earth materials. Variations in electrical resistivity typically correlate with variations in lithology, water saturation, fluid conductivity, porosity and permeability. Depending on the particular site, these variations may be used to map stratigraphic units, geological structure, sinkholes, fractures, and groundwater.

Measured *apparent resistivity* data are plotted initially as a ‘pseudo-section’ image based on the current and potential electrode separations or "n" level and horizontal position of the centre of the active electrodes. This term 'pseudo-section' means that the measured values are only *apparent* in terms of magnitude, location and depth. The modelled true subsurface resistivity/chargeability image is then derived from finite-difference forward modelling via RES2DINV software.

Data processing is based on an iterative routine involving determination of a two-dimensional (2D) simulated model of the subsurface that is then compared to the observed data and revised. Convergence between theoretical and observed data is achieved by non-linear least squares optimisation. The procedure is smoothness constrained to improve stability in the iterative process, the degree of smoothness being determined by a user-specified damping factor. The extent to which the observed and calculated theoretical models agree is an indication of the validity of the true resistivity model (indicated by the final root-mean-squared (RMS) error).

The true resistivity models are presented as colour-scaled contour plots of changes in subsurface resistivity with depth. The 2D method of presenting resistivity data is limited when irregular or complex geological features are present where the simple cross-section may not be indicative of the true geometry.

Geological materials have characteristic resistivity values that enable identification of boundaries between distinct lithologies. However, at some sites there are overlaps between the ranges of possible values for the targeted materials, which therefore necessitates additional use of other geophysical surveys and/or drilling to confirm the nature of identified features.

Constraints

Readings can be affected by poor electrical contact at the surface or by the presence of geo-electrical noise sources e.g. services, rebars & other metal structures. An increased electrode array length is required to locate increased depths of interest therefore the site layout must permit long arrays. Resolution of target features decreases with increased depth of burial.

2.2 Electromagnetic (Ground Conductivity; EM)

Survey Description

A GEONICS EM-38 and integrated dGPS system were used to acquire ground conductivity data over a number of pre-selected survey grids (Figure 1). The integrated system was mounted in a non-metallic trailer and towed behind a quad-bike along 6m separated survey lines. The EM-38 was configured in the vertical dipole mode, providing signal response to a depth of approximately 1.0m below ground level.

Background

Electromagnetic (EM) surveys are carried out using man-portable instruments with readings taken on a regular grid or along selected traverse lines. The equipment functions by inducing current into the ground via a transmitter coil which causes the generation of secondary electromagnetic fields in any ground conductors present within the depth range of the particular instrument. These secondary fields are measured at a receiver coil and the instrument produces both ground conductivity and metal detector data at each survey station. Conductivity readings are reported in milliSiemens per meter (equivalent to millimhos per meter) and metal detector readings are generally reported in parts per thousand of the total field.

Data are recorded on site via an automated logger and subsequently downloaded to a field computer at the end of each day. The data are then processed to enhance any identifiable anomalies and presented on colour-contoured plans overlain with site maps where available.

Constraints

Power lines buildings, metal structures (fences, rebars, vehicles, debris etc.) and buried services can interfere with the electro-magnetic measurements.

3. RESULTS & DISCUSSION

3.1 Resistivity Tomography

The results of the resistivity survey are presented in Figures 2 and 3 as scale sections of the subsurface showing depth (below ground level) on the vertical axis and distance along the profile on the horizontal axis.

The interpretation of the resistivity tomography data is based on the known physical properties of *sand/granular deposits*, which are generally resistive, and *clay minerals*, which are very conductive (Table 1).

Resistivity (ohm.m)	**Description**
Low	Clay-rich sediment or zones of groundwater saturation
Intermediate	Mixed sediments
High	Dry, granular material, clay-deficient sediment, bedrock

Table 1- Relative guide to resistivity values

Given the typical resistivity values of clay-rich/drift material (< 100 ohm.m) and limestones (>600 ohm.m), resistivity boundary based on the 540 ohm.m contour has been selected to represent the limestone rockhead boundary. The selected resistivity boundary should be used for guide purposes only and once the borehole information becomes available, it will be possible to re-calibrate the range of resistivity values for the encountered sub-surface materials.

Line 1

The final modeled section comprises of relatively thin upper conductive layer overlying more resistive material. Given the range of resistivity values and the local geological information, the upper conductive layer may be interpreted as a drift unit, (comprising of both clay and sand units) overlying limestone bedrock. Between chainage 40 and 120m, the thickness of the drift sediments appear to be less 3m, however towards both ends of the profile line, there are marked increases in thickness. Given the proximity of the nearby river system, the zone of more conductive material centred at chainage 145m, may represent an in-filled ‘channel’ like feature. Alternatively, this decrease in resistivity values may reflect lithological (e.g. increase in clay content) or structural (e.g. fracture zone) variations within the bedrock unit.

Line 2

The boundary between the drift layer and the limestone appears to relatively planar at approximately 3-4m below ground level. Given the proximity of the nearby river system, the zone of more conductive material centred at chainage 210m may represent an in-filled ‘channel’ like feature. Alternatively, this decrease in resistivity values may reflect lithological (e.g. increase in clay content) or structural (e.g. fracture zone) variations within the bedrock unit.

Line 3

The interpreted bedrock boundary appears to exhibit a 'terrace' like profile, increasing in depth towards the southeast.

Line 4

The thickness of the drift layer generally appears to be approximately 5-6m with a relatively planar rockhead profile. However towards the start of the line (west), the rockhead profile appears to increase in depth suggesting the onset of a possible 'channel' like feature.

Line 5

This line was acquired in the Garryard area and the observed range of resistivity values are considerably lower than those observed in profile lines 1-4. The decreases in resistivity values are believed to reflect a change in bedrock lithology i.e. increase in the clay content and correlates with the information shown on the local geological map. Due to the lack of contrast in the electrical properties, the boundary between the drift and bedrock unit is not well defined and therefore not shown on the section.

Line 6

The general decrease in resistivity values towards the southwest are believed to reflect a transitional lithological sequence. The observed zone of high resistivity values (>540 ohm.m) indicate limestone bedrock, while the intermediate zone (250-500 ohm.m) suggest either an interbedded limestone unit or a sandstone/mudstone unit. Towards the start of the line (southwest), the conductive values suggest a further increase in clay content. Alternatively, the observed decrease in resistivity values could also indicate an increase in groundwater saturation due to increase permeability.

Line 7

This displays a similar transitional sequence as observed beneath Line 6, i.e. a decrease in resistivity values towards the south. The lateral extent of the 'intermediate' resistivity zone (250-500 ohm.m) is much narrower; suggesting that the orientation of line 7 is closer to the dip direction of this bedrock unit. Centred at chainage 95m, there is an increase in the thickness of the upper conductive layer, indicating a possible 'channel' like feature. Given its proximity, this may be a paleo-channel feature associated with the present day stream.

3.2 Electromagnetic (Ground Conductivity; EM)

The resulting conductivity contour plans are presented in Figure 4 and 5 and the main sources of geophysical anomalies that may require further consideration are outlined in Table 2.

Conductivity (mS/m)	**Description**
High	Clay-rich sediment, increase in drift thickness or groundwater saturation.
Low	Dry, granular material, clay-deficient sediment, bedrock.
‘High’	Possible mine-waste contamination (metals).

Table 2 - Guide to interpretation of conductivity data

A number of features have been identified and reflect both lateral and vertical variations within the shallow sub-surface (~1.0m below ground level). There appears to be a high degree of correlation between the conductivity survey and the resistivity sections and variations between the two data sets are a result of the different levels of survey resolution.

In terms of considering possible mine-waste contamination, if it is assumed that the main source of contamination is ‘heavy-metals’, then key zones to target with a soil-sampling/trial pit programme would be those that exhibit increased conductivity values.

3.0 CONCLUSIONS

- The selected geophysical survey techniques have provided a rapid and non-invasive means for investigating the shallow geological structure beneath the survey area.

- The final modeled resistivity sections comprise of relatively thin upper drift layer (~3 to 6m thick) overlying more resistive bedrock units. In general, the interpreted rockhead boundary (based on 540 ohm.m contour) appears to be relatively planar with moderate undulations.

- At a number of locations, there are zones of more conductive material that given the proximity of present-day river systems, may be interpreted as in-filled ‘channel’ like features. Alternatively, these conductive zones may reflect lithological (e.g. increase in clay content/saturation) or structural (e.g. in-filled fracture zones) variations within the bedrock unit.

- Resistivity lines 5-7 were acquired in the Garryard area and the general decrease in resistivity values towards the south/southwest reflect a change in bedrock lithology i.e. increase in the clay content or groundwater saturation. Due to the lack of contrast in the electrical properties, the boundary between the drift and more conductive bedrock units becomes less defined.

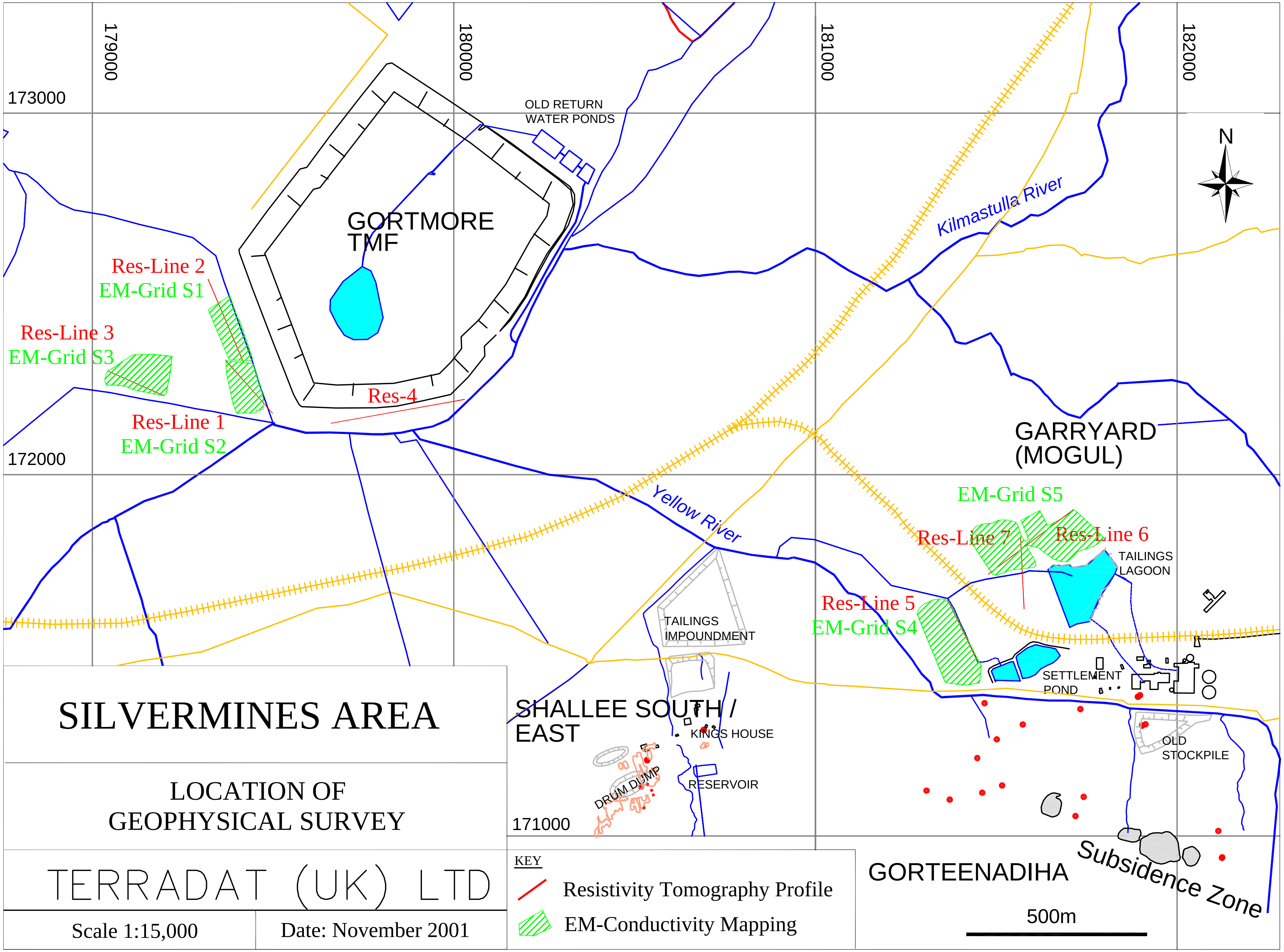
- The conductivity survey has identified a number of features that reflect both lateral and vertical variations within the shallow sub-surface (~1.0m below ground level). In terms of considering possible mine-waste contamination, key zones to target with a soil-sampling/trial pit programme would be those zones that exhibit increased conductivity values.

4.0 RECOMMENDATIONS

For each identified geophysical feature that may be of concern, it is recommended that a follow-up intrusive investigation be carried out in order to provide physical ground truthing of its origins. Once information becomes available, it will be possible to re-calibrate the range of geophysical values for the sub-surface materials.

Disclaimer

This report represents an opinionated interpretation of the geophysical data. It is intended for guidance with follow-up invasive investigation. Features that do not produce measurable geophysical anomalies or are hidden by other features may remain undetected. Geophysical surveys compliment invasive/destructive methods and provide a tool for investigating the subsurface; they do not produce data that can be taken to represent all of the ground conditions found within the surveyed area. Areas that have not been surveyed due to obstructed access or any other reason are excluded from the interpretation.



SILVERMINES AREA

LOCATION OF
GEOPHYSICAL SURVEY

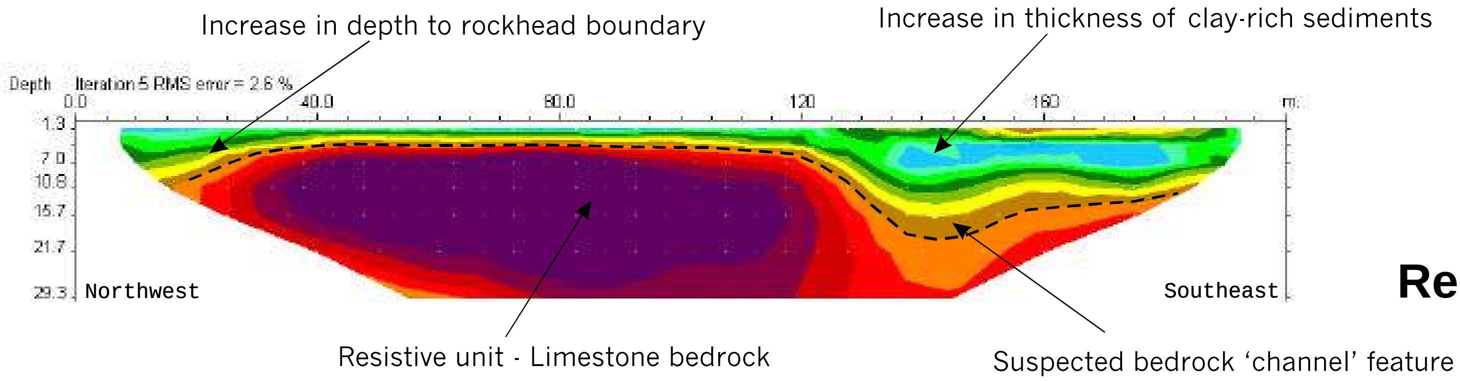
TERRADAT (UK) LTD

Scale 1:15,000	Date: November 2001

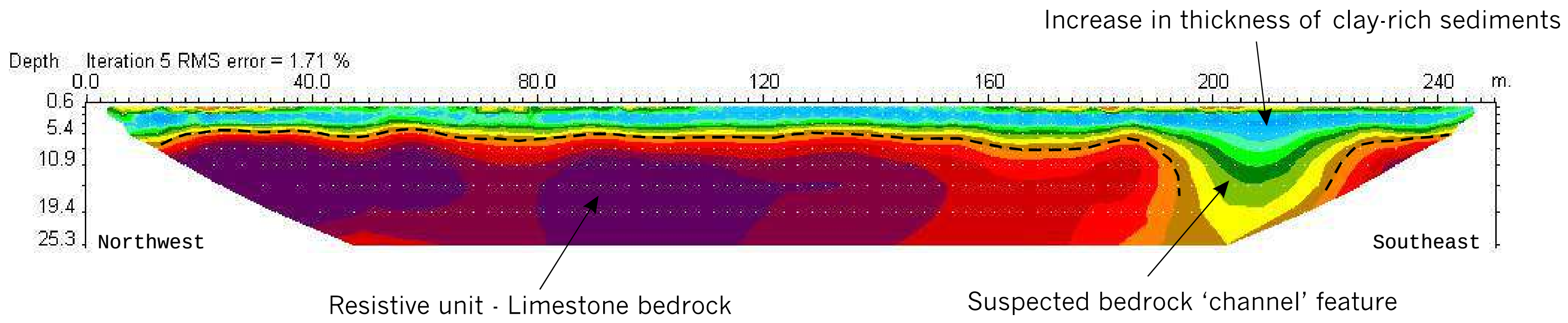
KEY

- ╱ Resistivity Tomography Profile
- ▨ EM-Conductivity Mapping

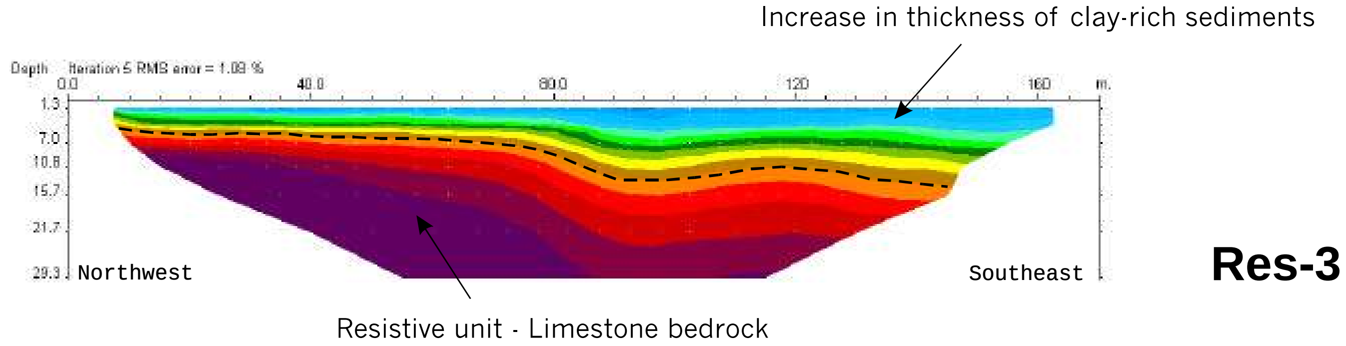
Figure 1



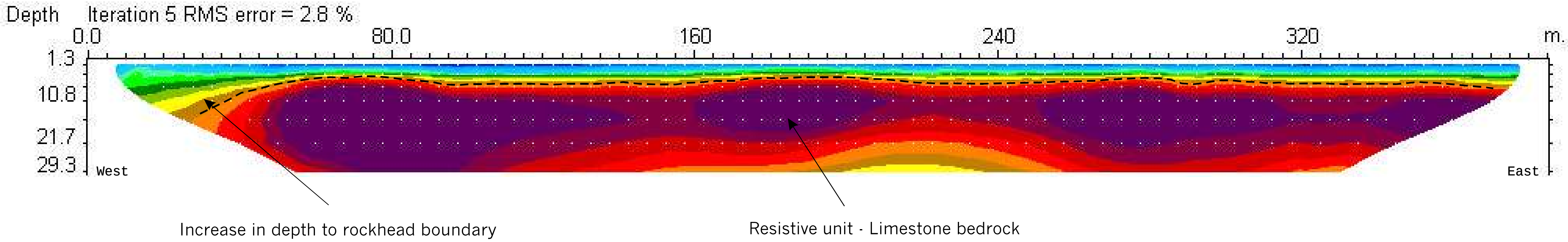
Res-1



Res-2



Res-3



Res-4

Scale
Horiz. 1:1250
Vert. 1.0 x exaggeration

No topographic correction
All depths given in metres below ground level

Start/End point Coordinates
for resistivity profile lines

		Eastings	Northings
Res-1	Start	179368	172317
	End	179499	172169
Res-2	Start	179320	172541
	End	179418	172311
Res-3	Start	179044	172286
	End	179199	172218
Res-4	Start	179660	172142
	End	180030	172208
Res-5	Start	181365	171654
	End	181452	171477
Res-6	Start	181478	171724
	End	181714	171904
Res-7	Start	181567	171829
	End	181577	171628

- - - - Rockhead (Limestone) boundary guide
(based on resistivity contour 540 ohm.m)

Resistivity Tomography
SILVERMINES
TERRADAT (UK) LTD

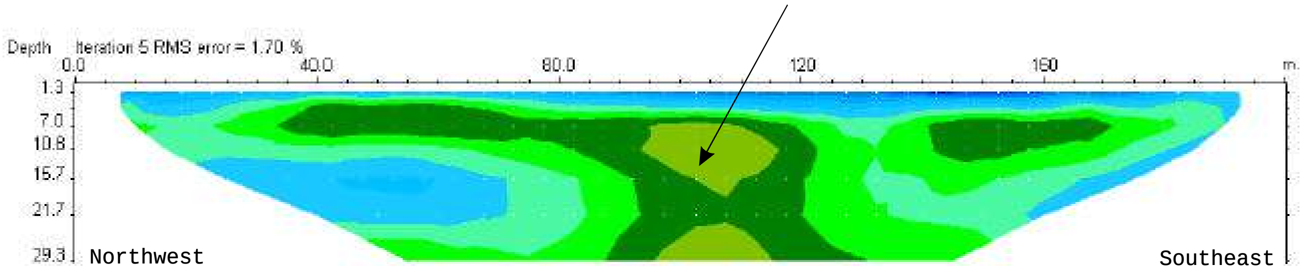
Figure 2

Scale
Horiz. 1:1250
Vert. 1.0 x exaggeration

No topographic correction
All depths given in metres below ground level

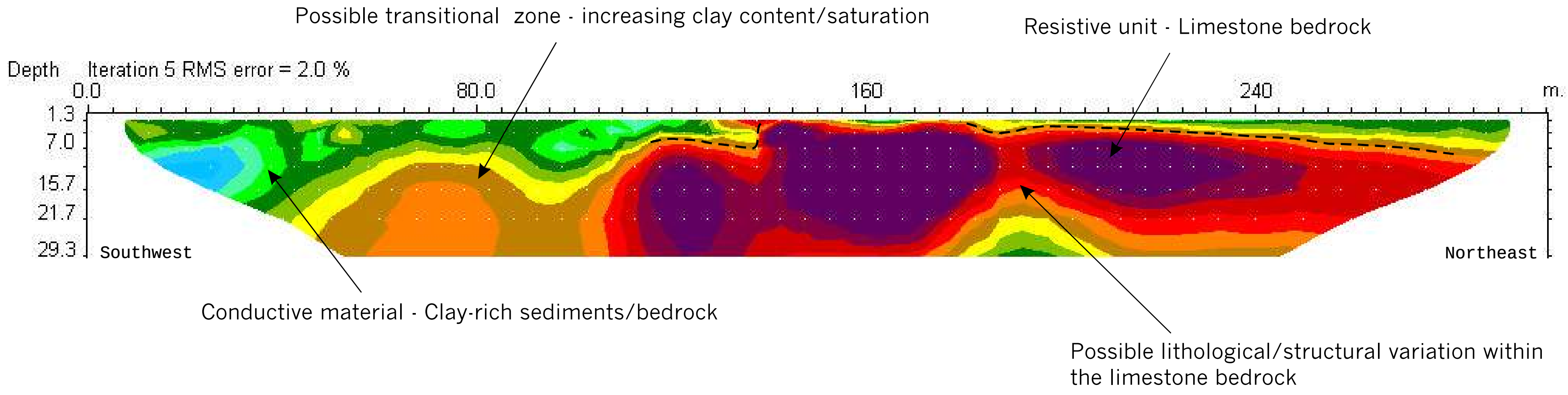
Start/End point Coordinates
for resistivity profile lines

		Eastings	Northings
Res-1	Start	179368	172317
	End	179499	172169
Res-2	Start	179320	172541
	End	179418	172311
Res-3	Start	179044	172286
	End	179199	172218
Res-4	Start	179660	172142
	End	180030	172208
Res-5	Start	181365	171654
	End	181452	171477
Res-6	Start	181478	171724
	End	181714	171904
Res-7	Start	181567	171829
	End	181577	171628



Conductive material - Clay-rich sediments/bedrock

Res-5



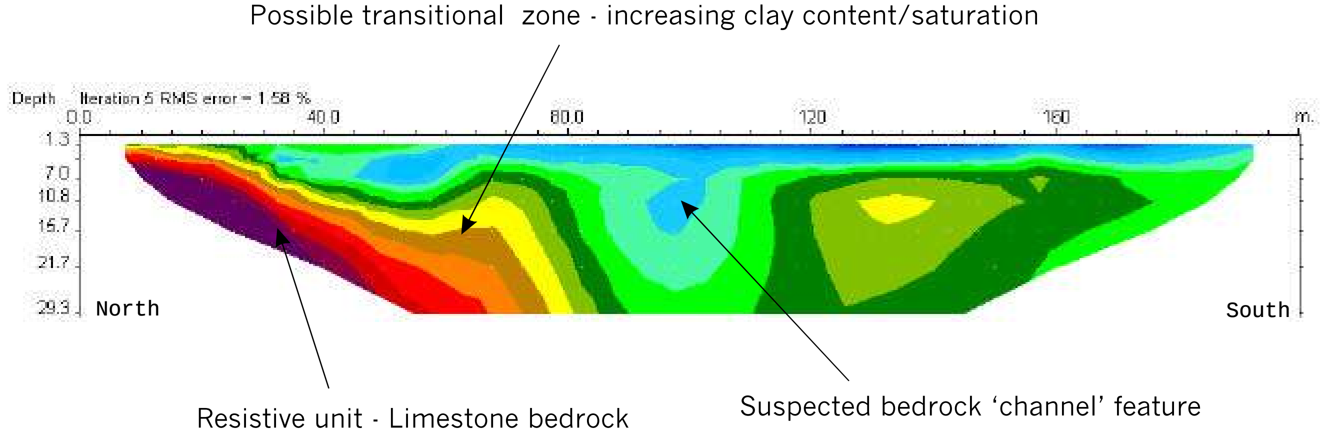
Possible transitional zone - increasing clay content/saturation

Resistive unit - Limestone bedrock

Conductive material - Clay-rich sediments/bedrock

Possible lithological/structural variation within the limestone bedrock

Res-6



Possible transitional zone - increasing clay content/saturation

Resistive unit - Limestone bedrock

Suspected bedrock 'channel' feature

Res-7

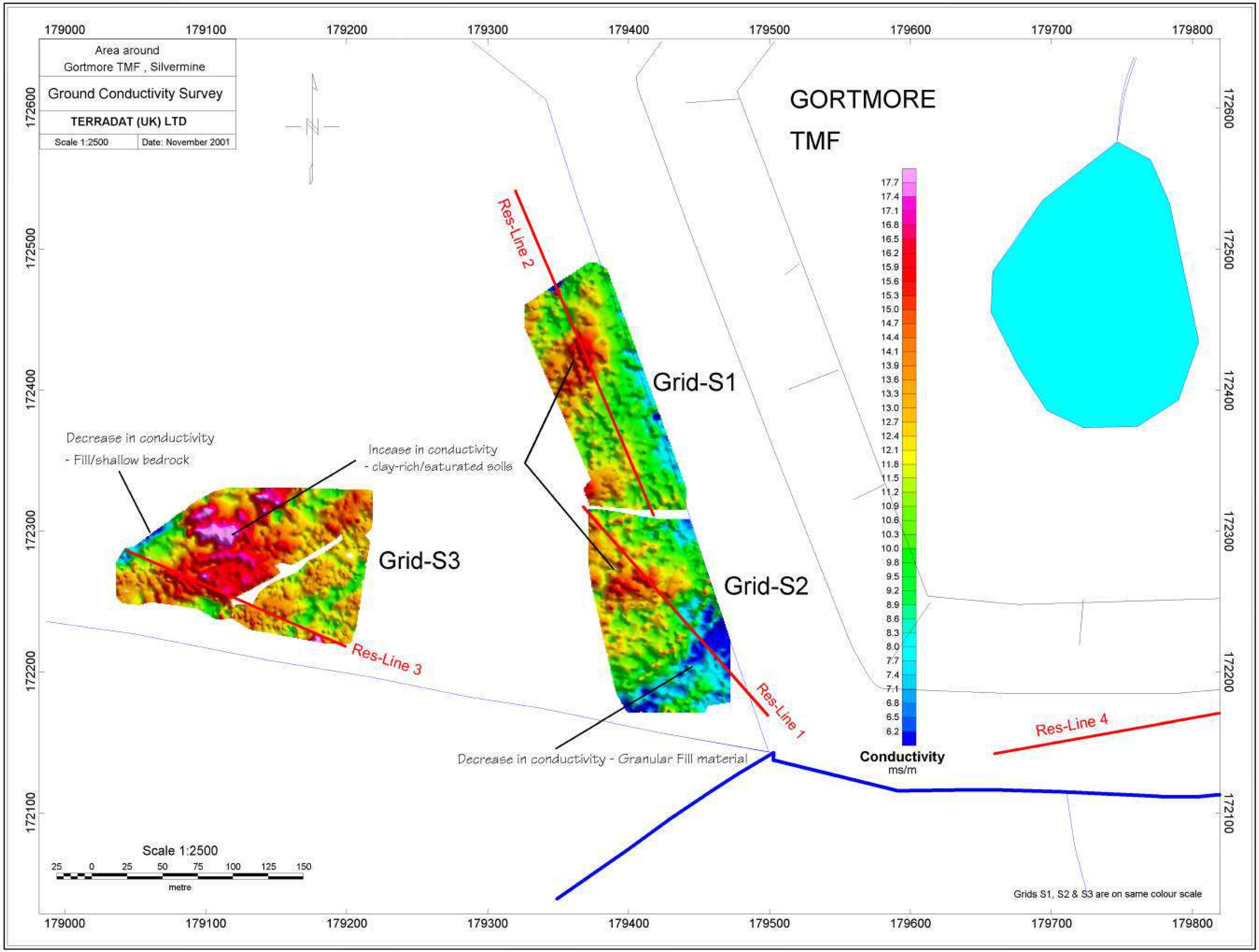
- - - - - Rockhead (Limestone) boundary guide (based on resistivity contour 540 ohm.m)

Resistivity Tomography

SILVERMINES

TERRADAT (UK) LTD

Figure 3


Area around
Gortmore TMF , Silvermine
Ground Conductivity Survey
TERRADAT (UK) LTD
Scale 1:2500
Date: November 2001
179000
179100
179200
179300
179400
179500
179600
179700
179800
172600
172500
172400
172300
172200
172100
GORTMORE
TMF
Res-Line 2
Grid-S1
Grid-S2
Grid-S3
Res-Line 1
Res-Line 3
Res-Line 4
Decrease in conductivity
- Fill/shallow bedrock
Incease in conductivity
- clay-rich/saturated soils
Decrease in conductivity - Granular Fill material
17.7
17.4
17.1
16.8
16.5
16.2
15.9
15.6
15.3
15.0
14.7
14.4
14.1
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7.4
7.1
6.8
6.5
6.2
Conductivity
ms/m
Scale 1:2500
25
0
25
50
75
100
125
150
metre
Grids S1, S2 & S3 are on same colour scale

Figure 4

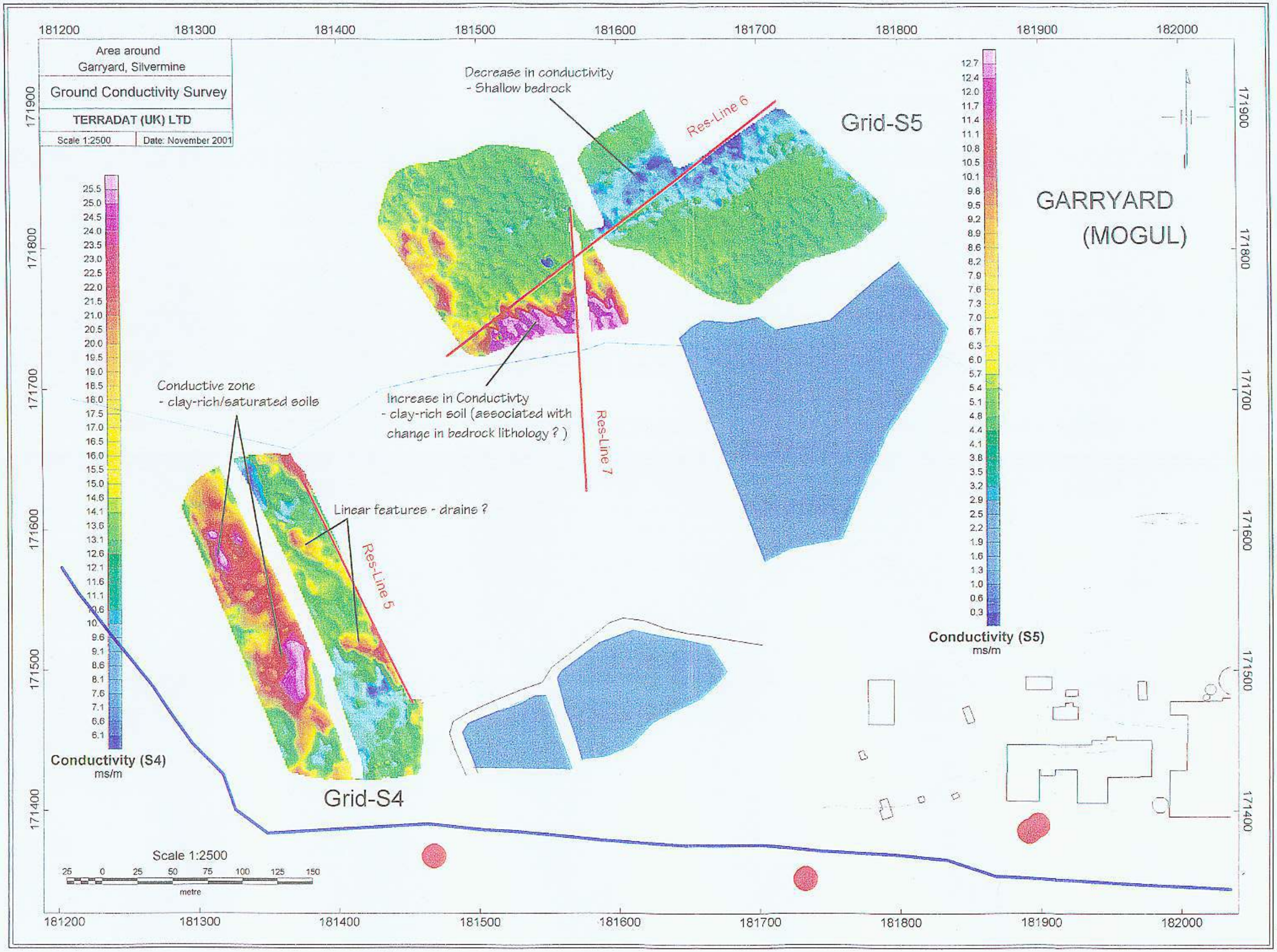

Area around
Garryard, Silvermine
Ground Conductivity Survey
TERRADAT (UK) LTD
Scale 1:2500
Date: November 2001
181200
181300
181400
181500
181600
181700
181800
181900
182000
171900
171800
171700
171600
171500
171400
Decrease in conductivity
- Shallow bedrock
Res-Line 6
Grid-S5
GARRYARD
(MOGUL)
Conductive zone
- clay-rich/saturated soils
Increase in Conductivty
- clay-rich soil (associated with
change in bedrock lithology ?)
Res-Line 7
Linear features - drains ?
Res-Line 5
Grid-S4
25.5
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.6
14.1
13.6
13.1
12.6
12.1
11.6
11.1
10.6
10.1
9.6
9.1
8.6
8.1
7.6
7.1
6.6
6.1
Conductivity (S4)
ms/m
12.7
12.4
12.0
11.7
11.4
11.1
10.8
10.5
10.1
9.8
9.5
9.2
8.9
8.6
8.2
7.9
7.6
7.3
7.0
6.7
6.3
6.0
5.7
5.4
5.1
4.8
4.4
4.1
3.8
3.5
3.2
2.9
2.5
2.2
1.9
1.6
1.3
1.0
0.6
0.3
Conductivity (S5)
ms/m
Scale 1:2500
25 0 25 50 75 100 125 150
metre

Figure 5

APPENDIX E

BOREHOLE PROFILES

SRK Consulting
Engineers and Scientists

Site Name/Project Title
SILVERMINES

Client
SILVERMINES

Borehole :
SRK/G/1

Project Number
U1606

Geologist/Engineer
R. LYNCH

Drilling Contractor: HILLYARDS
Rig Type: ~
Drill Diameter: #
Method & Medium: Rotary/hammer

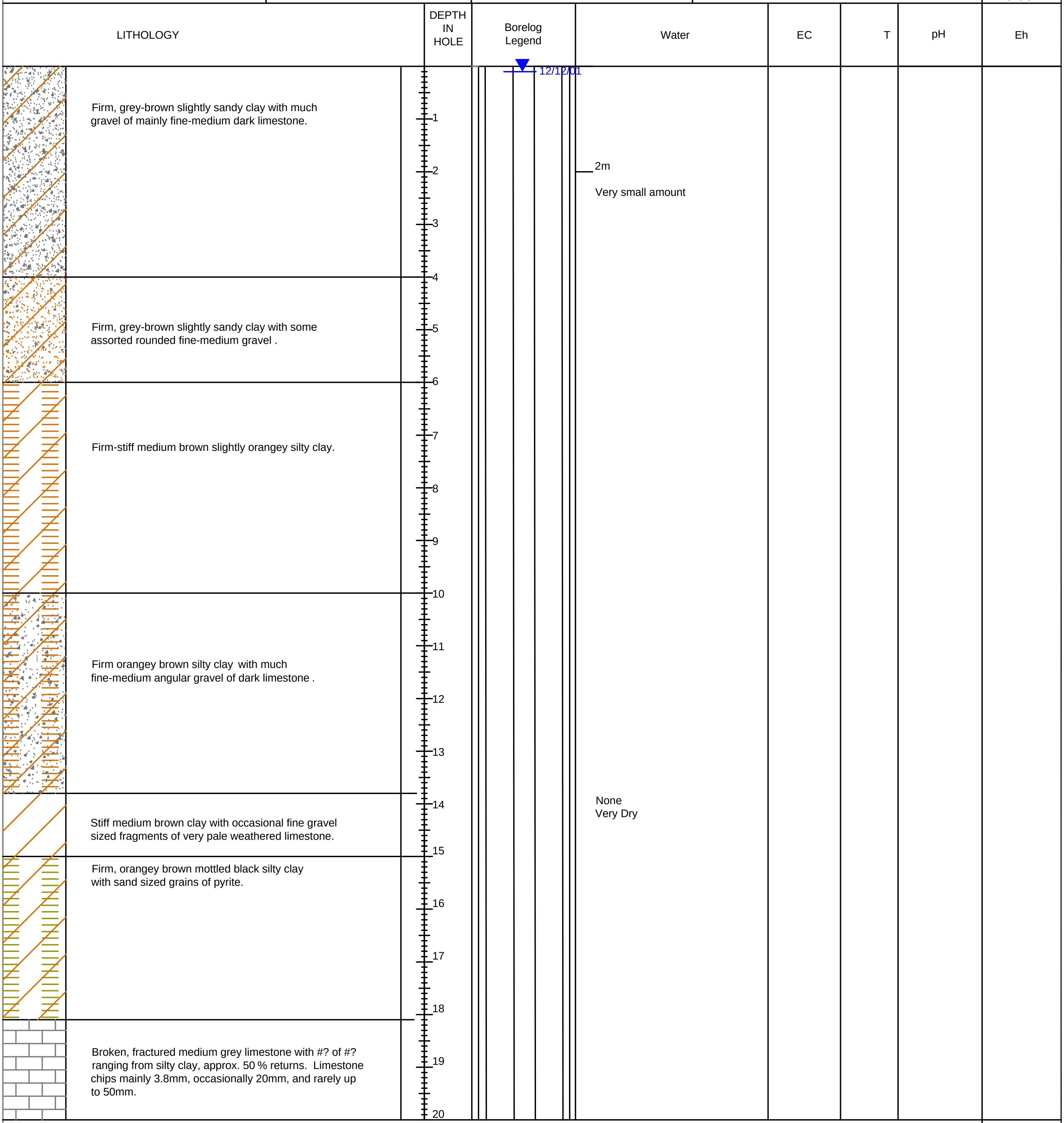
Page Number
1 of 2

Surface Level
60m
A.O.D.

Surface Location
181370E
171654N

Inclination: Vertical
Azimuth:
Start Date: 21/11/01
End Date: 24/11/01

Depth
0.00m
To
20.00m



Firm, grey-brown slightly sandy clay with much gravel of mainly fine-medium dark limestone.

Firm, grey-brown slightly sandy clay with some assorted rounded fine-medium gravel .

Firm-stiff medium brown slightly orangey silty clay.

Firm orangey brown silty clay with much fine-medium angular gravel of dark limestone .

Stiff medium brown clay with occasional fine gravel sized fragments of very pale weathered limestone.

Firm, orangey brown mottled black silty clay with sand sized grains of pyrite.

Broken, fractured medium grey limestone with #? of #? ranging from silty clay, approx. 50 % returns. Limestone chips mainly 3.8mm, occasionally 20mm, and rarely up to 50mm.

2m
Very small amount

None
Very Dry

Cont'd

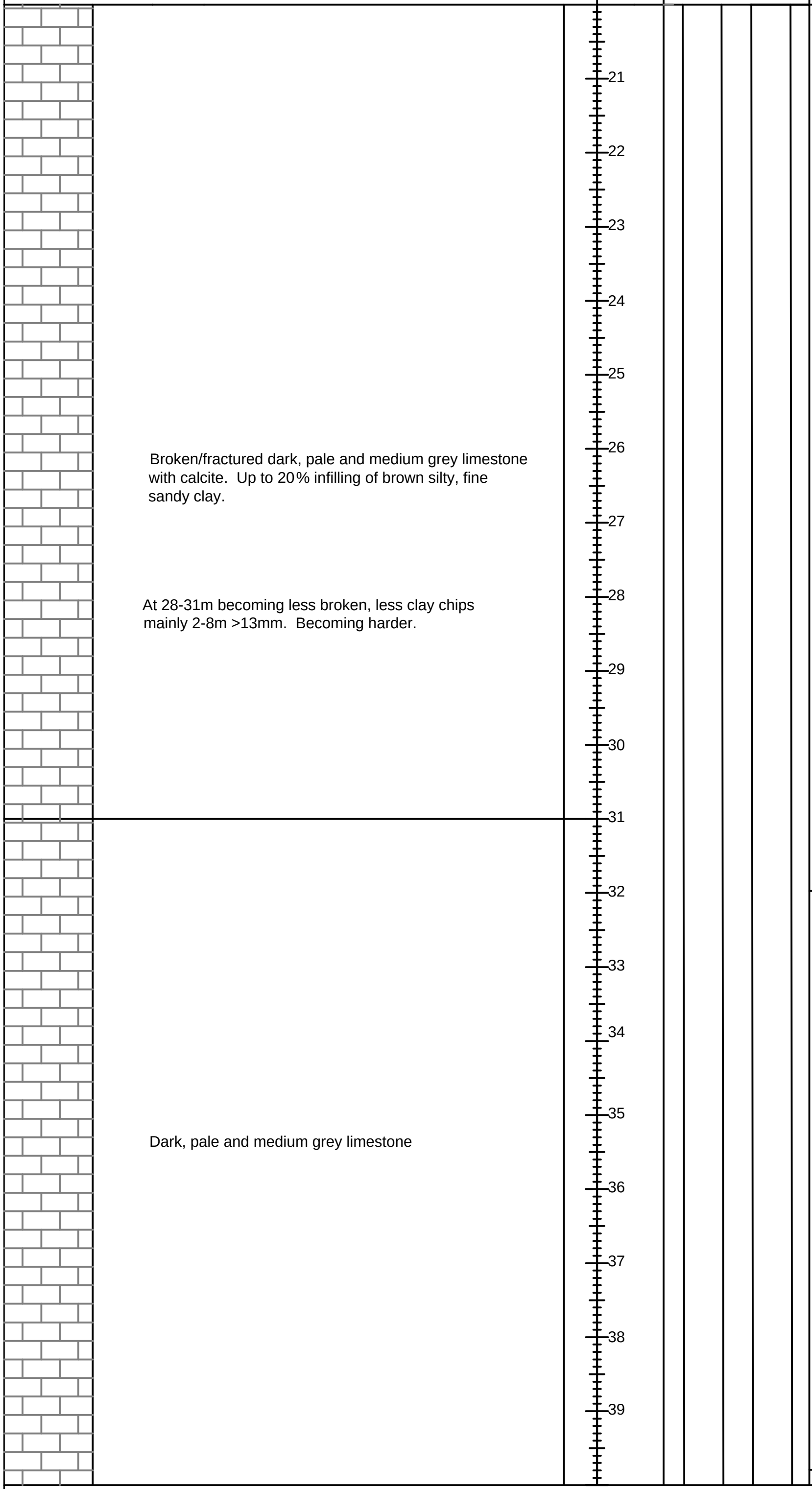
Not to Scale

KEY

▨ CLAY
▤ SILT
▒ SAND
░ GRAVEL
▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES		Borehole : SRK/G/1
Project Number U1606	Geologist/Engineer R.LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer		Page Number 2 of 2
Surface Level 60m A.O.D.	Surface Location 181370E 171654N	Inclination: Vertical Azimuth: Start Date: 06/11/01 End Date: 07/11/01		Depth 20.00m To 40.00m



LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Broken/fractured dark, pale and medium grey limestone with calcite. Up to 20% infilling of brown silty, fine sandy clay. At 28-31m becoming less broken, less clay chips mainly 2-8m >13mm. Becoming harder.			Dry				
Dark, pale and medium grey limestone			32m 0.2 l/s 0.3 l/s	528	16.9	7.3	218
Develop.		EOH		525 540	16.4 16.5	6.4 6.5	20(?) 20(?)

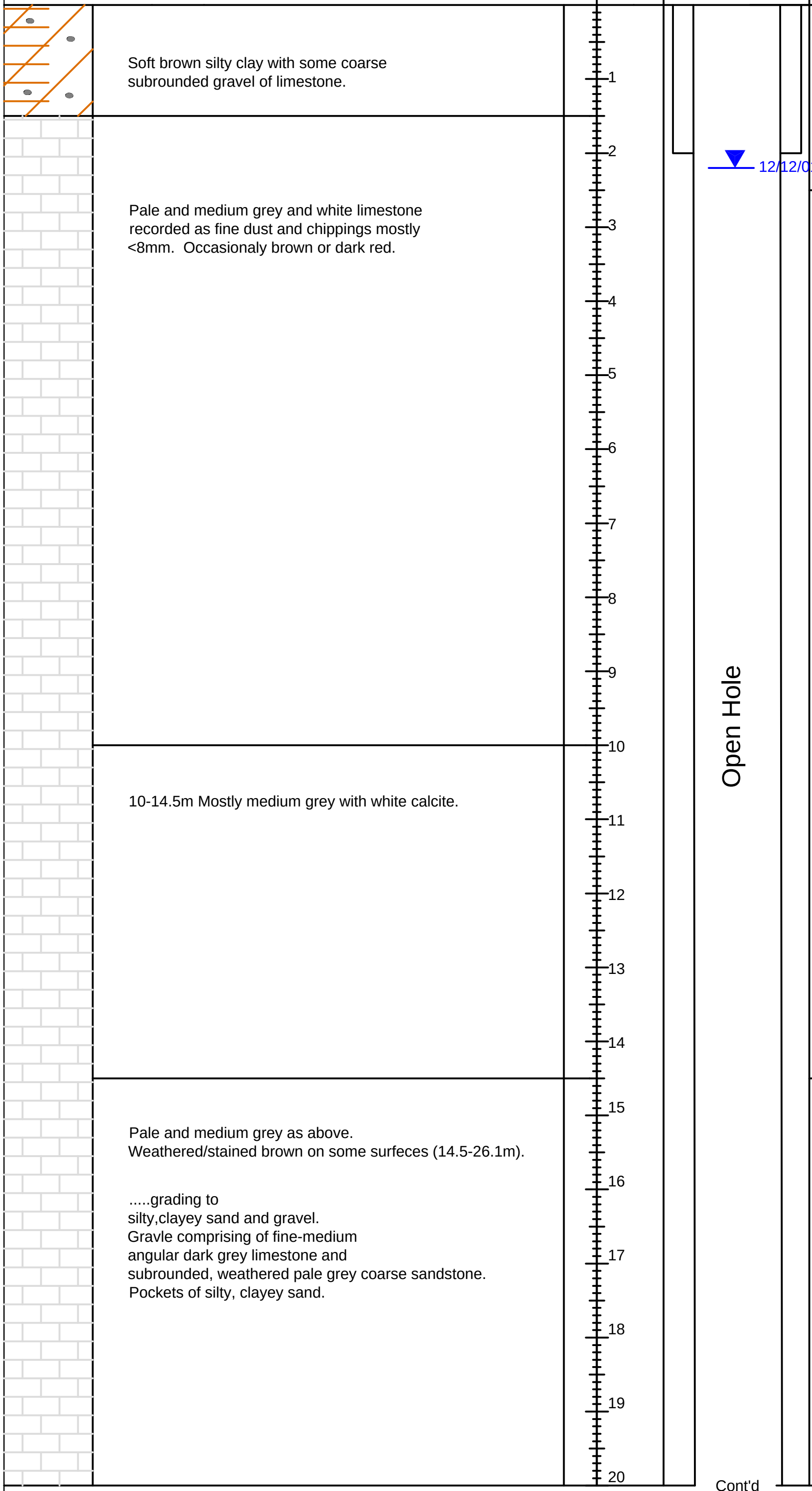
Scale 1 : 100

KEY

▨ CLAY ☰ SILT ░ SAND ▒ GRAVEL ▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/G/2
Project Number U1606	Geologist/Engineer R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 1 of 2
Surface Level 62m A.O.D.	Surface Location 181598E 171825N	Inclination: Vertical Azimuth: Start Date: 06/11/01 End Date: 07/11/01	Depth 0.00m To 20.00m



LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Soft brown silty clay with some coarse subrounded gravel of limestone.							
Pale and medium grey and white limestone recorded as fine dust and chippings mostly <8mm. Occasionaly brown or dark red.		12/12/01	2.5m 7 Nov 2001 (Day 2)				
10-14.5m Mostly medium grey with white calcite.		Open Hole	Very small amount, damp dust				
Pale and medium grey as above. Weathered/stained brown on some surfeces (14.5-26.1m). .....grading to silty,clayey sand and gravel. Gravle comprising of fine-medium angular dark grey limestone and subrounded, weathered pale grey coarse sandstone. Pockets of silty, clayey sand.		Cont'd	14.5m Slight increase <0.1 l/s slurry	1550	14.5	7.5	221

Not to Scale

KEY

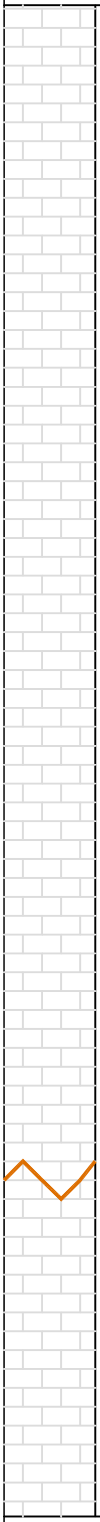
▨ CLAY
▤ SILT
▨ SAND
▨ GRAVEL
▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title	Client	Borehole :
SILVERMINES	SILVERMINES	SRK/G/2

Project Number	Geologist/Engineer	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number
U1606	R. LYNCH		2 of 2

Surface Level	Surface Location	Inclination: Vertical Azimuth:	Depth
62m A.O.D.	181598E 171825N	Start Date: 06/11/01 End Date: 07/11/01	20.00m To 40.00m



LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
	21	Open Hole					
	22		0.5 l/s (400 gal/s)	1299	15.5	7.5	204
	23						
	24						
	25			1388	13.0	7.8	210
Pale medium grey and white limestone as above	26						
	27						
	28			1474	13.6	7.7	221
	29						
	30						
	31						
	32			1480	13.7	7.6	207
	33						
	34						
	35						
At 35.4m, fissure, weaterhed orange brown			Increase to 0.7 l/s				
	36						
	37						
	38		Increase to 0.81 l/s				
	39						
		EOH					
Develop by airlift for 1hr.				1480	13.7	7.7	209

Not toScale

KEY

▨ CLAY
☰ SILT
▒ SAND
▓ GRAVEL
▦ LIMESTONE

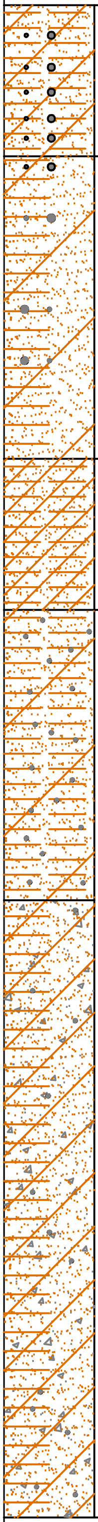
SRK Consulting
Engineers and Scientists

Site Name/Project Title: SILVERMINES
Client: SILVERMINES
Borehole : SRK/G/3

Project Number: U1606
Geologist/Engineer: R.LYNCH
Drilling Contractor: HILLYARDS
Rig Type: ~
Drill Diameter: #
Method & Medium: Rotary/hammer
Page Number: 1 of 2

Surface Level: 76m A.O.D.
Surface Location: 182060E 171618N
Inclination: Vertical
Azimuth:
Start Date: 08/11/01
End Date: 14/11/01
Depth: 0.00m To 20.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh



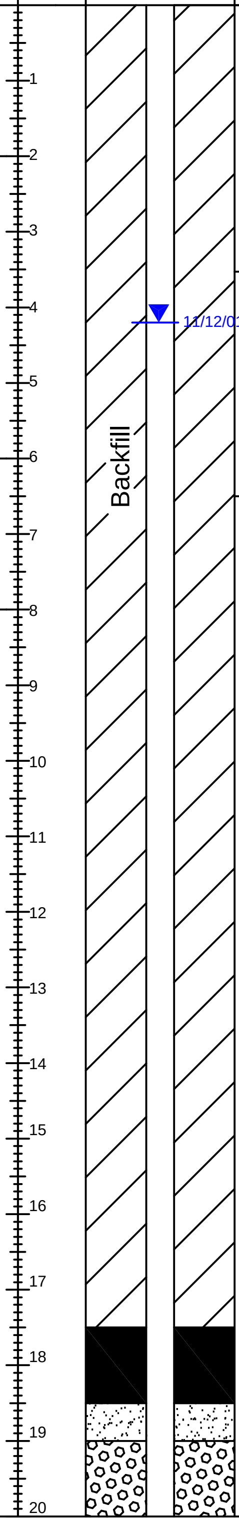
Brown clayey fine sandy silt with much fine-medium gravel of dark limestone.

Brown slightly clayey silty fine sand with assorted fine-medium gravel (dry)

Becoming very clayey, very silty. (wet).

Slightly clayey, very silty. Fine-medium sand with assorted fine gravel (dry).

.....grading to silty,clayey sand and gravel. Gravle comprising of fine-medium angular dark grey limestone and subrounded, weathered pale grey coarse sandstone. Pockets of silty, clayey sand.



W/L 3.53
@12.0m drill
12.11.2001

6.5m 1st strike
small amount perched

Possibly 5 l/s

?

Formation being eased off during drilling

KEY- PIEZOMETER INSTALLATION

▨ BACKFILL
■ BENTONITE SEAL
SAND FILTER
PEA GRAVEL

Not toScale

KEY

▨ CLAY
☰ SILT
SAND
GRAVEL

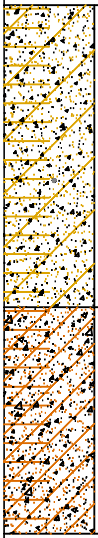
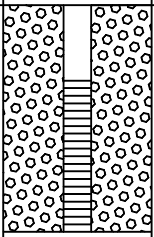
SRK Consulting *Engineers and Scientists*	Site Name/Project Title SILVERMINES	Client SILVERMINES	Borehole : SRK/G/3
	Project Number U1606	Geologist/Engineer R.LYNCH	Page Number 2 of 2

Drilling Contractor: HILLYARDS
Rig Type: #
Drill Diameter: #
Method & Medium: Rotary/hammer

Surface Level 76m A.O.D.
Surface Location 182060E 171618N

Inclination: Vertical
Azimuth:
Start Date: 08/11/01
End Date: 14/11/01

Depth 20.00m To 27.00m

LITHOLOGY		DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
	.....grading to: Pale brown, slightly clayey, silty sand with much fine-medium gravel of dark limestone	21 22 23						
	Soft brown silty very sandy clay with some fine-coarse gravel, mainly dark limestone.	24 25 26	Collapsed/ squeezed in.					

EOH

KEY

CLAY ▨ SILT ▤ SAND ░ GRAVEL ░

KEY- PIEZOMETER INSTALLATION

▨ BACKFILL ■ BENTONITE SEAL ░ SAND FILTER ○ PEA GRAVEL

▤ PIEZOMETER SLOTTED SECTION

Not to Scale

SRK Consulting
Engineers and Scientists

Site Name/Project Title
SILVERMINES

Client
SILVERMINES

Borehole :
SRK/G/4

Project Number
U1606

Geologist/Engineer
R.LYNCH

Drilling Contractor: HILLYARDS
Rig Type: ~
Drill Diameter: #
Method & Medium: Rotary/hammer

Page Number
1 of 2

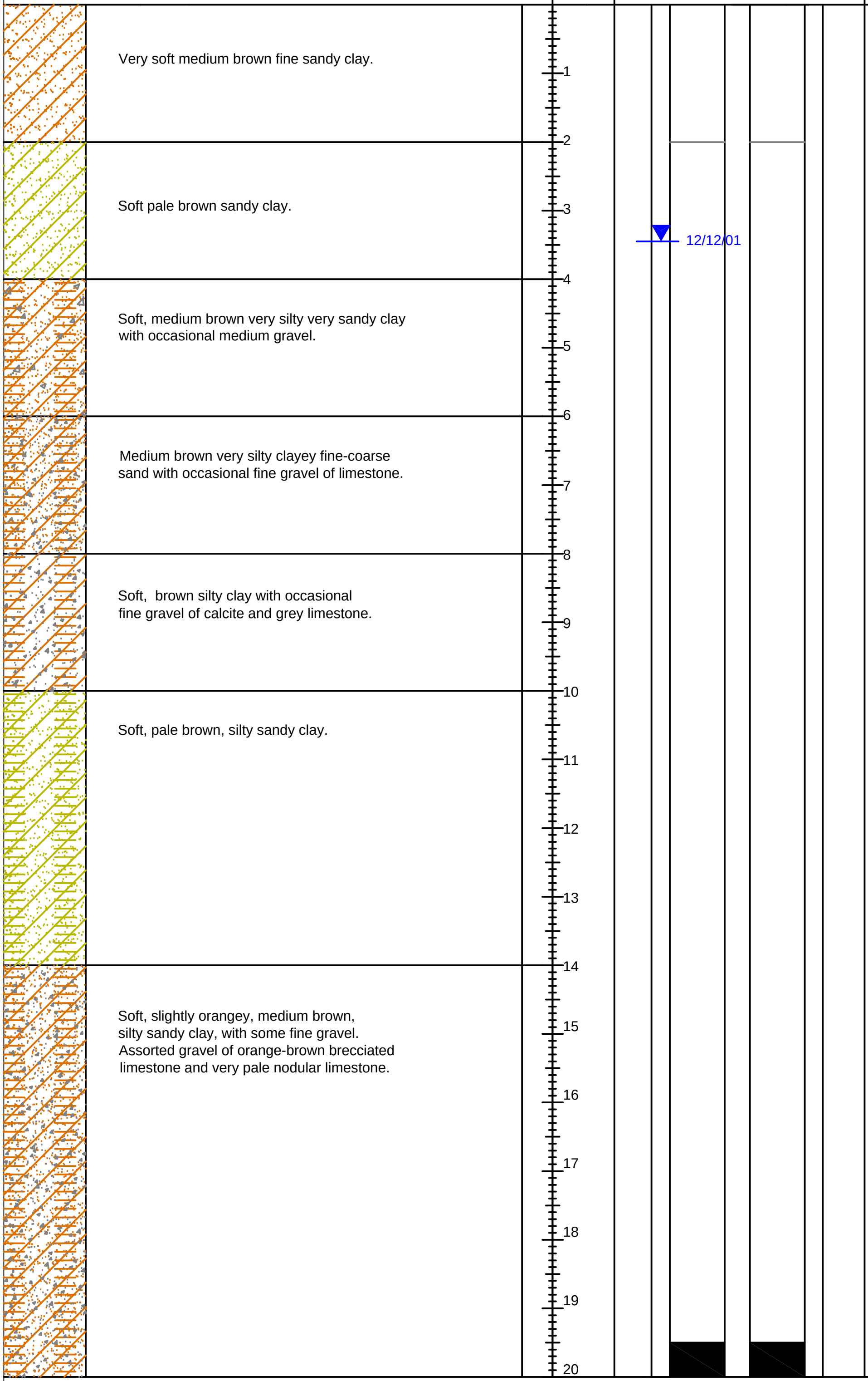
Surface Level
80m
A.O.D.

Surface Location
182354E
171554N

Inclination: Vertical
Azimuth:
Start Date: 15/11/01
End Date: 04/12/01

Depth
0.00m
To
20.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh



Very soft medium brown fine sandy clay.

Soft pale brown sandy clay.

Soft, medium brown very silty very sandy clay with occasional medium gravel.

Medium brown very silty clayey fine-coarse sand with occasional fine gravel of limestone.

Soft, brown silty clay with occasional fine gravel of calcite and grey limestone.

Soft, pale brown, silty sandy clay.

Soft, slightly orangey, medium brown, silty sandy clay, with some fine gravel. Assorted gravel of orange-brown brecciated limestone and very pale nodular limestone.

5.10m SWL
24th Nov
@14m depth

Wet clay

Not to Scale

KEY- PIEZOMETER INSTALLATION

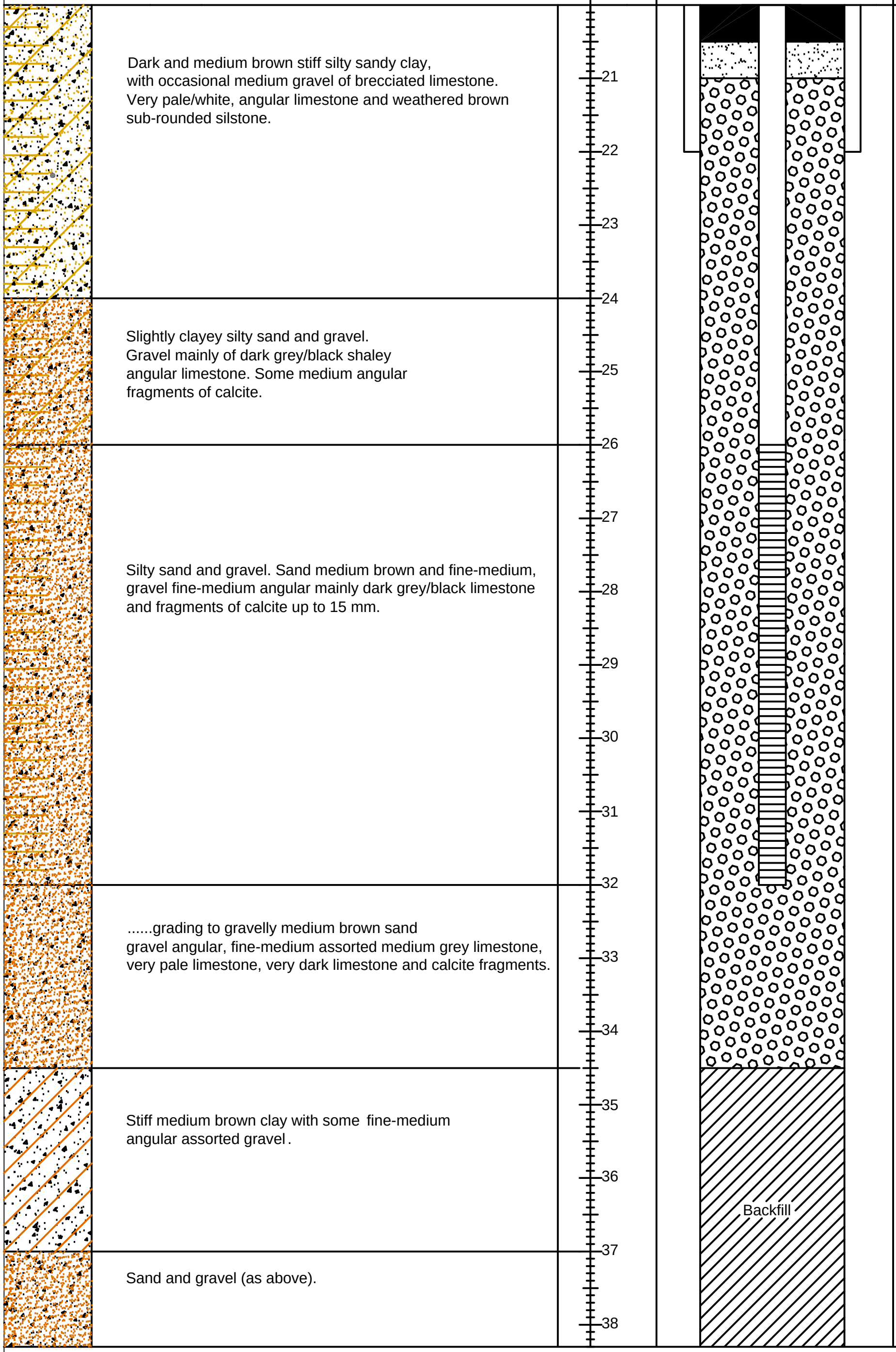
KEY

▨	BACKFILL
■	BENTONITE SEAL
░	SAND FILTER
○	PEA GRAVEL
▨	CLAY
☰	SILT
░	SAND
▒	GRAVEL
▦	LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/G/4
Project Number U1606	Geologist/Engineer R.LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 2 of 2
Surface Level 80m A.O.D.	Surface Location 182354E 171554N	Inclination: Vertical Azimuth: Start Date: 15/11/01 End Date: 04/12/01	Depth 20.00m To 38.30m

LITHOLOGY | DEPTH IN HOLE | Borelog Legend



Dark and medium brown stiff silty sandy clay, with occasional medium gravel of brecciated limestone. Very pale/white, angular limestone and weathered brown sub-rounded silstone.

Slightly clayey silty sand and gravel. Gravel mainly of dark grey/black shaley angular limestone. Some medium angular fragments of calcite.

Silty sand and gravel. Sand medium brown and fine-medium, gravel fine-medium angular mainly dark grey/black limestone and fragments of calcite up to 15 mm.

......grading to gravelly medium brown sand gravel angular, fine-medium assorted medium grey limestone, very pale limestone, very dark limestone and calcite fragments.

Stiff medium brown clay with some fine-medium angular assorted gravel.

Sand and gravel (as above).

Water	EC	T	pH	Eh
1000 gal/hr 1.3 l/s	687	11.7		224
None				
0.5 l/s	684	11.7		192

EoH 38.3m

KEY- PIEZOMETER INSTALLATION

Not to Scale

KEY

▨ BACKFILL
■ BENTONITE SEAL
▒ SAND FILTER
○ PEA GRAVEL
☰ PIEZOMETER SLOTTED SECTION

▨ CLAY
☰ SILT
▒ SAND
▒ GRAVEL

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES	Client SILVERMINES	Borehole : SRK/S/1

Project Number: U1606

Geologist/Engineer: R. LYNCH

Drilling Contractor: HILLYARDS
Rig Type: ~
Drill Diameter: #
Method & Medium: Rotary/hammer

Page Number: 1 of 3

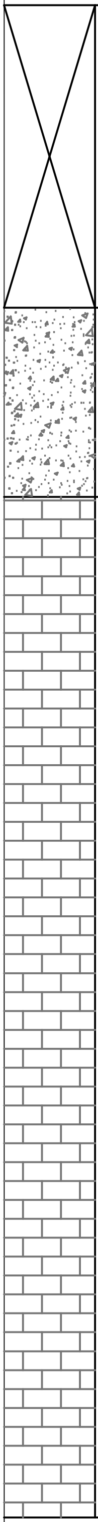
Surface Level: 125m A.O.D.

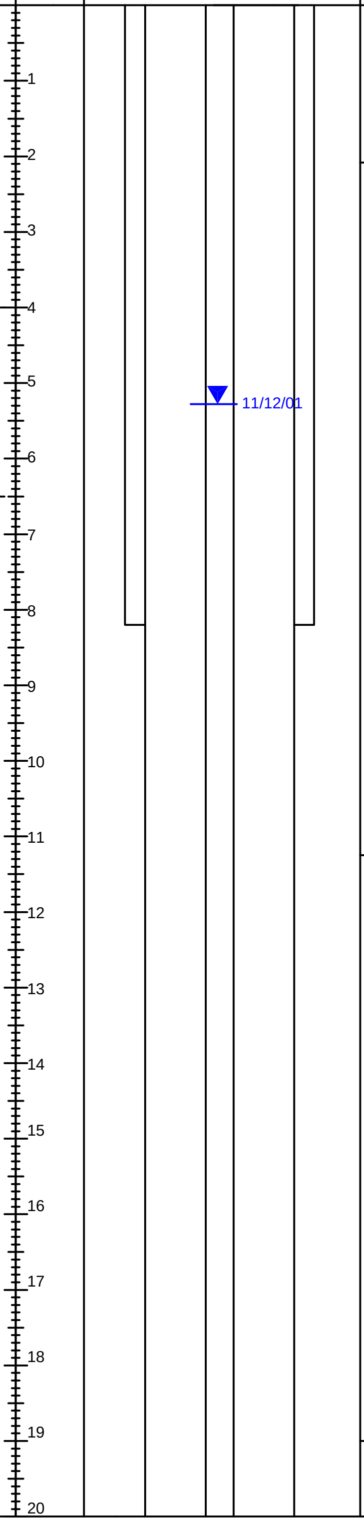
Surface Location: 184185E 171112N

Inclination: Vertical
Azimuth:
Start Date: 07/11/01
End Date: 08/11/01

Depth 0.00m To 20.00m

LITHOLOGY	DEPTH IN HOLE	Water	EC	T	pH	Eh
Soft brown with fine gravel (made ground).	0 – 4	0.2 l/s @ bedrock (at ~2.1)				
Fine to medium gravel of dark grey muddy limestone.	4 – 6.5					
Very dark grey muddy limestone recovered as chips <8mm. Relatively homogenous.	6.5 – 20	11.25m @34m 08/11/01 (at ~11.2)				
	~15.8		1630	14.1	7.5	233
......damp dust.	~19	@ 19.0 m small amount damp dust				
	~20		1630	16.6	7.6	155





Cont'd

Not to Scale

KEY

▨ CLAY ▤ SILT ░ SAND ▒ GRAVEL ▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES			Client SILVERMINES	Borehole : SRK/S/1
Project Number U1606	Geologist/Engineer R. LYNCH		Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 2 of 3
Surface Level 125m A.O.D.	Surface Location 184185E 171112N	Inclination: Vertical Azimuth: Start Date: 07/11/01 End Date: 08/11/01		Depth 20.00m To 40.00m

LITHOLOGY		DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
▦		21						
▦	As above, very dark grey muddy limestone. Chips < 5 - 8 mm, platey.	22						
▦		23						
▦		24						
▦		25						
▦		26						
▦		27						
▦		28						
▦		29						
▦		30						
▦		31						
▦		32						
▦		33						
▦		34						
▦		35						
▦		36		0.2 l/s	876	9.3	7.8	155
▦		37						
▦		18						
▦	......damp dust.	39						
▦		40						

Cont'd

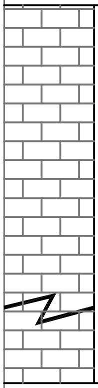
Not to Scale

KEY

▨ CLAY ▤ SILT ░ SAND ▒ GRAVEL ▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/S/1
Project Number U1606	Geologist/Engineer R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 3 of 3
Surface Level 125m A.O.D.	Surface Location 184185E 171112N	Inclination: Vertical Azimuth: Start Date: 07/11/01 End Date: 08/11/01	Depth 40.00m To 45.00m



LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
	41						
	42						
	43						
Fissured zone at 44.0 m, with larger fragments up to 40mm, some with ore body alteration	44		1.0 l/s				
Develop by airlift 1hr. Pulled out temporary 195 sentance casing. Installed plain steel casing 165mm to 8.5m. Use as pumping borehole, Leave as open hole to 45m. Slight cavity from overburden to 44.7m.		EOH 45.0m		741	10.2	8.2	175

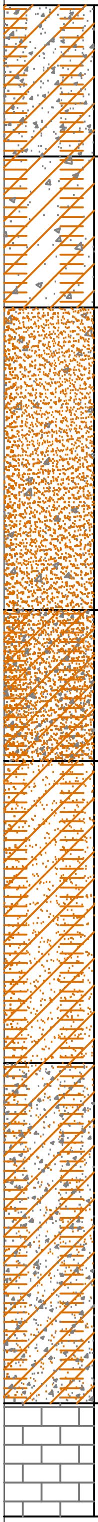
KEY

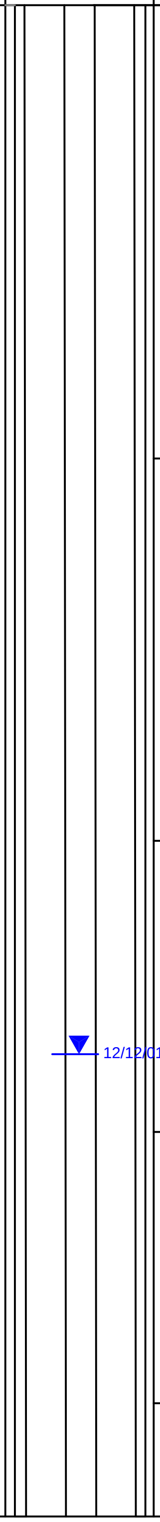
▨ CLAY ☰ SILT ░ SAND ▒ GRAVEL ▦ LIMESTONE

Not to Scale

SRK Consulting
Engineers and Scientists

	Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/S/2
	Project Number U1606	Geologist/Engineer R.LYNCH	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 1 of 3
	Surface Level 125m A.O.D.	Surface Location 183665E 171040N	Inclination: Vertical Azimuth: Start Date: 09/11/01 End Date: 16/11/01	Depth 0.00m To 20.00m





LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Soft - firm brown silty clay with assorted fine gravel.	1 2						
Soft - firm brown silty clay with assorted fine-coarse gravel.	3 4						
Soft very sandy with assorted fine sub-rounded gravel.	5 6 7 8		None				
.......grading to brown, very silty clayey fine sand with assorted fine gravel.	9 10						
Soft brown silty sandy clay.	11 12 13 14	12/12/01	Dry				
........becoming very soft. ....slightly sandy with occasional fine sub-rounded gravel.	15 16 17 18		Wet				
Very dark grey/black shaley limestone.	19 20		18.5m Very small amount of water. Wet cuttings only.				

Cont'd

Not to Scale

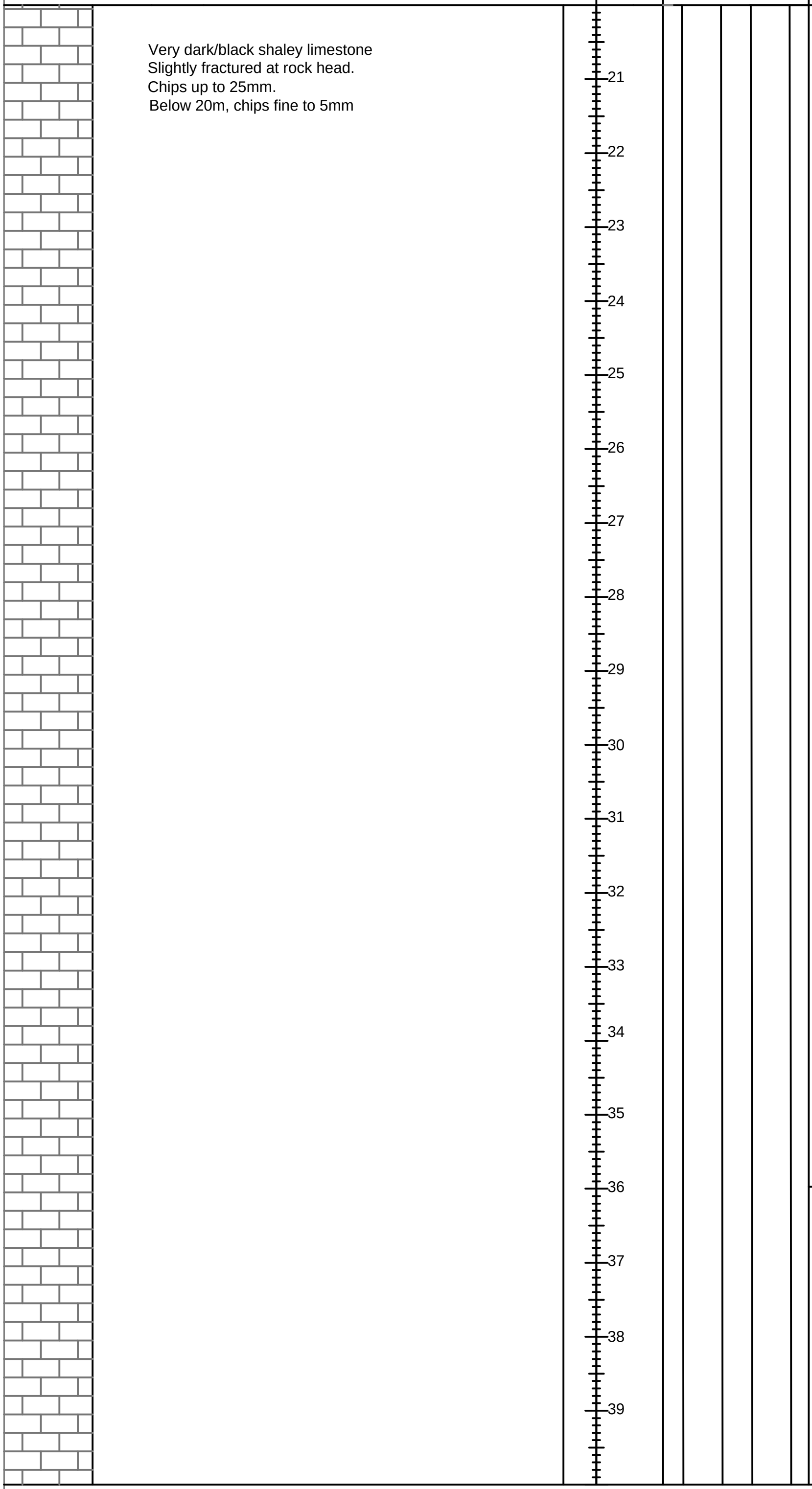
KEY

▨ CLAY	☰ SILT	░ SAND	⁘ GRAVEL	▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/S/2
Project Number U1606	Geologist/Engineer R.LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 2 of 3
Surface Level 138m A.O.D.	Surface Location 183665E 171040N	Inclination: Vertical Azimuth: Start Date: 09/11/01 End Date: 16/11/01	Depth 20.00m To 40.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Very dark/black shaley limestone Slightly fractured at rock head. Chips up to 25mm. Below 20m, chips fine to 5mm	20–21						
	24.3		Damp				
	26		Dry				
	36		Gradual increase to 0.4l /s. Driller 400 gal/hr 0.5 l/s.				



Cont'd

Not to Scale

KEY

▨ CLAY
▤ SILT
▒ SAND
▒ GRAVEL
▦ LIMESTONE

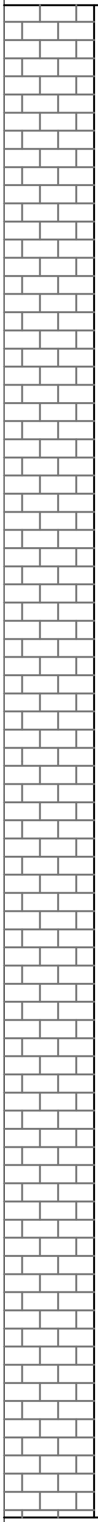
SRK Consulting
Engineers and Scientists

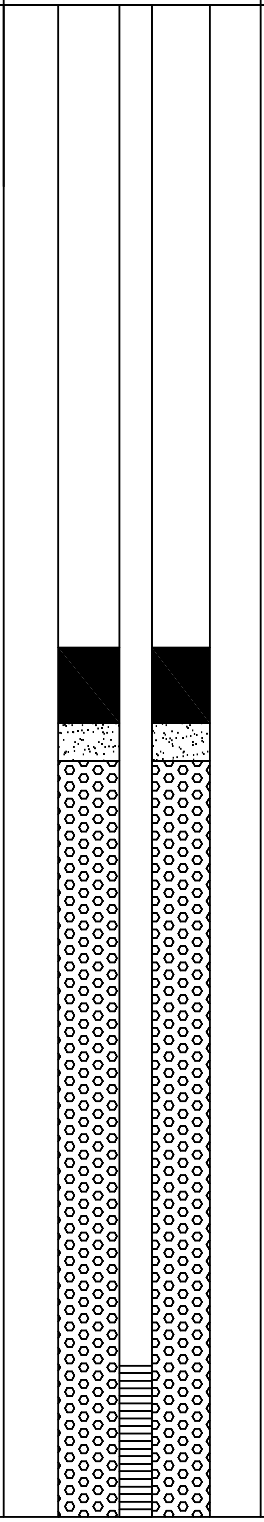
Site Name/Project Title	Client	Borehole :
SILVERMINES	SILVERMINES	SRK/S/2

Project Number	Geologist/Engineer	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number
U1606	R.LYNCH		3 of 3

Surface Level	Surface Location	Inclination: Vertical Azimuth:	Depth
138m A.O.D.	183665E 171040N	Start Date: 09/11/01 End Date: 16/11/01	40.00m To 60.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Dark grey/black shaley limestone.							
	41						
	42						
	43						
	44						
	45						
	46						
	47						
	48						
	49						
	50						
.......with calcite veins and occasional brown weathered surfaces, chips up to 10mm.							
	51						
	52						
Dark grey/black shaley limestone with calcite veins and brown weathered surfaces between 52-57m.			Gradual increase				
	53						
	54						
	55						
	56						
	57						
	58						
	59						
			1000 gal/hr 1.3 l/s	697	10.2	8.2	18?





Develop for 1hr, install pipe.

EOH 60.0m

Backfill, pull out casing and move off.

Not to Scale

KEY

CLAY

SILT

SAND

GRAVEL

LIMESTONE

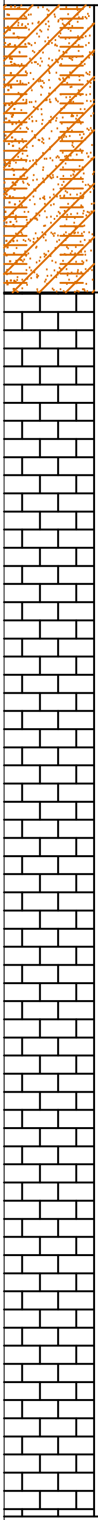
SRK Consulting
Engineers and Scientists

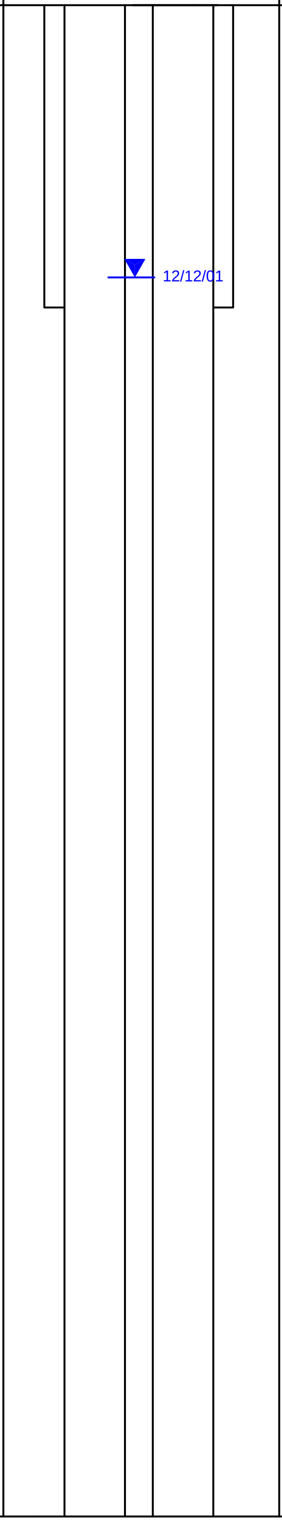
Site Name/Project Title	Client	Borehole :
SILVERMINES	SILVERMINES	SRK/S/3

Project Number	Geologist/Engineer	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number
U1606	R. LYNCH		1 of 3

Surface Level	Surface Location	Inclination: Vertical Azimuth:	Depth
97m A.O.D.	184232E 171617N	Start Date: 19/11/01 End Date: 21/11/01	0.00m To 20.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Very soft brown silty sandy clay.	0–3.8						
Medium and dark grey muddy limestone occasionally weathered brown om surfaces. 6-8m chips 5-8mm occasionally 25mm. Between 8-27.8m chips mainly 2-8mm.	3.8–20	12/12/01	Very small amount @ bedrock <0.1 l/s damp cuttings only				





1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Cont'd

Not to Scale

KEY

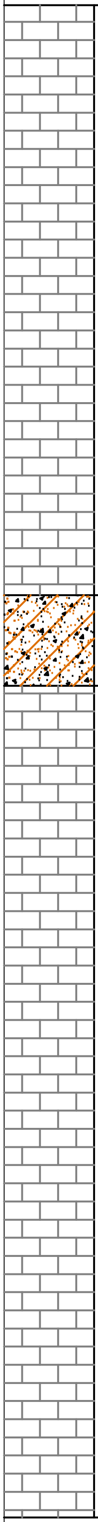
▨ CLAY ▤ SILT ▨ SAND ▨ GRAVEL ▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title	Client	Borehole :
SILVERMINES	SILVERMINES	SRK/S/3

Project Number	Geologist/Engineer	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number
U1606	R. LYNCH		2 of 3

Surface Level	Surface Location	Inclination: Vertical Azimuth:	Depth
97m A.O.D.	184232E 171617N	Start Date: 19/11/01 End Date: 21/11/01	20.00m To 40.00m



LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
	21						
	22						
	23						
	24		Slight increase <0.1 l/s slurry				
Medium dark grey limestone.	25						
	26						
	27						
Cavity, infilled with brown very clayey fine - coarse sand and coarse gravel of dark grey limestone and reddish brown slatey lmestone.	28		0.3 l/s				
	29						
Medium dark grey limestone chips 3-8mm. Brown clayey sand contamination from cavity.	30			636	12.5	7.6	208?
	31						
	32						
	33						
	34						
	35						
	36						
	37						
	18						
	39		Develop 1/4 hr				
	40						

Cont'd

Not toScale

KEY

▨ CLAY
☰ SILT
▒ SAND
▒ GRAVEL
▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title: SILVERMINES
Client: SILVERMINES
Borehole : SRK/S/3

Project Number: U1606
Geologist/Engineer: R. LYNCH
Drilling Contractor: HILLYARDS
Rig Type: #
Drill Diameter: #
Method & Medium: Rotary/hammer
Page Number: 3 of 3

Surface Level: 97m A.O.D.
Surface Location: 184232E 171617N
Inclination: Vertical
Azimuth:
Start Date: 07/11/01
End Date: 08/11/01
Depth 40.00m To 50.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
▦ Fissured zone at 44.0 m, with larger fragments up to 40mm, some with ore body alteration	41 42 43 44 45 46 47 48 19		Interception: Increase in water either from limestone or from cavity being progressively developed.				
Develop by airlift 1hr. Muddy brown but clearing. CRT 10 hr @ 0.28 l/s sample "S32107" 17.00hrs approximately.		EOH 50.0m		685	13.5	7.5	?
		At end →	DO	720	11.9	7.2	?

Not to Scale

KEY

▨ CLAY

☰ SILT

▒ SAND

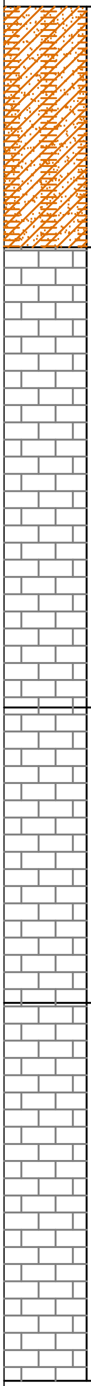
▓ GRAVEL

▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/SH/1
Project Number U1606	~~Geologist/Engineer~~ R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 1 of 2
Surface Level 52m A.O.D.	Surface Location 180929E 172131N	Inclination: Vertical Azimuth: Start Date: 31/10/01 End Date: 02/11/01	Depth 0.00m To 20.00m

LITHOLOGY | DEPTH IN HOLE | Borelog Legend | Water | EC | T | pH | Eh



Soft medium brown very clayey very sandy silt with some gravel of limestone.

(Weathered brown on some surfaces)
Medium grey fossiliferous limestone,
recovered as fine dust and angular platy chips up to 15mm.

Limestone as above. Medium and dark grey.
Chips < 8mm.

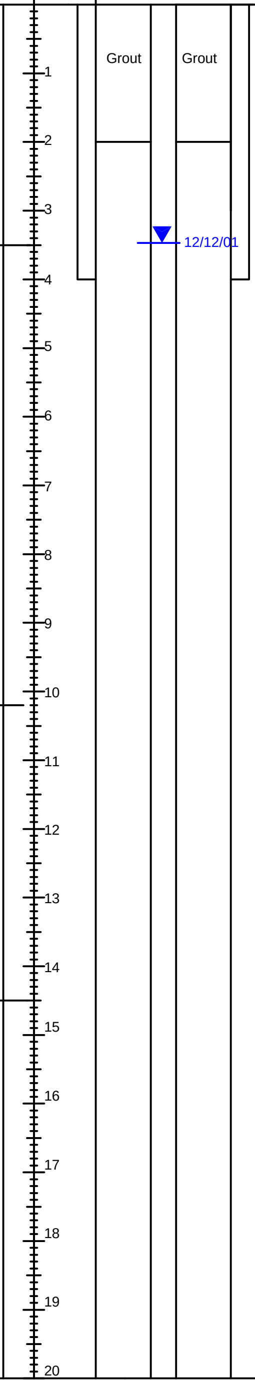
Platy grey limestone.
Angular chippings < 5mm.

Soft, pale and dark grey,
fine chippings.

Medium and dark grey limestone.
Chips fine to 7mm.

Pale grey and medium grey limestone
chippings < 6mm.

Medium grey with calcite veins
and bioclasts
chippings mostly fine (2-3mm
up to 5mm).



10.8m
1st water strike
Muddy brown
<0.5l/s

0.5 l/s
(400 gal/hr)

Water	EC	T	pH	Eh
0.5 l/s (400 gal/hr)	735	14.5	7.6	136
19.7m Increase to 0.6 l/s	748	14.3	7.9	261

Cont'd

Not to Scale

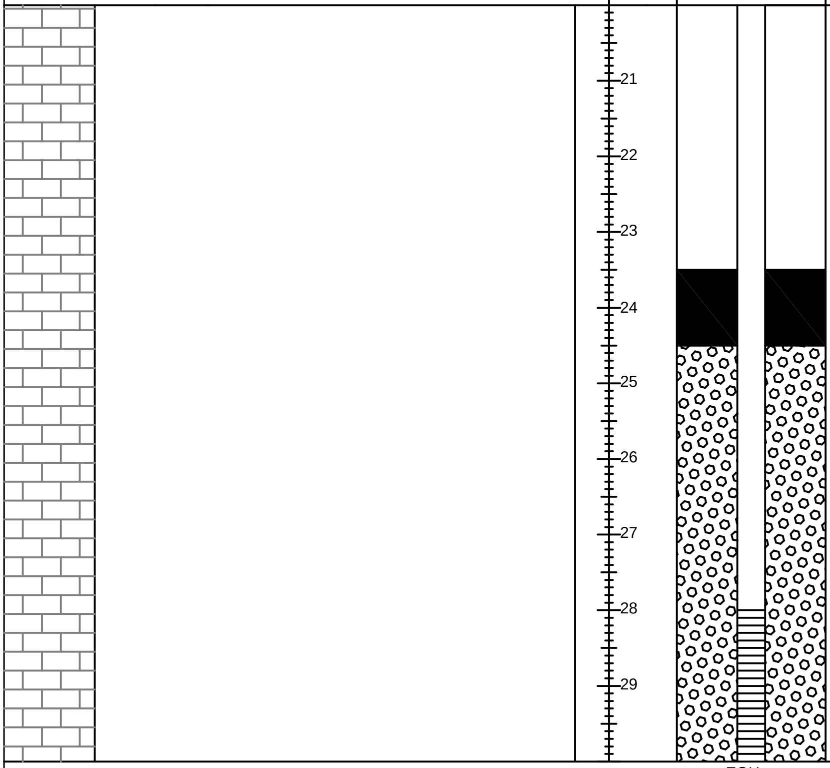
KEY

▨ CLAY ☰ SILT ▒ SAND ▓ GRAVEL ▦ LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/SH/1
Project Number U1606	Geologist/Engineer R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 2 of 2
Surface Level 52m A.O.D.	Surface Location 180929E 172131N	Inclination: Vertical Azimuth: Start Date: 31/10/01 End Date: 02/11/01	Depth 20.00m To 30.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend		Water	EC	T	pH	Eh
	25			0.6 l/s				
	30			0.6 l/s	747	14.2	8.2	302



After 1 hr development

KEY

KEY- PIEZOMETER INSTALLATION

Not to Scale

▨	BACKFILL
■	BENTONITE SEAL
░	SAND FILTER
○	PEA GRAVEL
☰	PIEZOMETER SLOTTED SECTION
▨	CLAY
☰	SILT
░	SAND
░	GRAVEL
▦	LIMESTONE

SRK Consulting
Engineers and Scientists

Site Name/Project Title
SILVERMINES

Client
SILVERMINES

Borehole :
SRK/TMF/1

Project Number
U1606

Geologist/Engineer
R. LYNCH

Drilling Contractor: HILLYARDS
Rig Type: ~
Drill Diameter: #
Method & Medium: Rotary/hammer

Page Number
1 of 2

Surface Level
49m
A.O.D.

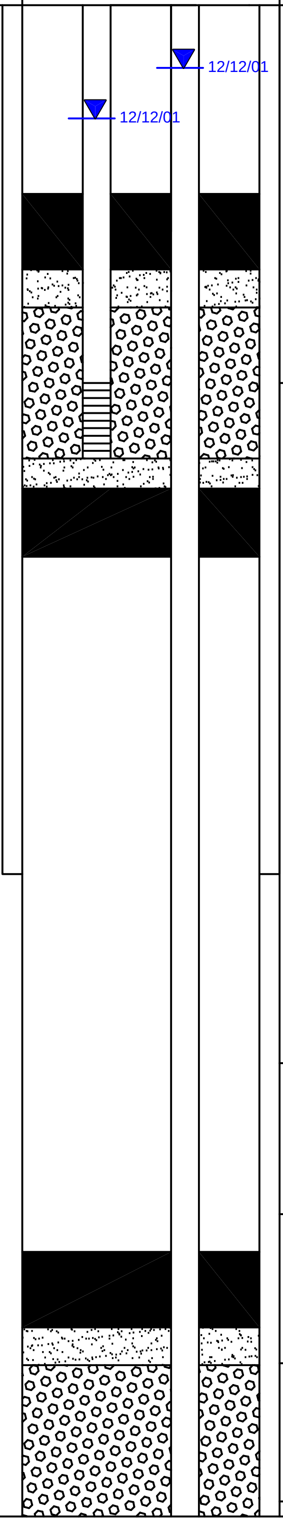
Surface Location
179829E
173168N

Inclination: Vertical
Azimuth:
Start Date: 23/10/01
End Date: 24/10/01

Depth
0.00m
To
20.00m

LITHOLOGY	DEPTH IN HOLE	Water	EC	T	pH	Eh
Very soft brown and grey silty clay with some fine gravel.	1					
	2					
Medium brown fine sand with some fine gravel (loose and wet).	3					
	4					
Medium to coarse rounded gravel of dark grey limestone. Some fine sand.	5	Strike Perched?				
	6					
Medium brown fine sand with some fine rounded gravel of limestone (wet).	7					
Very soft grey-brown silty sandy gravelly clay.	8					
	9					
	10					
Medium to coarse assorted (dry) gravel, mostly of rounded limestone	11					
	12					
Medium weathered hard, pale grey sanstone weathered to orange brown on surfaces. Thin vein of quartz.	13					
	14	0.5 l/s				
	15					
	16	0.5 l/s				
	17					
	18	0.5 l/s	424	14.1	8.9	162
	19					
	20	0.5 l/s				

Borelog Legend



Not to Scale

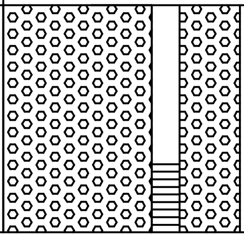
KEY

KEY- PIEZOMETER INSTALLATION Cont'd

▨ BACKFILL	■ BENTONITE SEAL	▨ SAND FILTER	▨ PEA GRAVEL
▨ CLAY	▨ SILT	▨ SAND	▨ GRAVEL
▨ LIMESTONE	▨ SANDSTONE		

SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES	Client SILVERMINES		Borehole : SRK/TMF/1
Project Number U1606	Geologist/Engineer R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 2 of 2
Surface Level 49m A.O.D.	Surface Location 179829E 173168N	Inclination: Vertical Azimuth: Start Date: 23/10/01 End Date: 24/10/01	Depth 20.00m To 23.00m



LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
				400	15.1	9.0	163
Reddish brown and pale grey mudstone and soft pale grey clay.	21						
Moderately weathered pale grey sandstone with occasional quartz.	22		<0.5 l/s	400	15.1	9.0	-

EOH 23m

Develop by airlift for 1hr.	After development	178	15.7	9.4	-

KEY

- ▨ CLAY
- ▤ SILT
- ▨ SAND
- ▨ GRAVEL
- ▦ LIMESTONE
- ▥ MUDSTONE

KEY- PIEZOMETER INSTALLATION

- ▨ BACKFILL
- ■ BENTONITE SEAL
- ▨ SAND FILTER
- ▨ PEA GRAVEL
- ☰ PIEZOMETER SLOTTED SECTION

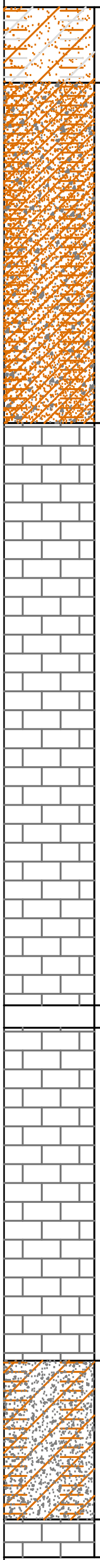
Not to Scale

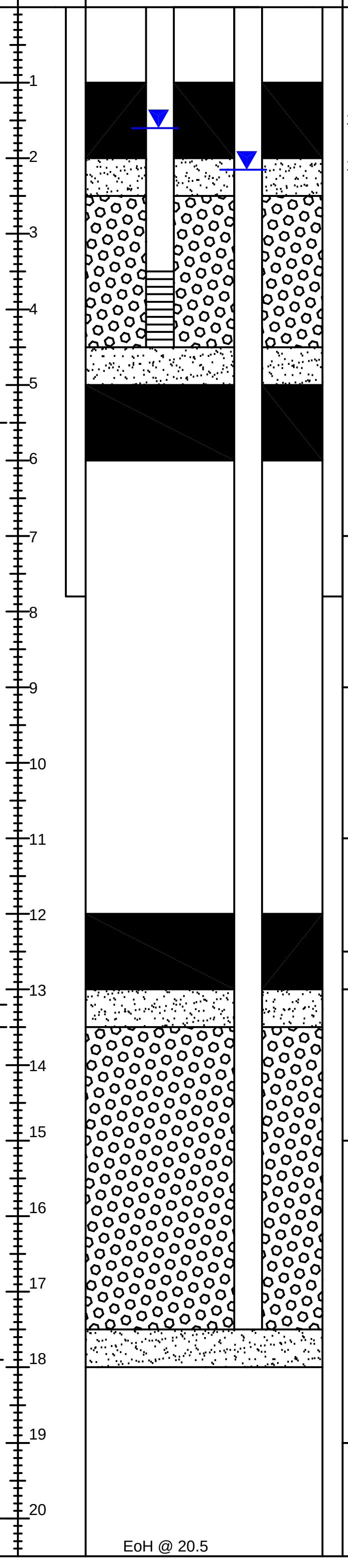
SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES	Client SILVERMINES	Borehole : SRK/TMF/2

Project Number U1606	Geologist/Engineer R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 1 of 1

Surface Level 48m A.O.D.	Surface Location 179447E 172313N	Inclination: Vertical Azimuth: Start Date: 24/11/01 End Date: 25/11/01	Depth 0.00m To 20.00m





LITHOLOGY	Water	EC	T	pH	Eh
Soft grey and brown silty sandy clay					
	11/12/01				
	11/12/01				
Medium brown very clayey very sandy silt with fine - medium gravel of limestone.					
Dark grey limestone with occasional infills of very soft brown. Coarse limestone chippings up to 20mm.	0.5 l/s				
	<0.1 l/s				
	<0.1 l/s				
Below 10m, co cavity infill, limestone chippings fine - 10mm.					
	0.2 l/s				
	<0.1 l/s	287	15.8	-	-
cavity/soft limestone no returns					
	<0.1 l/s				
Dark grey limestone. Recovered as fine chips.					
Cavity, infilled with very soft brown calyey silt and assorted fine gravel.	1.0 l/s Brown, muddy	226	14.5	7.9	208
Dark grey limestone					

KEY

Developed by airlift @ 20m - 1hr.
Sediment in cavity collapsed after development.
Completed from 18.0m.

KEY- PIEZOMETER INSTALLATION

- ▨ BACKFILL
- ■ BENTONITE SEAL
- ▨ SAND FILTER
- ○ PEA GRAVEL
- ▨ CLAY
- ☰ SILT
- ▨ SAND
- ▨ GRAVEL
- ▦ LIMESTONE
- ☰ PIEZOMETER SLOTTED SECTION

Not to Scale

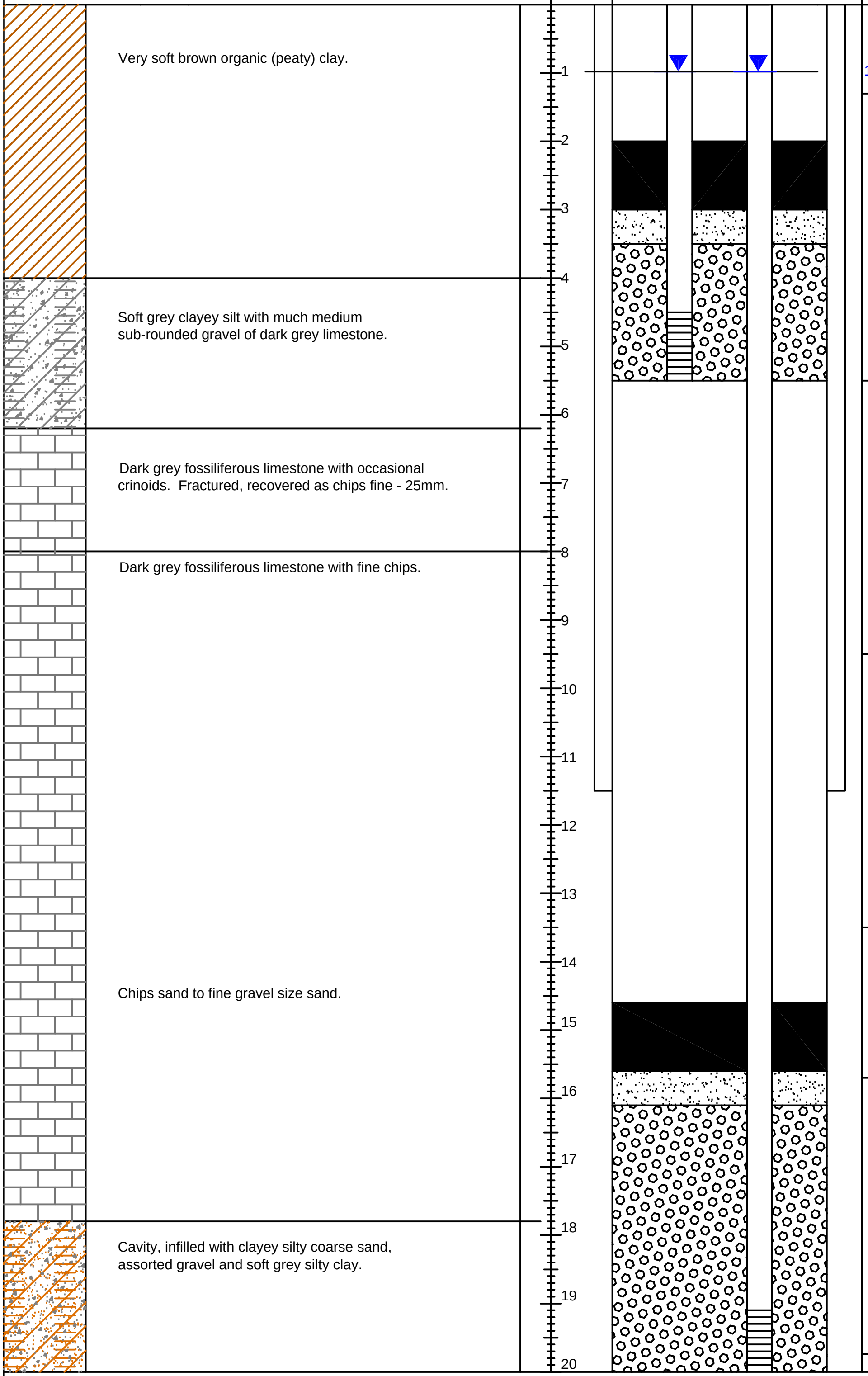
SRK Consulting
Engineers and Scientists

Site Name/Project Title	Client	Borehole :
SILVERMINES	SILVERMINES	SRK/TMF/3

Project Number	Geologist/Engineer		Page Number
U1606	R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: ~ Drill Diameter: # Method & Medium: Rotary/hammer	1 of 2

Surface Level	Surface Location		Depth
47m A.O.D.	179102E 172243N	Inclination: Vertical Azimuth: Start Date: 30/10/01 End Date: 31/10/01	0.00m To 20.00m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh



Very soft brown organic (peaty) clay.

Soft grey clayey silt with much medium sub-rounded gravel of dark grey limestone.

Dark grey fossiliferous limestone with occasional crinoids. Fractured, recovered as chips fine - 25mm.

Dark grey fossiliferous limestone with fine chips.

Chips sand to fine gravel size sand.

Cavity, infilled with clayey silty coarse sand, assorted gravel and soft grey silty clay.

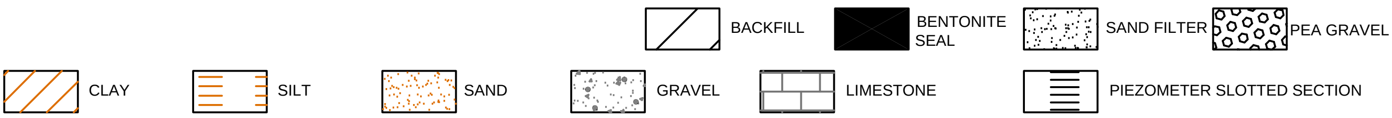
12/12/01
SWL 1.26
30/10/01

Water	EC	T	pH	Eh
0.8 l/s	662	13.3	7.5	-5
	641	13.3	6.6	?
0.5 l/s	625	14.3	7.1	?
<0.5 l/s				
<0.5 l/s				
0.8 l/s Brown muddy	529	13.5	?	?

Not to Scale

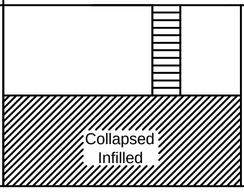
KEY

KEY- PIEZOMETER INSTALLATION



SRK Consulting
Engineers and Scientists

Site Name/Project Title SILVERMINES		Client SILVERMINES	Borehole : SRK/TMF/3
Project Number U1606	Geologist/Engineer R. LYNCH	Drilling Contractor: HILLYARDS Rig Type: # Drill Diameter: # Method & Medium: Rotary/hammer	Page Number 2 of 2
Surface Level 47m A.O.D.	Surface Location 179102E 172243N	Inclination: Vertical Azimuth: Start Date: 30/10/01 End Date: 31/10/01	Depth 20.00m To 22.40m

LITHOLOGY	DEPTH IN HOLE	Borelog Legend	Water	EC	T	pH	Eh
Dark grey limestone		 Collapsed Infilled					
No return?	21 22						
After 30 minutes development		EOH 22.4m	<0.5 l/s	710	15.9	7.7	275

Note: Borehole bakfilled to 8.7m, pulled casing 8.0 - 7.0m
Borehole base risen up inside casing. Therefore installed U. piezometer at 5.0 - 6.0m.

KEY

KEY- PIEZOMETER INSTALLATION

▨ BACKFILL
■ BENTONITE SEAL
▒ SAND FILTER
○ PEA GRAVEL

▨ CLAY
☰ SILT
▒ SAND
▒ GRAVEL
▦ LIMESTONE
☰ PIEZOMETER SLOTTED SECTION

Not to Scale

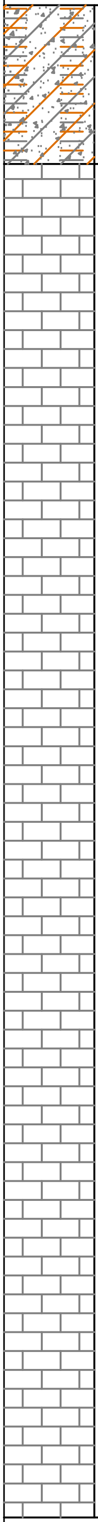
SRK Consulting
Engineers and Scientists

Site Name/Project Title	Client	Borehole :
SILVERMINES	SILVERMINES	SRK/TMF/4

Project Number: U1606
Geologist/Engineer: R.LYNCH
Drilling Contractor: HILLYARDS
Rig Type: ~
Drill Diameter: #
Method & Medium: Rotary/hammer
Page Number: 1 of 1

Surface Level: 115m A.O.D.
Surface Location: 179871E 172185N
Inclination: Vertical
Azimuth:
Start Date: 02/11/01
End Date: 05/11/01
Depth: 0.00m To 20.00m

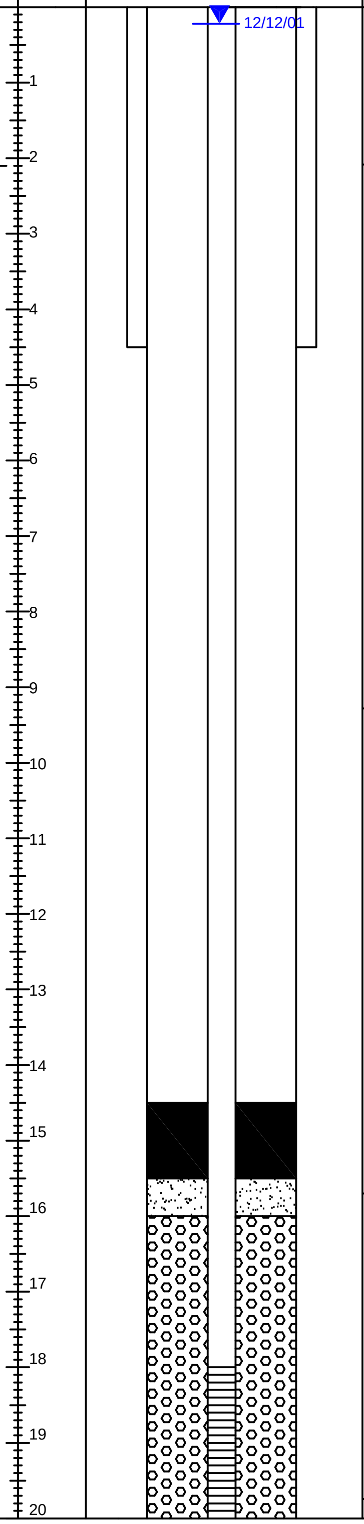
LITHOLOGY	DEPTH IN HOLE	Borelog Legend



Soft grey and brown silty clay with some assorted fine-coarse gravel mainly of dark limestone.

Hard, fresh, dark grey/black limestone. Homogenous, recovered as chips mostly 2-4 mm, up to 8 mm.

......with very occasional quartz veins.



Water	EC	T	pH	Eh
0.2 l/s @ bedrock				
0.2 l/s				
0.2 l/s	1630	14.1	7.5	233
↓ Slight increase ↓				
0.3 l/s	1630	16.6	7.6	155

Developed for 1 hr

EoH @ 20.0m

Scale 1 : 100

KEY

▨ CLAY ☰ SILT ▨ SAND ▨ GRAVEL ▦ LIMESTONE

APPENDIX F

TEST PUMPING AND MODELLING

APPENDIX F

TEST PUMPING AND MODELLING

1 TEST PUMPING

1.1 Introduction

Constant rate pumping tests were performed in Boreholes SRK/S/1 and SRK/S/3, both of which are located in proximity to the Silvermines Village and nearby river that goes by the same name.

The purpose of these tests was to ascertain the hydraulic characteristics of the limestone.

The analyses have been undertaken using Satem, which is a DOS-based well test interpretation package intended for use primarily in water resource investigations, where porous medium flow is assumed.

The tests have been analysed using the Jacob solution on the grounds that the geology of the boreholes is such that confined, or partially confined conditions are likely to prevail. Interpretation of each test includes an initial assessment of the flow model followed by an analysis to yield transmissivity.

The original test data and the detailed analyses are attached.

1.2 Borehole SRK/S/1

Borehole SRK/S/1 was tested on the 13th November. The test consisted of a production phase, which lasted 10 hours, followed by a recovery phase that lasted a further 4 hours. The static water level prior to the start of the test was 6.85m below the top of the casing (bTOC). The average pumping rate during the production phase was 39 l/min, during which time the water level was drawn down some 16m. The water level rebounded by more than 98% during the ensuing 4 hours of monitored recovery.

The test engineer did not report any anomalies, or concerns during the test period. However, a discrepancy between the end measurement of the pumping phase and the start of the recovery came to light after the test was complete. As a result, although the pumping phase was considered amenable for analysis, the recovery period that followed was not.

Diagnosis of the pumping phase has been performed using the drawdown curve generated in Satem (Figures F1a and F1b). The curve is characterised by a brief period of wellbore storage in early time, which lasted some 2 to 3 minutes, followed by two periods of radial flow stabilisation during the middle and latter portions of the test. These stabilisations are characterised by two distinct straight lines of varying slope that are divided by an inflection point at about 90 minutes elapsed time. This behaviour may indicate either a composite-type response with increasing transmissivity away from the hole, or an unconfined condition. However, the test was not of sufficient duration to prove conclusively whether an unconfined condition prevailed at this location

The test has been analysed assuming composite behaviour. Analysis of the pumping phase yielded an inner zone transmissivity of 1 m^2/day. Beyond the composite interface, some 5m from the source well, the transmissivity increases to 10 m^2/day.

1.3 Borehole SRK/S/3

Borehole SRK/S/3 was tested on the 21st November 2001. The test consisted of a production phase, which lasted 10 hours, followed by a recovery phase that lasted a further 2 hours. The static water level prior to the start of the test was 4.35m bTOC. The average pumping rate during the production phase was 16.8 l/min, during which time the water level was drawn down some 8m. The water level rebounded by more than 97% during the ensuing 2 hours of monitored recovery.

The test engineer did not report any anomalies, or concerns during the test period. As a result both the pumping and the recovery phases were considered amenable for analysis.

Diagnosis of the pumping and recovery phases has been performed using the curves generated in Satem (Figures F2 and F3). Both curves are characterised by a brief period of wellbore storage in early time. This is followed by a stabilisation (straight line) in mid-time that is evident in both phases, though it is more distinct in the recovery. The pumping phase lasted long enough to pick up a second stabilisation beyond an inflection at about 100 minutes elapsed time.

This behaviour may indicate either a composite-type response with increasing transmissivity away from the hole, or an unconfined condition. However, the test was not of sufficient duration to prove conclusively whether an unconfined condition prevailed at this location.

The test has been analysed assuming composite behaviour. Analysis of the pumping and recovery phases yielded an inner zone transmissivity of 1 m^2/day and an outer zone transmissivity of 4 m^2/day.

1.5 Water Chemistry

Water samples were taken from all boreholes after establishing the piezometers. The piezometers were bailed using a submersible electric sampling pump although failure of the pump during the sampling meant that some of the holes were bailed manually before taking a sample.

The samples were split and part filtered and stabilised for metal analysis and the other part unfiltered. All samples were packed in cool boxes and despatched to Alcontrol Geochem in Dublin for analysis.

The results are presented in Appendix A.

Following review of the results, it was noted that Mercury was recorded in the boreholes downstream of the Gortmore TMF. An additional set of samples were taken to confirm the results. The second set of results did not report Mercury and it is assumed that although there is mercury occurring naturally in the Silvermines environment, the levels are so low in the groundwater, that analysis may or may not identify it.

Initial analysis of the ionic balance showed some significant variances of over 40% in some cases. This has been queried with the laboratory and a report will be forthcoming.

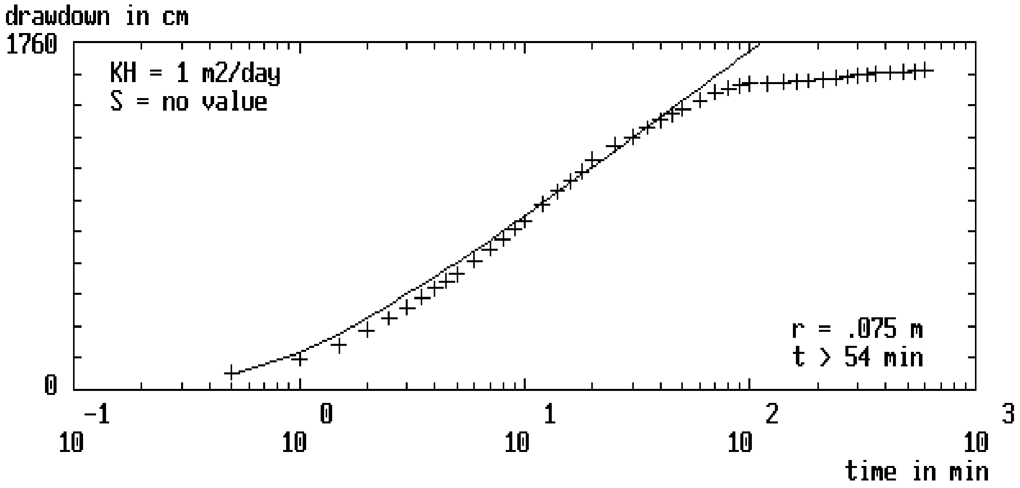


Figure F 1a: Borehole SRK/S/1: Constant Rate Pumping Test; Pumping Phase; Composite Flow Model; Match to Inner Composite Zone.

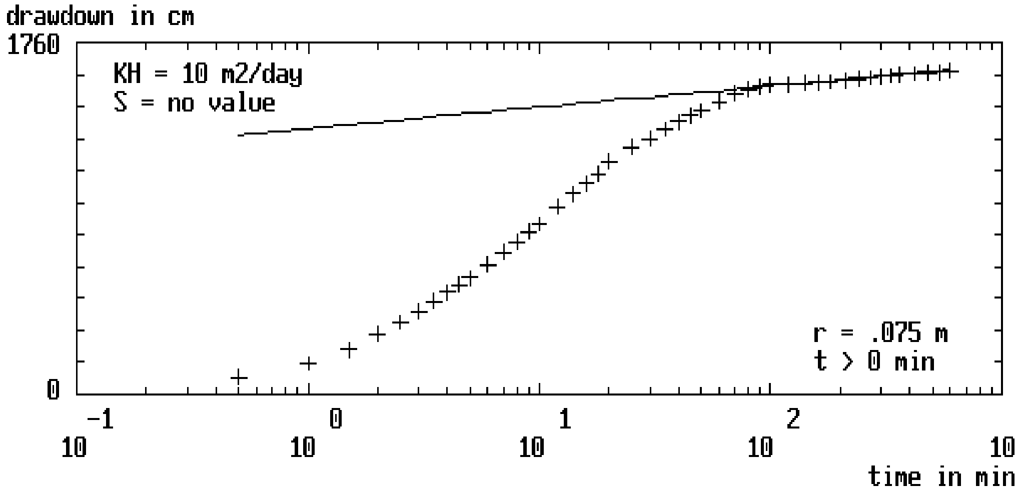


Figure E 1b: Borehole SRK/S/1: Constant Rate Pumping Test; Pumping Phase; Composite Flow Model; Match to Outer Composite Shell.

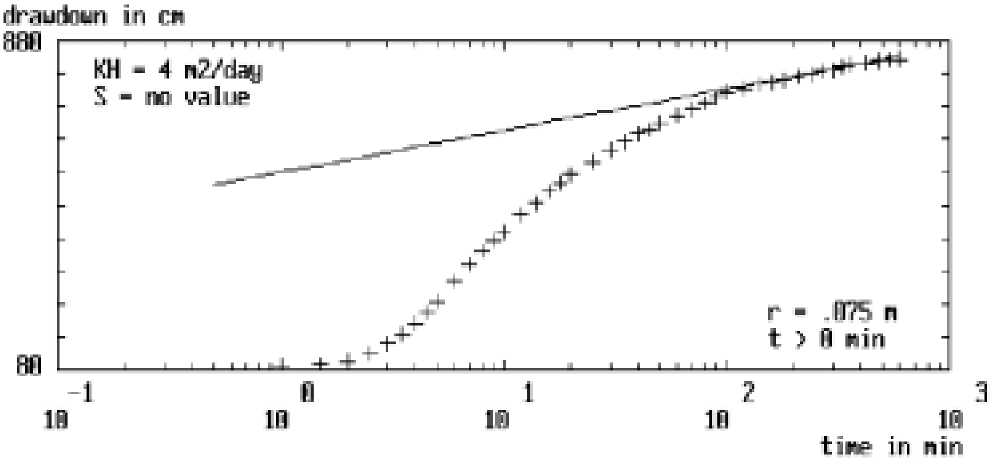


Figure F 2: Borehole SRK/S/3: Constant Rate Pumping Test; Pumping Phase.

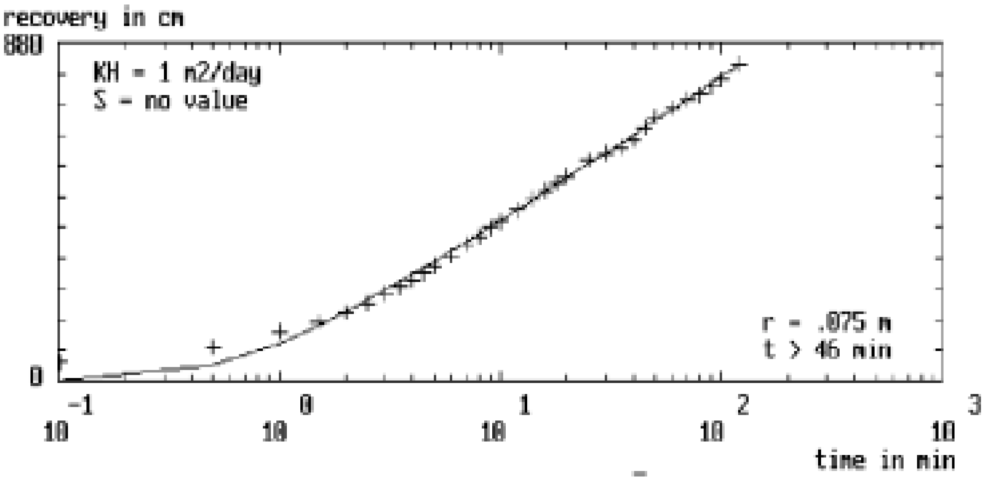


Figure F 3: Borehole SRK/S/3: Constant Rate Pumping Test; Recovery Phase.

Silvermines: Pumping Well No. SRK/S/1; Constant Rate Pumping Test in Limestone.

1. General information.

Type of Well:	Source (pumping)	
Test Date:	13th November 2001	
Approximate Borehole Coord's:		
Easting:	82062	
Northing:	71625	
Borehole Elevation:		m asl
Interval Length (l):	36.5	m
Borehole Diameter:	0.150	m
Borehole Radius (rw):	0.075	m
Casing Radius (ID):	None	m
(1) Viscosity (μ)	1.00E-03	Pa.s
(1) Compressibility (Ct)	5.00E-09	1/Pa
(1) Porosity (ϕ)	0.15	-
(1) Gravity (g)	9.81	$m.s^{-2}$
(1) Atmospheric Pressure (Atmos)	100	kPa
(2) Fluid Density (ρ)	1000	Kg/m^3
(3) Static Water Level	6.85	WL TOC
(4) Initial Pressure	1013.80	kPa
Pumping Rate	39	l/min
Duration Pumping Phase	10.00	hours

Comments:

(1). Fissured Zone @ 44mbgl.

(2). Tested open hole with temporary casing from 8.5m to 45mbgl

Notes:

(1). Assumed values.

(2). Density of fresh water.

(3). Last dip measurement before test.

(4). Static water level converted to equivalent pressure (exerted by column of water above Datum).

Pumping Well No. SRK/S/1: Constant Rate Pumping Test
Pumping Phase.

2. Data.

Elapsed Time (hours)	Depth of water [(1)] (m bPC)	Depth of water [(2)] (m bGL)	G'water Head [(3)] (m asl)	Equivalent Pressure (kPa)
0.0000	6.85	6.85	93.15	1013.8015
0.0083	7.70	7.70	92.3	1005.463
0.0167	8.40	8.40	91.6	998.596
0.0250	9.10	9.10	90.9	991.729
0.0333	9.85	9.85	90.15	984.3715
0.0417	10.45	10.45	89.55	978.4855
0.0500	11.00	11.00	89	973.09
0.0583	11.50	11.50	88.5	968.185
0.0667	11.95	11.95	88.05	963.7705
0.0750	12.35	12.35	87.65	959.8465
0.0833	12.70	12.70	87.3	956.413
0.1000	13.35	13.35	86.65	950.0365
0.1167	14.00	14.00	86	943.66
0.1333	14.50	14.50	85.5	938.755
0.1500	15.03	15.03	84.97	933.5557
0.1667	15.40	15.40	84.6	929.926
0.2000	16.24	16.24	83.76	921.6856
0.2333	16.90	16.90	83.1	915.211
0.2667	17.41	17.41	82.59	910.2079
0.3000	17.90	17.90	82.1	905.401
0.3333	18.50	18.50	81.5	899.515
0.4167	19.21	19.21	80.79	892.5499
0.5000	19.65	19.65	80.35	888.2335
0.5833	20.12	20.12	79.88	883.6228
0.6667	20.50	20.50	79.5	879.895
0.7500	20.81	20.81	79.19	876.8539
0.8333	21.05	21.05	78.95	874.4995
1.0000	21.50	21.50	78.5	870.085
1.1667	21.90	21.90	78.1	866.161
1	22.12	22.12	77.88	864.0028
1.5000	22.28	22.28	77.72	862.4332
1.6667	22.35	22.35	77.65	861.7465
2.0000	22.35	22.35	77.65	861.7465
2.3333	22.4	22.40	77.6	861.256
2.666666667	22.45	22.45	77.55	860.7655
3	22.5	22.50	77.5	860.275
3.5	22.57	22.57	77.43	859.5883
4	22.64	22.64	77.36	858.9016
4.5	22.7	22.70	77.3	858.313
5	22.76	22.76	77.24	857.7244
5.5	22.81	22.81	77.19	857.2339
6	22.86	22.86	77.14	856.7434
7	22.91	22.91	77.09	856.2529
8	22.95	22.95	77.05	855.8605
9	22.99	22.99	77.01	855.4681
10	23.04	23.04	76.96	854.9776

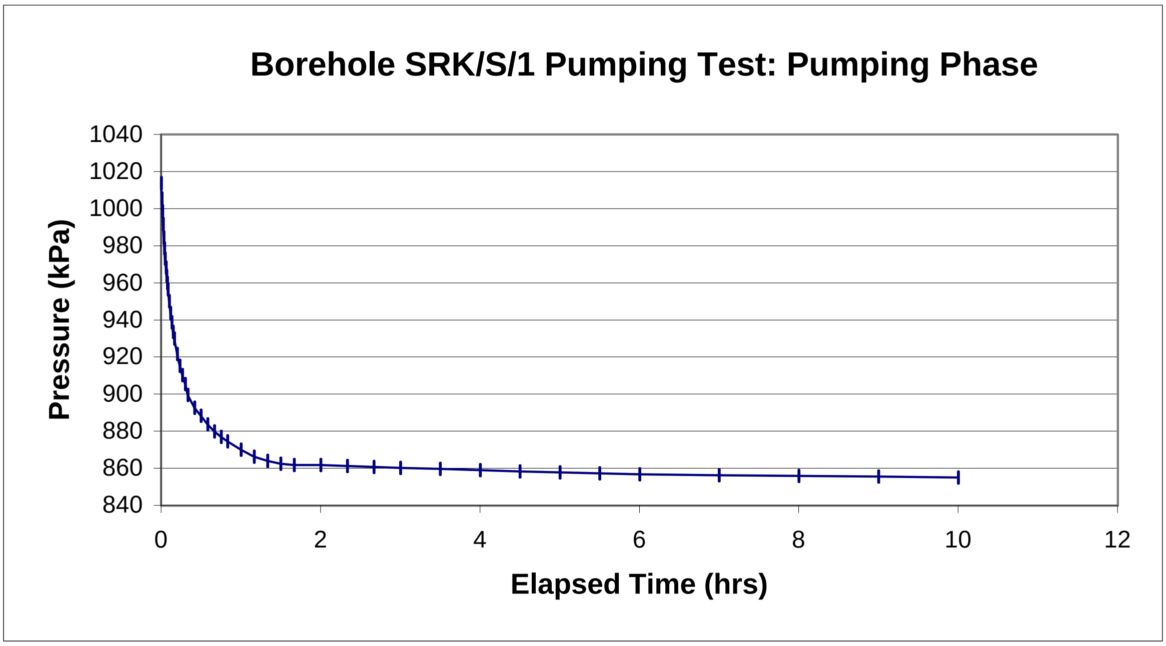
Notes:

(1). m bPC = metres below top of temporary casing. N.B. temporary casing is 0

(2). m bGL = metres below ground level.

(3). Head of water above Datum where Datum is sea level (sl).

NB. Ground level = 100 asl (approximate)


Borehole SRK/S/1 Pumping Test: Pumping Phase
Pressure (kPa)
1040
1020
1000
980
960
940
920
900
880
860
840
0
2
4
6
8
10
12
Elapsed Time (hrs)

Pumping Well No. SRK/S/1: Constant Rate Pumping Test Build-Up Phase.

2. Data.

Elapsed Time (hours)	Depth of water [1] (m bPC)	Depth of water [2] (m bGL)	G'water Head [3] (m asl)	Equivalent Pressure (kPa)
0.0000				
0.0017	25.95	25.95	74	826.4305
0.0083	25.70	25.70	74.3	828.883
0.0167	24.55	24.55	75.45	840.1645
0.0250	23.81	23.81	76.19	847.4239
0.0333	23.10	23.10	76.9	854.389
0.0417	22.40	22.40	77.6	861.256
0.0500	21.85	21.85	78.15	866.6515
0.0583	21.30	21.30	78.7	872.047
0.0667	20.80	20.80	79.2	876.952
0.0750	20.01	20.01	79.99	884.7019
0.0833	19.60	19.60	80.4	888.724
0.1000	18.80	18.80	81.2	896.572
0.1167	17.90	17.90	82.1	905.401
0.1333	17.10	17.10	82.9	913.249
0.1500	16.40	16.40	83.6	920.116
0.1667	15.11	15.11	84.89	932.7709
0.2000	14.66	14.66	85.34	937.1854
0.2333	14.10	14.10	85.9	942.679
0.2667	13.65	13.65	86.35	947.0935
0.3000	13.20	13.20	86.8	951.508
0.3333	12.50	12.50	87.5	958.375
0.4167	11.10	11.10	88.9	972.109
0.5000	10.05	10.05	89.95	982.4095
0.5833	9.30	9.30	90.7	989.767
0.6667	8.70	8.70	91.3	995.653
0.7500	8.50	8.50	91.5	997.615
0.8333	8.28	8.28	91.72	999.7732
1.0000	8.01	8.01	91.99	1002.4219
1.1667	7.85	7.85	92.15	1003.9915
1	7.70	7.70	92.3	1005.463
1.5000	7.62	7.62	92.38	1006.2478
1.6667	7.55	7.55	92.45	1006.9345
2.0000	7.44	7.44	92.56	1008.0136
2.3333	7.35	7.35	92.65	1008.8965
2.666666667	7.3	7.30	92.7	1009.387
3	7.24	7.24	92.76	1009.9756
3.5	7.18	7.18	92.82	1010.5642
4	7.15	7.15	92.85	1010.8585

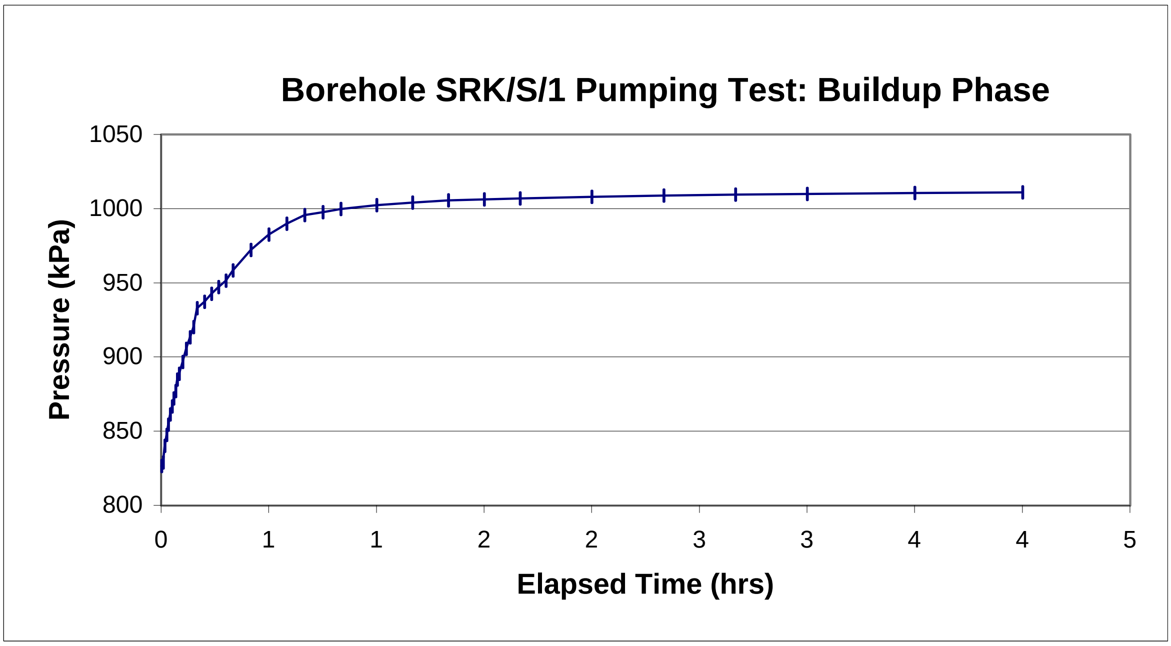
Notes:

(1). m bPC = metres below top of temporary casing. N.B. temporary casing is 0

(2). m bGL = metres below ground level.

(3). Head of water above Datum where Datum is sea level (sl).

NB. Ground level = 100 asl (approximate)


Borehole SRK/S/1 Pumping Test: Buildup Phase
1050
1000
950
900
850
800
Pressure (kPa)
0
1
1
2
2
3
3
4
4
5
Elapsed Time (hrs)

APPENDIX F2

MODELLING

1 MODELLING

1.1 Introduction

The primary objective of this modelling exercise is to determine the likely impact of leachate generated by the Gortmore TMF on certain vulnerable receptors that have been identified downstream of the site and to assess whether specific remedial measure may be required. A probabilistic approach has been used with a spreadsheet-based package called @Risk with equations and inputs that have been defined by SRK

Deterministic methods for resolving this issue are not considered appropriate because many of the factors that influence the passage of contaminants between the source and the receptor are both poorly quantified and highly variable. In other words, a realistic assessment of the site should adequately reflect the large range of possible outcomes arising from this variability. The advantage of a probabilistic approach is that the potential for any such outcome can be measured; this potential is given in terms of percentiles and as minimum, maximum and most likely values. The percentiles of the output distribution specify the probability with which a certain value (e.g. contaminant travel time) will not be exceeded.

This study falls into five parts:

1. Model conceptualisation;
2. Model set-up and calibration;
3. Model description;
4. Model simulations; and
5. A discussion of the results and any conclusions that may be drawn from them.

1.2 Conceptual Model

Two potentially vulnerable receptors have been identified downstream of the Gortmore TMF (the 'source'), these are:

1. The River Kilmastulla, which traces around the southern and western edges of the TMF at a distance of approximately 100m. The Kilmastulla is the main watercourse which drains the catchment that is fringed by the northern

slopes of the Silvermine Mountains and the southern slopes of the Arra Mountains; and

2. A number of water-supply holes that draw water from the limestone aquifer between 500 and 1500m to the West of Gortmore.

There are several pathways that could be followed by contaminants between the source and the receptors identified above; these are illustrated in Figure 1.

Should contaminants reach the Kilmastulla River, they are likely to do so by way of the alluvium upon which the river resides. Contaminant may escape the TMF by seeping through the toe of the dam and flowing along the ground surface for a short distance. This run-off should eventually infiltrate the ground and flow the remaining distance to the river in the alluvium The alternative scenario involves the seepage of leachate through the base of the TMF direct into the alluvium that sub-crops the site and the subsequent passage of contaminants through the alluvium to the river.

It is envisaged that the alluvium, which is unconsolidated and contains a mixture of clays, silts, sands and gravels, will have the properties of a porous medium and that flow will therefore be confined to the matrix of the sediment. Also the presence of clays and silts, with their potentially high Fraction of Organic Carbon (FOC) and Cation Exchange Capacity (CEC), will mean that the alluvium will possess some potential to retard the progress of contaminants in the geosphere.

Figure.1: Conceptual Model of Mass Transport

Lithological logs from boreholes sunk around the periphery of the Gortmore TMF indicate that the thickness of alluvium underpinning the site varies considerably from only a few metres up to ten metres. The alluvium is sub-cropped by limestone, so it is conceivable that leachate seeping from the base of the TMF may pass into this aquifer relatively unimpeded. The conceptual model for this scenario adopts a conservative approach by assuming that leachate from the TMF seeps directly into the limestone without including the attenuating effects of the intervening alluvium and then flows downstream to the nearest of the pumping wells, some 500m away.

It is envisaged that the limestone, which has karstic characteristics in this area, will have the properties of a fractured medium and that flow will therefore occur almost exclusively along discrete features in the rock. It is likely that the retarding potential of this medium is limited because of the speed that groundwater generally passes along conduits, the limited surface area of rock exposed to contaminants and the low FOC and CEC properties of limestone.

1.3 Model Description

The spreadsheet-based model constructed for this study considers all of the major processes that effect a potential contaminant as it travels from source to receptor. The program is broken down in to a series of steps that reflect the major stages in the evolution of a contaminant plume; these are the determination of:

1. 'Pore water concentration' at source;
2. The volume of contaminated water leaking from the source;
3. Dilution effects due to groundwater passing under the source;
4. Travel times to the receptor; and
5. Contaminant concentration at receptor.

Direct measurements of pore water concentrations in the field are preferred; however, these measurements were not available at the time the model was constructed, so concentrations are estimated using a theoretical approach based on soil/water partitioning equations.

The volume of contaminated water infiltrating the formations that underlie the source are estimated on the basis of how much effective rainfall recharges the soil after discounting for run-off and the effects of evapotranspiration.

The dilution effects due to groundwater passing under the source are estimated using a mass balance formula that is the same in principle to the one illustrated in Section 5 of this chapter.

The travel time of the contaminant to the receptor is calculated using a version of the Darcy Equation that incorporates the 'retardation coefficient'. The final concentration of contaminant at the receptor is estimated using the Domenico steady-state solution. This formula, which is a simplified version of the Ogata-Banks equation, was considered suitable for making preliminary predictions of contaminant concentration. Where the receptor is a river course, the model also considers the diluting effect of this feature by using a mass balance formula

1.4 Model Set-up and Calibration

Calibration is the first stage in the development of a model to characterise an existing tailings facility. The success of this stage depends on there being sufficient information available about the site. Data from preliminary site investigations have been used to calibrate the model.

This risk assessment aims to predict the leakage volumes from the site, dilution rates, travel times in the geosphere and likely concentrations of contaminant at the receptors. One of these outputs, contaminant concentration, can be compared with actual data from the site and is therefore suitable for the purposes of calibration.

Input parameters relevant to the calibration, with ranges where appropriate, are tabulated in the attached tables. Justification for the use of all input parameters is provided along-side these tables. Where there is no site-specific information on which to base these inputs, values have been either gleaned from relevant texts or generated on the basis of our expert opinion ('assumption').

The fate of two important leachate constituents is investigated in this study; these are Lead and Cadmium, both of which are present in soil samples taken from the TMF. Subsequent to this evaluation, Mercury was identified in the downstream boreholes. The evaluation for Mercury will be similar to Cadmium, although it occurs at much lower levels in the soil at Gortmore than Cadmium.

Cadmium and Mercury are List 1 substances (Directive 76/464/EEC); a category containing compounds that are recognised for their persistence in the environment and for their high toxicity and bio-accumulation potential. Lead is a List 2 substance; a category containing compounds recognised as having a 'deleterious effect on the aquatic environment'. All of these potential contaminants can take part in cation exchange and can partition onto clay, thereby retarding their transport.

The results of the calibration exercise are summarised in Table 1. The output parameters were considered sufficiently close to the concentrations of Lead and Cadmium in monitoring wells along the periphery of the site to go ahead with the next stage of modelling.

Table .1: Results of calibration model

Monitoring Borehole	Approx. Distance from TMF (m)	Field Values (ppb)		Calibration Output (ppb)	
		Lead	Cadmium	Lead	Cadmium
TMF1	50	20	<0.4	18	0.6
TMF2	75	10	<0.4	17	0.6
TMF3	400	7	<0.4	9	0.3
TMF4	15	50	<0.4	21	0.7

1.5 Model Simulations

The probabilistic risk assessment of the fate of contaminants leaking from the Gortmore TMF was carried out by running a series of simulations to assess travel times and final concentrations of Lead and Cadmium at the nearby water supply hole and the Kilmastulla River.

Results of the contaminant transport model are shown in Tables.2 and 3 below:

Table 2: Lead: Summary of Results of Contaminant Transport Model

Receptor (& distance)	Output	Mean or expected	95 percentile	5 percentile
Kilmastulla River (100m)	Contaminant travel time (yrs)	2.01E+06	7.32E+6	3.66+04
	Saturated zone concentration without river dilution (ppb)	15.0	37.5	4.5
	(1) Saturated zone concentration with river dilution (ppb)	1	1	1
Water Supply Borehole (500m)	Contaminant travel time (yrs)	3.62E+06	1.18E+7	3.34+05
	Saturated zone concentration (ppb)	10.3	23.3	3.3

Notes: (1). Equivalent to the assumed background concentration of lead in the River Kilmastulla.

Table 3: Cadmium: Summary of Results of Contaminant Transport Model

Receptor (& distance)	Output	Mean or expected	95 percentile	5 percentile
Kilmastulla River (100m)	Contaminant travel time (yrs)	2.64E+05	1.09E+06	5.47E+03
	Saturated zone concentration without river dilution (ppb)	0.64	1.50	0.20
	Saturated zone concentration with river dilution (ppb)	0.41	0.81	0.10
Water Supply Borehole (500m)	Contaminant travel time (yrs)	4.60E+05	1.72E+06	2.08E+04
	Saturated zone concentration (ppb)	0.37	0.88	0.11

Lead will take part in cation exchange and partition into the clay and silt components of the alluvium, thereby retarding its transport. It's travel time through the geosphere is likely to be in the region of 2E+06 years, though there is a 5% chance that it will take only 4E+04 years.

The concentration of Lead in the groundwater entering the River Kilmastulla is likely to plateau at about 15ppb, though there is a 5% chance of it being as high as 37.5ppb.

An estimate of metal concentration in the river after mixing of the contaminated groundwater with river water can be calculated using the following mass balance equation:

$$C_R = \frac{(WBV_d \text{ x } C_G) + (Q_{DWF} \text{ x } C_W)}{WBV_d + Q_{DWF}}$$

Where:

C_R = Resultant concentration in River Kilmastulla after mixing.

W = Width of site perpendicular to flow

B = Depth of mixing zone

V_d = Darcy velocity

= K x I

= Permeability x Hydraulic Gradient

C_G = Concentration of Lead in groundwater

Q_{DWF} = Flow rate in the River Kilmastulla

C_W = Initial concentration of Lead in River Kilmastulla

The concentration of Lead in the River Kilmastulla after mixing is likely to be of the order of 1ppb i.e. the same as the assumed background concentration of lead in the river. This result demonstrates that the impact of extra loading is likely to be negligible in the event of any Lead reaching the River Kilmastulla. These concentrations compare to a maximum permissible concentration for Lead (in running water) of 50ppb, based on EEC drinking water limits (Council Directive No. 80/778/EEC; 15th July 1980).

Cadmium is also a metal, so that the travel time through the geosphere is again likely to be considerable. The model estimates that Cadmium will take in the region of 3E+05 years, though there is a 5% chance that it will take only 5E+03 years.

The concentration of Cadmium in the groundwater entering the River Kilmastulla is likely to plateau at about 0.64ppb, though there is a 5% chance of it being as high as 1.5ppb. However, after mixing with river flow in the Kilmastulla this concentration is likely to reduce even further to 0.41ppb, though there is a 5% chance it may be as high as 0.81ppb These concentrations compare to a maximum permissible concentration for Cadmium of 5ppb, based on EEC drinking water limits (Council Directive No. 80/778/EEC; 15th July 1980). The limited decline in Cadmium concentration after mixing groundwater with river water is due to the choice of a background Cadmium value for the river ('assumed' most likely value: 0.2ppb) that, in the event, did not differ greatly from the low concentration already issuing from the alluvium.

The travel time of Lead to the pumping well is likely to be in the region of 4E+06 years, though there is a 5% chance that it will take only 3E+05 years. This is broadly similar to the travel time predicted for Lead between Gortmore TMF and the River Kilmastulla, although the distance covered is much greater. The more rapid transit of Lead in the limestone probably reflects the higher permeability and lower retardation potential of this medium when compared to the alluvium. The concentration of Lead is likely to plateau at about 10ppb, though there is a 5% chance of it being as high as 23ppb.

The model estimates that Cadmium will take in the region of 5E+05 years to reach the water supply well, though there is a 5% chance that it will take only 2E+04 years. The concentration of Cadmium in the groundwater entering the well is likely to plateau at about 0.37ppb, though there is a 5% chance of it being as high as 0.88ppb.

1.6 Discussion

The impact of the Gortmore TMF on the Kilmastulla River and on nearby water supply holes has been investigated probabilistically by considering the fate of Lead and Cadmium produced by waste at the site.

The risk assessment has shown that the concentrations of metallic pollutants modelled in the study are likely to be so low as to pose little or no threat to the River Kilmastulla and the water supply well. This has been attributed to a combination of factors including high retardation coefficients, the CEC of the alluvium and the dilution effects of the underlying formations, infiltration from rainfall between the source and the receptor and the Kilmastulla River.

Calculation of Contaminant Concentration at Receptor.

Receptor: **Water Supply Borehole**
Modelled Contaminant: **Cadmium (Cd)**

Parameter	Symbols	Minimum	Most Likely / Mean	Maximum / SD	Unit	(1)@Risk	Distribution
1. Calculation of Contaminant Concentration at Source:							
Soil contaminant conc'n	C_s	9.00	17.67	36.00	mg/kg	**21**	Triangular
Water filled soil porosity	q_W	0.1	0.25	0.4	fraction	**0.25**	Triangular
Air filled soil porosity	q_a	0.05	0.1	0.3	fraction	**0.15**	Triangular
Bulk density of source substrate e.g. tailings.	ρ_s	1.5	1.88	2.1	g/cm^3	**1.83**	Triangular
Henry's Law constant	H	0	0	0	dimensionless	**0**	Triangular
Soil-water partition coefficient	K_d	4	26	452	l/kg	**160.40**	Triangular
Factor (partitioning between soil and water)	F_1	-	-	-	dimensionless	**160.53**	-
Concentration of Contaminant in water at Source	$\mathbf{C_w}$	-	-	-	**mg/l**	**0.13**	-
2. Calculation of Dilution Factor (mass balance estimate):							
[A]. Source							
Effective Rainfall at Source	ER_s	-	1197	200	mm/yr	**1197**	Normal
Run-off Coefficient at Source	RC_s	0.1	-	0.4	dimensionless	**0.25**	Uniform
Infiltration	Inf	-	-	-	mm/yr	**898**	N/A
Source Length	L	-	-	-	m	**3.43E-03**	N/A
Source Width	W	-	480	-	m	**480**	N/A
Plume thickness at Source (assume equals aquifer thickness)							
Source Surface Area	As	-	-	-	m^2	**1.65**	N/A
Recharge Rate	Qr	-	-	-	m^3/day	**4.05E-03**	N/A
Check of Recharge Rate using Darcy Equation:							
Combined K of Tailings (5E-8m/s) & Overburden (1E-7m/s)	K	-	-	-	m/day	6.13E-03	N/A
Combined thickness of Tailings (9m) & Overburden (mean: 13.5m)	d	-	-	-	m	22.5	N/A
Vertical Hydraulic Gradient	I	-	-	-	dimensionless	0.45	N/A
	Q	-	-	-	m^3/day	4.59E-03	N/A
[B]. Groundwater							
Saturated aquifer thickness (active zone)	d_a	10	-	34	m	**22.00**	Uniform
Aquifer Cross-sectional Area	Aaq	-	-	-	m^2	**10560**	N/A
Hydraulic Conductivity of aquifer	K	1.00E-02	8.64E-02	1	m/day	**9.52E-02**	N/A
Hydraulic Conductivity of aquifer - Log$_{10}$(K)	K	-2.00E+00	-1.06E+00	0.00E+00	m/day	**-1.021**	Triangular
Hydraulic gradient	i	0.0011	-	0.0025	fraction	**0.0018**	Uniform
Background Concentration of Contaminant in Groundwater	C_u	0	0.0002	0.001	mg/l	**4.00E-04**	Triangular
Aquifer Flowrate	Qaq	-	-	-	m^3/day	**1.81**	N/A
Dilution Factor at Source	$\mathbf{DF_s}$	-	-	-	**fraction**	**447.23**	N/A
Concentration of Contaminant in groundwater under Source (after dilution)	$\mathbf{C_{gw}}$	-	-	-	**mg/l**	**6.89E-04**	N/A

3. Calculation of Travel Time to Receptor:

Soil-water partition coefficient	K_d	0.38	2.55	45.19	l/kg	16.04	Triangular
Bulk density of aquifer material.	ρ_a	1.7	2.3	2.8	g/cm^3	2.27	Triangular
Porosity of Aquifer material	n	0.02	0.05	0.08	fraction	0.05	Triangular
Retardation Factor	Rc	-	-	-	fraction	**728.13**	N/A
Diatance to Receptor	x	450	-	550	m	500	Uniform
Rate of Groundwater Movement	**v**	-	-	-	**m/day**	**3.43E-03**	N/A
Groundwater Travel Time to Receptor	t_{gw}	-	-	-	**days**	**1.46E+05**	N/A
Rate of Contaminant Movement	**u**	-	-	-	**m/day**	**4.71E-06**	N/A
Contaminant Travel Time to Receptor	t_c	-	-	-	**days**	**1.06E+08**	N/A
					years	**2.91E+05**	N/A

4. Calculation of Contaminant Concentration at Receptor (WITHOUT dilution due to recharge/leakance between Source & Receptor):

Half life for degradation of contaminant in water	$t_{1/2}$	9.9E+99	9.9E+99	9.9E+99	days	9.9E+99	Triangular
Decay Constant	λ	-	-	-	1/days	**7.00E-101**	N/A
(2) Longitudinal dispersivity	a_x	-	-	-	m	**50**	N/A
(2) Transverse dispersivity	a_z	-	-	-	m	**5**	N/A
(2) Vertical dispersivity	a_y	-	-	-	m	**0.5**	N/A
(3) Distance (lateral) to compliance point perpendicular to flow direction	z	-	-	-	m	**0**	N/A
(3) Distance (depth) to compliance point perpendicular to flow direction	y	-	-	-	m	**0**	N/A
(4) Concentration at Receptor	C_{ED1}	-	-	-	**mg/l**	**2.60E-04**	N/A

5. Calculation of Contaminant Concentration at Receptor (WITH dilution due to recharge/leakance between Source & Receptor):

Effective Rainfall between Source & Receptor	ERr	-	1197	200	mm/yr	1197	Normal
Run-off Coefficient on ground between Source & Receptor	RC_r	0.2	-	0.5	dimensionless	0.35	Uniform
Background Concentration of Contaminant in Rain	C_r	0	0.0002	0.001	mg/l	4.00E-04	Triangular
Infiltration	Inf	-	-	-	mm/yr	**778**	N/A
Total Volume Recharge	Rech	-	-	-	m^3	**3.73E+05**	N/A
Concentration at Receptor	C_{ED2}	-	-	-	**mg/l**	**4.00E-04**	N/A

Notes:

(1). Input highlighted in **RED**; Output highlighted in **BLUE**

(2). Calculated values assume:

ax = 0.1 *x
az = 0.01 * x
ay = 0.001 * x

(3). These parameters should be set to '0' barring exceptional circumstances. They simulate a point that is offset from the centre of the plume.

(4). Domenico Steady State Solution:

Concentration at Receptor = Cgw*EXP(x/(2*ax)*(1-(1+(4*(decay/Rf)*ax)/u)^0.5))*ERF(b/(4*SQRT(ay*x)))*ERF(W/(4*SQRT(az*x)))

Comments, Assumptions and References for Risk Modelling.

1. Calculation of Contaminant Concentration at Source:	
Soil contaminant conc'n	Based on paste samples from TMF
Water filled soil porosity	Assumed
Air filled soil porosity	Assumed
Bulk density of source substrate e.g. tailings.	Assumed
Henry's Law constant	N/A (metal)
Soil-water partition coefficient	

2. Calculation of Dilution Factor (mass balance estimate): [A]. Source	
Effective Rainfall at Source	Using area-specific rainfall data and assumed PE values (PE derived from site with equivalent rainfall in West Wales)
Run-off Coefficient at Source	Assumed
Source Length	Governed by Darcian velocity of aquifer
[B]. Groundwater	
Saturated aquifer thickness (active zone)	Based on lithological logs for TMF boreholes.
Hydraulic Conductivity of aquifer	Assumed based on typical K values for boulder clay and alluvium.
Hydraulic gradient	Site specific measurements (difference between elevation of water in TMF and nearby b'holes)
Background Concentration of Contaminant in Groundwater	From Hem, 1985: 'Mean composition of river water of the world'

3. Calculation of Travel Time to Receptor:	
Soil-water partition coefficient	
Bulk density of aquifer material.	From McGown, A. et al., 1975; Geotech. properties of the tills in West central Scotland. In engineering behaviour of glacial materials. Proc.Sym.Univ.Birmingham. pp.89-99
Porosity of Aquifer material (effective)	From Wiedemeier, T. et al., 1995; Tech. protocol for implementing Intrinsic remediation with long-term monitoring for attenuation of fuel contam'n. dissolved in g'water. Vol. 1. brooks AFB, Texas
Diatance to Receptor	Downstream end of TMF to receptor (River Kilmastulla)

Half life for degradation of contaminant in water	N/A Metal

5. Calculation of Contaminant Concentration at Receptor (WITH dilution due to mixing with low flows in river):	
Flow rate in River (low flow)	Based on stage records during Summer months for the River Kilmastula
Background Concentration of Contaminant in River	From Hem, 1985: 'Mean composition of river water of the world'

Comments, Assumptions and References for Risk Modelling.

1. Calculation of Contaminant Concentration at Source:

Soil contan	Based on paste samples from TMF
Water fille	Assumed
Air filled s	Assumed
Bulk densi	Assumed
Henry's La	N/A (metal)
Soil-water	From EPA, 1999: 'Understanding variation in Partition Coefficient, Kd, values'

2. Calculation of Dilution Factor (mass balance estimate):

[A]. Source

Effective R	Using area-specific rainfall data and assumed PE values (PE derived from site with equivalent rainfall in West Wales)
Run-off Co	Assumed
Source Ler	Governed by Darcian velocity of aquifer

[B]. Groundwater

Saturated a	Based on lithological logs for TMF boreholes.
Hydraulic	Assumed based on typical K values for boulder clay and alluvium.
Hydraulic g	Site specific measurements (difference between elevation of water in TMF and nearby b'holes)
Backgroun	From Hem, 1985: 'Mean composition of river water of the world'

3. Calculation of Travel Time to Receptor:

Soil-water	From EPA, 1999: 'Understanding variation in Partition Coefficient, Kd, values'
Bulk densi	From McGown, A. et al., 1975; Geotech. properties of the tills in West central Scotland. In engineering behaviour of glacial materials. Proc.Sym.Univ.Birmingham. pp.89-99
Porosity of	From Wiedemeier, T. et al., 1995; Tech. protocol for implementing Intrinsic remediation with long-term monitoring for attenuation of fuel contam'n. dissolved in g'water. Vol. 1. brooks AFB, Texas
Diatance to	Downstream end of TMF to receptor (River Kilmastulla)

4. Calculation of Contaminant Concentration at Receptor (WITHOUT dilution due to recharge/leakance between Source & Receptor):

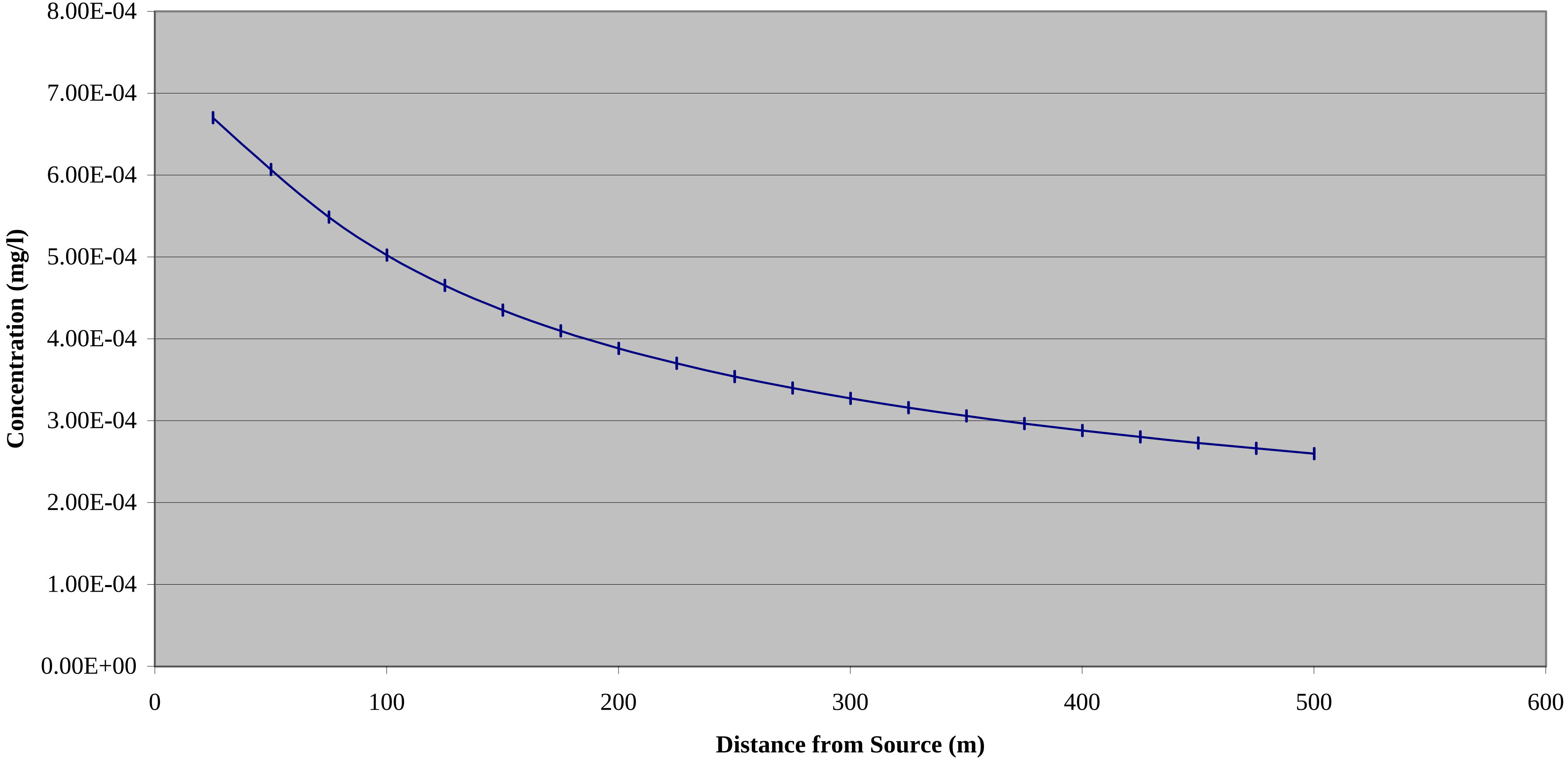
Half life fo	N/A Metal

5. Calculation of Contaminant Concentration at Receptor (WITH dilution due to mixing with low flows in river):

Flow rate i	Based on stage records during Summer months for the River Kilmastula
Backgroun	From Hem, 1985: 'Mean composition of river water of the world'

File Name: Cd_Bhole_1

Cadmium; Water Supply Hole;
Contaminant Concentration using Domenico Steady State Solution
('Most Likely' Concentration)



DOMENICO (STEADY STATE)

Calculations for source located at top of aquifer (ie vertical dispersion in one direction)

	Distance	Term 1	Term 2	EXP	Term 3A	ERF	Term 3B	ERF	Term 4A	ERF	Term 4B	ERF	Concentration
1	25	0.0002	0.00E+00	1.00E+00	1.07E+01	1	-1.07E+01	-1	1.56E+00	0.972193103	-1.56E+00	-0.972193103	6.70E-04
2	50	0.0002	0.00E+00	1.00E+00	7.59E+00	1	-7.59E+00	-1	1.10E+00	0.880205041	-1.10E+00	-0.880205041	6.07E-04
3	75	0.0002	0.00E+00	1.00E+00	6.20E+00	1	-6.20E+00	-1	8.98E-01	0.795976026	-8.98E-01	-0.795976026	5.49E-04
4	100	0.0002	0.00E+00	1.00E+00	5.37E+00	1	-5.37E+00	-1	7.78E-01	0.728667676	-7.78E-01	-0.728667676	5.02E-04
5	125	0.0002	0.00E+00	1.00E+00	4.80E+00	1	-4.80E+00	-1	6.96E-01	0.674820508	-6.96E-01	-0.674820508	4.65E-04
6	150	0.0002	0.00E+00	1.00E+00	4.38E+00	0.999999999	-4.38E+00	-0.999999999	6.35E-01	0.630892407	-6.35E-01	-0.630892407	4.35E-04
7	175	0.0002	0.00E+00	1.00E+00	4.06E+00	0.99999999	-4.06E+00	-0.99999999	5.88E-01	0.594321104	-5.88E-01	-0.594321104	4.10E-04
8	200	0.0002	0.00E+00	1.00E+00	3.79E+00	0.99999992	-3.79E+00	-0.99999992	5.50E-01	0.563323359	-5.50E-01	-0.563323359	3.88E-04
9	225	0.0002	0.00E+00	1.00E+00	3.58E+00	0.99999958	-3.58E+00	-0.99999958	5.19E-01	0.536644848	-5.19E-01	-0.536644848	3.70E-04
10	250	0.0002	0.00E+00	1.00E+00	3.39E+00	0.999998413	-3.39E+00	-0.999998413	4.92E-01	0.513383953	-4.92E-01	-0.513383953	3.54E-04
11	275	0.0002	0.00E+00	1.00E+00	3.24E+00	0.999995275	-3.24E+00	-0.999995275	4.69E-01	0.492877544	-4.69E-01	-0.492877544	3.40E-04
12	300	0.0002	0.00E+00	1.00E+00	3.10E+00	0.999988229	-3.10E+00	-0.999988229	4.49E-01	0.474627213	-4.49E-01	-0.474627213	3.27E-04
13	325	0.0002	0.00E+00	1.00E+00	2.98E+00	0.999974449	-2.98E+00	-0.999974449	4.31E-01	0.458250942	-4.31E-01	-0.458250942	3.16E-04
14	350	0.0002	0.00E+00	1.00E+00	2.87E+00	0.999950238	-2.87E+00	-0.999950238	4.16E-01	0.443450747	-4.16E-01	-0.443450747	3.06E-04
15	375	0.0002	0.00E+00	1.00E+00	2.77E+00	0.999911151	-2.77E+00	-0.999911151	4.02E-01	0.429990534	-4.02E-01	-0.429990534	2.96E-04
16	400	0.0002	0.00E+00	1.00E+00	2.68E+00	0.999852198	-2.68E+00	-0.999852198	3.89E-01	0.417680624	-3.89E-01	-0.417680624	2.88E-04
17	425	0.0002	0.00E+00	1.00E+00	2.60E+00	0.999768072	-2.60E+00	-0.999768072	3.77E-01	0.406366726	-3.77E-01	-0.406366726	2.80E-04
18	450	0.0002	0.00E+00	1.00E+00	2.53E+00	0.999653381	-2.53E+00	-0.999653381	3.67E-01	0.395921908	-3.67E-01	-0.395921908	2.73E-04
19	475	0.0002	0.00E+00	1.00E+00	2.46E+00	0.999502848	-2.46E+00	-0.999502848	3.57E-01	0.386240704	-3.57E-01	-0.386240704	2.66E-04
20	500	0.0002	0.00E+00	1.00E+00	2.40E+00	0.999311486	-2.40E+00	-0.999311486	3.48E-01	0.377234673	-3.48E-01	-0.377234673	2.60E-04

Simulation Results for Cd_Bhole_1.XLS

Contaminant: Cadmium
Receptor: Water Supply Boreholes

Iterations= 500
Simulations= 1
# Input Variables= 20
# Output Variables= 6
Sampling Type= Monte Carlo
Runtime= 00:00:05
Run on 03/01/02 at 12:55:52 PM

Summary Statistics

[A] Outputs:

Cell	Name		Minimum	Mean	Maximum	5% Perc	50% Perc	95% Perc
G15	Conc. of Contaminant in water at Source	mg/l	0.0319931	0.2461271	4.320005	0.049552	0.13526	0.832048
G41	Dilution Factor at Source	Fraction	106.3114	463.7764	1419.853	187.8538	426.0478	848.2528
G42	Conc. of Contaminant under Source	mg/l	1.06E-04	1.06E-03	0.0124768	0.000314	0.000793	0.00262
G52	Groundwater Travel Time to Receptor	days	8636.051	239681.8	1761601	24925.76	154744.5	794103.6
G54	Contaminant Travel Time to Receptor	days	1.80E+06	1.68E+08	2.17E+09	7583256	86890260	6.28E+08
G65	Concentration at Receptor	mg/l	5.99E-05	3.71E-04	4.24E-03	0.000108	0.00028	0.000879

[B] Inputs:

G8	Soil contaminant conc'n	mg/kg	10.08228	20.78807	34.42185	12.51695	20.0252	31.16839
G9	Water filled soil porosity	fraction	0.112231	0.25121	0.3974298	0.153258	0.251863	0.344346
G10	Air filled soil porosity	fraction	5.27E-02	0.1491118	0.2923143	0.071392	0.141099	0.250329
G11	Bulk density of source substrate e.g. tailings	g/cm3	1.537383	1.825798	2.073219	1.599371	1.827527	2.026729
G12	Henry's Law constant	dimensionless	0	0	0	0	0	0
G13	Soil-water partition coefficient	l/kg	5.934933	163.1348	444.8925	26.57291	149.7078	357.1924
G19	Effective Rainfall at Source	mm/yr	560.8957	1222.974	1869.411	919.8018	1212.625	1553.713
G20	Run-off Coefficient at Source	dimensionless	0.1000096	0.2536995	0.398976	0.114065	0.257989	0.384152
G34	Saturated aquifer thickness (active zone)	m	10.058	22.02474	33.9283	11.07064	21.83417	32.93589
G37	Hydraulic Conductivity of aquifer - Log10(K)	m/day	-1.924336	-1.023727	-6.08E-02	-1.7313	-1.02544	-0.33932
G38	Hydraulic gradient	fraction	1.10E-03	1.81E-03	2.49E-03	0.00118	0.001818	0.002419
G39	Background Concentration of Contaminant in Groundwater	mg/l	1.25E-05	3.92E-04	9.51E-04	9.86E-05	0.000348	0.000794
G46	Soil-water partition coefficient	l/kg	1.136462	15.48652	43.10258	2.257905	13.67424	33.79206
G47	Bulk density of aquifer material.	g/cm3	1.741976	2.259346	2.774767	1.898335	2.255397	2.643006
G48	Porosity of Aquifer material	fraction	2.14E-02	5.05E-02	7.83E-02	0.030841	0.050716	0.071204
G50	Diatance to Receptor	m	450.1592	500.5491	549.9501	455.2633	502.4903	543.9445
G58	Half life for degradation of contaminant in water	days	0	0	0	1	10	19
G68	Effective Rainfall between Source & Receptor	mm/yr	692.3005	1199.209	1797.975	873.44	1190.345	1539.989
G69	Run-off Coefficient on ground between Source & Receptor	dimensionless	0.2014657	0.3486621	0.4995585	0.219047	0.345188	0.484255
G70	Background Concentration of Contaminant in Rain	mg/l	2.86E-05	4.05E-04	9.88E-04	0.000117	0.000372	0.000808

@RISK Si	Run on 03/	Simulation Iterations=														
Name	mg/l / (1)@	fraction / (	mg/l / (1)@	days / (1)@	days / (1)@	mg/l / (1)@	mg/kg / (1)	fraction / (	fraction / (	g/cm3 / (1)	dimensionl	l/kg / (1)@	mm/yr / (1	dimensionl	m / (1)@R	m/day / (1)
Descriptio	Output	Output	Output	Output	Output	Output	Triang(C8,	Triang(C9,	Triang(C1(	Triang(C1	Triang(C1	Triang(C1	Normal(D1	Uniform(C	Uniform(C	Triang(C3
Cell	G15	G41	G42	G52	G54	G65	G8	G9	G10	G11	G12	G13	G19	G20	G34	G37
Minimum =	3.20E-02	106.3114	1.06E-04	8636.051	1796528	5.99E-05	10.08228	0.112231	5.27E-02	1.537383	0	5.934933	560.8957	0.10001	10.058	-1.92434
Maximum	4.320005	1419.853	1.25E-02	1761601	2.17E+09	4.24E-03	34.42185	0.39743	0.292314	2.073219	0	444.8925	1869.411	0.398976	33.9283	-6.08E-02
Mean =	0.246127	463.7764	1.06E-03	239681.8	1.68E+08	3.71E-04	20.78807	0.25121	0.149112	1.825798	0	163.1348	1222.974	0.2537	22.02474	-1.02373
Std Deviati	0.348794	215.1262	1.10E-03	260169.9	2.32E+08	3.55E-04	5.587244	5.89E-02	5.46E-02	0.126739	0	102.3428	198.2557	8.69E-02	7.012592	0.416297
Variance =	0.121657	46279.3	1.21E-06	6.77E+10	5.37E+16	1.26E-07	31.21729	3.47E-03	2.98E-03	0.016063	0	10474.04	39305.33	7.55E-03	49.17644	0.173303
Skewness =	5.763278	0.975306	5.209792	2.328102	3.339176	5.026823	0.357292	-3.17E-02	0.498346	-0.16479	0	0.562718	0.035953	-8.01E-02	1.89E-02	-1.46E-02
Kurtosis =	53.26772	4.326954	41.10995	9.702259	19.53071	41.28916	2.383711	2.42768	2.466624	2.294235	0	2.473461	3.125846	1.802661	1.783823	2.321558
Errors Calc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode =	5.38E-02	511.7467	8.09E-04	36696.75	1.51E+07	2.44E-04	17.39539	0.253994	0.107176	1.843717	0	49.15735	1116.27	0.102835	14.79688	-1.11932
5% Perc =	4.96E-02	187.8538	3.14E-04	24925.76	7583256	1.08E-04	12.51695	0.153258	7.14E-02	1.599371	0	26.57291	919.8018	0.114065	11.07064	-1.7313
10% Perc =	5.54E-02	217.7447	4.04E-04	39737.29	1.36E+07	1.40E-04	14.01426	0.171502	8.40E-02	1.645719	0	37.80799	973.8869	0.132274	12.38993	-1.60372
15% Perc =	6.91E-02	246.8815	4.50E-04	48779.58	2.01E+07	1.60E-04	14.80668	0.184772	9.27E-02	1.689928	0	52.41592	1019.405	0.146027	13.70858	-1.47913
20% Perc =	7.82E-02	269.1476	4.89E-04	60048.36	2.79E+07	1.82E-04	16.00128	0.198605	9.98E-02	1.714502	0	64.1049	1053.208	0.157512	14.7653	-1.40875
25% Perc =	8.90E-02	303.6802	5.45E-04	66884.97	3.41E+07	2.03E-04	16.42361	0.209268	0.105732	1.739418	0	77.98866	1084.247	0.17513	15.75345	-1.32103
30% Perc =	9.61E-02	325.1653	5.89E-04	77422.04	4.03E+07	2.14E-04	16.99767	0.217623	0.110566	1.754074	0	93.72493	1113.521	0.198014	16.92194	-1.24505
35% Perc =	0.106883	350.6262	6.44E-04	94700.52	4.92E+07	2.32E-04	17.77925	0.227867	0.119073	1.772363	0	104.8143	1137.938	0.210488	17.86827	-1.19366
40% Perc =	0.116435	376.3241	6.90E-04	114510.1	5.74E+07	2.44E-04	18.63067	0.235914	0.12444	1.791874	0	119.2045	1163.573	0.228551	19.8132	-1.14385
45% Perc =	0.124875	396.0316	7.39E-04	134771.4	6.85E+07	2.59E-04	19.28786	0.243078	0.131071	1.808627	0	136.254	1197.633	0.24357	20.93514	-1.09337
50% Perc =	0.13526	426.0478	7.93E-04	154744.5	8.69E+07	2.80E-04	20.0252	0.251863	0.141099	1.827527	0	149.7078	1212.625	0.257989	21.83417	-1.02544
55% Perc =	0.149347	459.1426	8.33E-04	172650.8	1.03E+08	3.03E-04	20.81099	0.258778	0.148964	1.844086	0	164.7629	1245.047	0.268622	23.24864	-0.96398
60% Perc =	0.165994	491.0267	9.05E-04	195052	1.18E+08	3.30E-04	21.67938	0.267534	0.155052	1.867186	0	177.9727	1271.041	0.280905	24.27406	-0.91103
65% Perc =	0.189349	522.8732	9.72E-04	218599.6	1.42E+08	3.48E-04	22.6391	0.275322	0.167632	1.883688	0	190.1556	1296.17	0.297581	25.5614	-0.84984
70% Perc =	0.222856	551.3983	1.05E-03	255661.3	1.63E+08	3.74E-04	23.82333	0.285509	0.177012	1.904541	0	209.0157	1325.223	0.316577	26.65679	-0.79199
75% Perc =	0.268942	595.4123	1.15E-03	307205.9	1.97E+08	4.15E-04	24.89785	0.296681	0.187412	1.926225	0	232.2258	1352.903	0.332288	27.9816	-0.71483
80% Perc =	0.319739	632.234	1.29E-03	366916.8	2.55E+08	4.52E-04	25.90559	0.305124	0.200776	1.947371	0	252.8846	1396.97	0.343015	29.49081	-0.65414
85% Perc =	0.391247	676.213	1.50E-03	426074.7	3.22E+08	5.08E-04	27.22272	0.316395	0.21026	1.965397	0	281.8811	1443.911	0.36132	30.35355	-0.5603
90% Perc =	0.508414	744.6439	1.90E-03	563708.3	4.06E+08	6.46E-04	28.6462	0.328688	0.224946	1.993247	0	321.2951	1476.956	0.370481	31.83968	-0.45644
95% Perc =	0.832048	848.2528	2.62E-03	794103.6	6.28E+08	8.79E-04	31.16839	0.344346	0.250329	2.026729	0	357.1924	1553.713	0.384152	32.93589	-0.33932
Filter Minimum =																
Filter Maximum =																
Type (1 or 2) =																
# Values F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenario #1	>75%	>75%	>75%	>75%	>75%	>75%										

Scenario #2	<25%	<25%	<25%	<25%	<25%	<25%
Scenario #3	>90%	>90%	>90%	>90%	>90%	>90%

fraction / (	mg/l / (1)@	l/kg / (1)@	g/cm3 / (1)	fraction / (	m / (1)@R	days / (1)@	mm/yr / (1	dimensionl	mg/l / (1)@Risk
Uniform(C	Triang(C3	Triang(C4	Triang(C4	Triang(C4	Uniform(C	Triang(C5	Normal(D	Uniform(C	Triang(C70,D70,E70)
G38	G39	G46	G47	G48	G50	G58	G68	G69	G70
1.10E-03	1.25E-05	1.136462	1.741976	2.14E-02	450.1592	0	692.3005	0.201466	2.86E-05
2.49E-03	9.51E-04	43.10258	2.774767	7.83E-02	549.9501	0	1797.975	0.499559	9.88E-04
1.81E-03	3.92E-04	15.48652	2.259346	5.05E-02	500.5491	0	1199.209	0.348662	4.05E-04
3.91E-04	2.19E-04	10.01417	0.22475	1.20E-02	28.91815	0	201.9517	0.084009	2.12E-04
1.53E-07	4.80E-08	100.2835	0.050513	1.45E-04	836.2595	0	40784.49	7.06E-03	4.48E-08
-4.18E-02	0.519528	0.624607	4.58E-02	4.09E-02	-6.28E-02	0	0.15462	5.12E-02	0.523073
1.865454	2.38849	2.577636	2.400201	2.327858	1.762943	0	2.833537	1.863258	2.527057
0	0	0	0	0	0	500	0	0	0
2.03E-03	2.07E-04	18.03645	2.224141	5.72E-02	548.6425	1.40E-45	1300.802	0.222316	3.40E-04
1.18E-03	9.86E-05	2.257905	1.898335	3.08E-02	455.2633	1	873.44	0.219047	1.17E-04
1.26E-03	1.37E-04	3.455507	1.970325	3.40E-02	460.1239	2	932.7867	0.231749	1.48E-04
1.33E-03	1.64E-04	4.899748	2.008969	3.68E-02	464.9348	3	986.7233	0.246161	1.82E-04
1.41E-03	1.92E-04	5.971523	2.04668	3.93E-02	469.7216	4	1035.868	0.262887	2.15E-04
1.47E-03	2.13E-04	7.241939	2.093462	0.041342	474.8179	5	1063.608	0.276306	2.37E-04
1.53E-03	2.40E-04	8.308152	2.128863	4.32E-02	479.007	6	1091.673	0.289849	2.60E-04
1.61E-03	2.67E-04	9.676046	2.166663	4.47E-02	485.2198	7	1112.785	0.309405	2.88E-04
1.70E-03	2.91E-04	11.12198	2.202177	0.047128	490.7253	8	1139.638	0.321074	3.11E-04
1.78E-03	3.17E-04	12.13692	2.232549	0.048932	497.2333	9	1161.762	0.332698	3.41E-04
1.82E-03	3.48E-04	13.67424	2.255397	5.07E-02	502.4903	10	1190.345	0.345188	3.72E-04
1.89E-03	3.79E-04	15.28288	2.290133	5.23E-02	507.3125	11	1216.477	0.36312	4.00E-04
1.94E-03	4.27E-04	17.0548	2.318326	5.40E-02	510.8518	12	1244.175	0.374668	4.40E-04
1.99E-03	4.61E-04	18.34137	2.343601	5.56E-02	516.6488	13	1273.411	0.388011	4.78E-04
2.04E-03	5.06E-04	20.17189	2.380434	5.76E-02	522.2568	14	1301.194	0.400475	5.16E-04
2.13E-03	5.54E-04	21.9768	2.417365	5.93E-02	526.2049	15	1338.353	0.417036	5.51E-04
2.21E-03	5.90E-04	24.63583	2.457998	6.08E-02	530.2168	16	1374.362	0.435261	5.88E-04
2.27E-03	6.44E-04	27.08025	2.497238	6.40E-02	534.0752	17	1410.045	0.45122	6.47E-04
2.35E-03	7.16E-04	30.61151	2.565627	6.64E-02	539.1831	18	1459.511	0.466173	7.05E-04
2.42E-03	7.94E-04	33.79206	2.643006	7.12E-02	543.9445	19	1539.989	0.484255	8.08E-04
0	0	0	0	0	0	-500	0	0	0

Calculation of Contaminant Concentration at Receptor.

Receptor: **Kilmastula River**
Modelled Contaminant: **Cadmium (Cd)**

Parameter	Symbols	Minimum	Most Likely / Mean	Maximum / SD	Unit	$^{(1)}$@Risk	Distribution
1. Calculation of Contaminant Concentration at Source:							
Soil contaminant conc'n	C_s	9	1.77E+01	3.60E+01	mg/kg	**21**	Triangular
Water filled soil porosity	q_W	0.1	0.25	0.4	fraction	**0.25**	Triangular
Air filled soil porosity	q_a	0.05	0.1	0.3	fraction	**0.15**	Triangular
Bulk density of source substrate e.g. tailings.	ρ_s	1.5	1.88	2.1	g/cm^3	**1.83**	Triangular
Henry's Law constant	H	0	0	0	dimensionless	**0**	Triangular
Soil-water partition coefficient	K_d	4	26	452	l/kg	**160.40**	Triangular
Factor (partitioning between soil and water)	F_1	-	-	-	dimensionless	**160.53**	-
Concentration of Contaminant in water at Source	$\mathbf{C_w}$	-	-	-	**mg/l**	**0.13**	-
2. Calculation of Dilution Factor (mass balance estimate):							
[A]. Source							
Effective Rainfall at Source	ER_s	-	1197	200	mm/yr	**1197**	Normal
Run-off Coefficient at Source	RC_s	0.1	-	0.4	dimensionless	**0.25**	Uniform
Infiltration	Inf	-	-	-	mm/yr	**898**	N/A
Source Length	L	-	-	-	m	**5.58E-03**	N/A
Source Width	W	-	480	-	m	**480**	N/A
Plume thickness at Source (assume equals aquifer thickness)							
Source Surface Area	As	-	-	-	m^2	**2.68**	N/A
Recharge Rate	Qr	-	-	-	m^3/day	**6.59E-03**	N/A
Check of Recharge Rate using Darcy Equation:							
Combined K of Tailings (5E-8m/s) & Overburden (1E-7m/s)	K	-	-	-	m/day	6.13E-03	N/A
Combined thickness of Tailings (9m) & Overburden (mean: 13.5m)	d	-	-	-	m	22.5	N/A
Vertical Hydraulic Gradient	I	-	-	-	dimensionless	0.45	N/A
	Q	-	-	-	m^3/day	7.47E-03	N/A
[B]. Groundwater							
Saturated aquifer thickness (active zone)	d_a	2	-	25	m	**13.50**	Uniform
Aquifer Cross-sectional Area	Aaq	-	-	-	m^2	**6480**	N/A
Hydraulic Conductivity of aquifer	K	8.64E-04	8.64E-03	0.864	m/day	**1.86E-02**	N/A
Hydraulic Conductivity of aquifer - Log_{10}(K)	K	-3.06E+00	-2.06E+00	-6.35E-02	m/day	**-1.730**	Triangular
Hydraulic gradient	i	0.03	-	0.05	fraction	**0.0400**	Uniform
Background Concentration of Contaminant in Groundwater	C_u	0	0.0002	0.001	mg/l	**4.00E-04**	Triangular
Aquifer Flowrate	Qaq	-	-	-	m^3/day	**4.82**	N/A
Dilution Factor at Source	$\mathbf{DF_s}$	-	-	-	**fraction**	**731.83**	N/A
Concentration of Contaminant in groundwater under Source (after dilution)	$\mathbf{C_{gw}}$	-	-	-	**mg/l**	**5.77E-04**	N/A

3. Calculation of Travel Time to Receptor:

Soil-water partition coefficient	K_d	4	26	452	l/kg	**160.40**	Triangular
Bulk density of aquifer material.	ρ_a	1.7	2.03	2.35	g/cm^3	**2.03**	Triangular
Porosity of Aquifer material (effective)	n	0.05	0.15	0.2	fraction	**0.133333333**	Triangular
Retardation Factor	Rc	-	-	-	fraction	**2439.03**	N/A
Diatance to Receptor	x	50	-	150	m	**100**	Uniform
Rate of Groundwater Movement	**v**	-	-	-	**m/day**	**5.58E-03**	N/A
Groundwater Travel Time to Receptor	$\mathbf{t_{gw}}$	-	-	-	**days**	**1.79E+04**	N/A
Rate of Contaminant Movement	**u**	-	-	-	**m/day**	**2.29E-06**	N/A
Contaminant Travel Time to Receptor	$\mathbf{t_c}$	-	-	-	**days**	**4.37E+07**	N/A
					years	**1.20E+05**	N/A

4. Calculation of Contaminant Concentration at Receptor (WITHOUT dilution due to recharge/leakance between Source & Receptor):

Half life for degradation of contaminant in water	$t_{1/2}$	9.9E+99	9.9E+99	9.9E+99	days	**9.9E+99**	Triangular
Decay Constant	λ	-	-	-	1/days	**7.00E-101**	N/A
(2) Longitudinal dispersivity	a_x	-	-	-	m	**10**	N/A
(2) Transverse dispersivity	a_z	-	-	-	m	**1**	N/A
(2) Vertical dispersivity	a_y	-	-	-	m	**0.1**	N/A
(3) Distance (lateral) to compliance point perpendicular to flow direction	z	-	-	-	m	**0**	N/A
(3) Distance (depth) to compliance point perpendicular to flow direction	y	-	-	-	m	**0**	N/A
(4) Concentration at Receptor	$\mathbf{C_{ED1}}$	-	-	-	**mg/l**	**5.01E-04**	N/A

5. Calculation of Contaminant Concentration at Receptor (WITH dilution due to mixing with low flows in river):

Flow rate in River (low flow)	Qr	0.1	0.2	0.3	Cumecs	**0.2**	Triangular
					m^3/day	**17280**	N/A
Background Concentration of Contaminant in River	C_r	0	0.0002	0.001	mg/l	**4.00E-04**	Triangular
Concentration at Receptor	$\mathbf{C_{ED2}}$	-	-	-	**mg/l**	**4.00E-04**	N/A

Notes:

(1). Input highlighted in **RED**; Output highlighted in **BLUE**

(2). Calculated values assume:

ax = 0.1 *x

az = 0.01 * x

ay = 0.001 * x

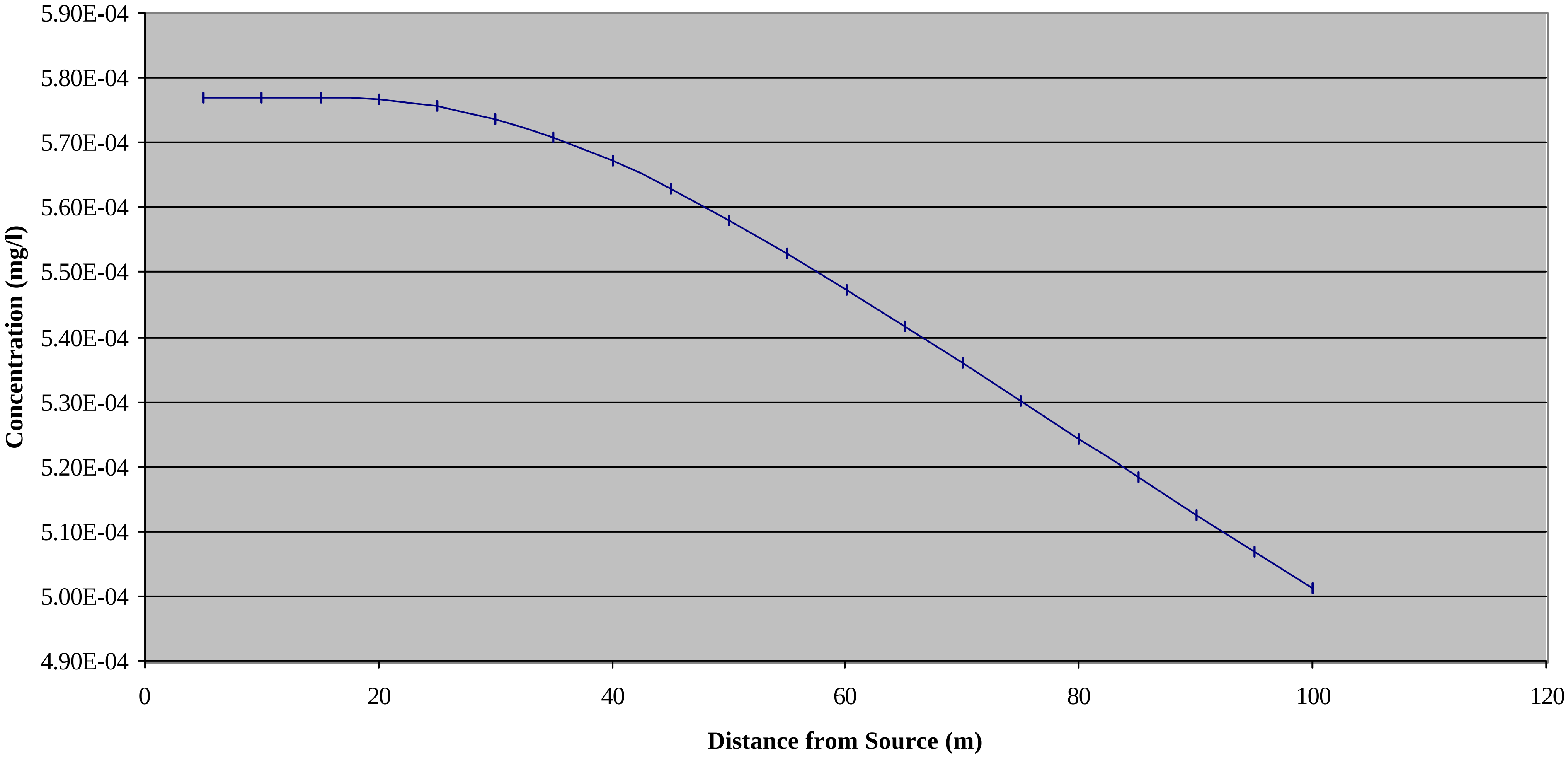
(3). These parameters should be set to '0' barring exceptional circumstances. They simulate a point that is offset from the centre of the plume.

(4). Domenico Steady State Solution:

Concentration at Receptor = Cgw*EXP(x/(2*ax)*(1-(1+(4*(decay/Rf)*ax)/u)^0.5))*ERF(b/(4*SQRT(ay*x)))*ERF(W/(4*SQRT(az*x)))

File Name: Cd_RKilm_1

Cadmium; Kilmastulla River; Contaminant Concentration using Domenico Steady State Solution ('Most Likely' Concentration)



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DOMENICO (STEADY STATE)

Calculations for source located at top of aquifer (ie vertical dispersion in one direction)

	Distance	Term 1	Term 2	EXP	Term 3A	ERF	Term 3B	ERF	Term 4A	ERF	Term 4B	ERF	Concentration
1	5	0.0001	0.00E+00	1.00E+00	5.37E+01	1	-5.37E+01	-1	4.77E+00	1	-4.77E+00	-1	5.77E-04
2	10	0.0001	0.00E+00	1.00E+00	3.79E+01	1	-3.79E+01	-1	3.38E+00	0.999998185	-3.38E+00	-0.999998185	5.77E-04
3	15	0.0001	0.00E+00	1.00E+00	3.10E+01	1	-3.10E+01	-1	2.76E+00	0.999902654	-2.76E+00	-0.999902654	5.77E-04
4	20	0.0001	0.00E+00	1.00E+00	2.68E+01	1	-2.68E+01	-1	2.39E+00	0.999261843	-2.39E+00	-0.999261843	5.77E-04
5	25	0.0001	0.00E+00	1.00E+00	2.40E+01	1	-2.40E+01	-1	2.13E+00	0.997461313	-2.13E+00	-0.997461313	5.76E-04
6	30	0.0001	0.00E+00	1.00E+00	2.19E+01	1	-2.19E+01	-1	1.95E+00	0.9941429	-1.95E+00	-0.9941429	5.74E-04
7	35	0.0001	0.00E+00	1.00E+00	2.03E+01	1	-2.03E+01	-1	1.80E+00	0.989266583	-1.80E+00	-0.989266583	5.71E-04
8	40	0.0001	0.00E+00	1.00E+00	1.90E+01	1	-1.90E+01	-1	1.69E+00	0.982989716	-1.69E+00	-0.982989716	5.67E-04
9	45	0.0001	0.00E+00	1.00E+00	1.79E+01	1	-1.79E+01	-1	1.59E+00	0.975551051	-1.59E+00	-0.975551051	5.63E-04
10	50	0.0001	0.00E+00	1.00E+00	1.70E+01	1	-1.70E+01	-1	1.51E+00	0.967201182	-1.51E+00	-0.967201182	5.58E-04
11	55	0.0001	0.00E+00	1.00E+00	1.62E+01	1	-1.62E+01	-1	1.44E+00	0.958169401	-1.44E+00	-0.958169401	5.53E-04
12	60	0.0001	0.00E+00	1.00E+00	1.55E+01	1	-1.55E+01	-1	1.38E+00	0.948651656	-1.38E+00	-0.948651656	5.47E-04
13	65	0.0001	0.00E+00	1.00E+00	1.49E+01	1	-1.49E+01	-1	1.32E+00	0.93880904	-1.32E+00	-0.93880904	5.42E-04
14	70	0.0001	0.00E+00	1.00E+00	1.43E+01	1	-1.43E+01	-1	1.28E+00	0.92877078	-1.28E+00	-0.92877078	5.36E-04
15	75	0.0001	0.00E+00	1.00E+00	1.39E+01	1	-1.39E+01	-1	1.23E+00	0.91863885	-1.23E+00	-0.91863885	5.30E-04
16	80	0.0001	0.00E+00	1.00E+00	1.34E+01	1	-1.34E+01	-1	1.19E+00	0.90849273	-1.19E+00	-0.90849273	5.24E-04
17	85	0.0001	0.00E+00	1.00E+00	1.30E+01	1	-1.30E+01	-1	1.16E+00	0.89839362	-1.16E+00	-0.89839362	5.18E-04
18	90	0.0001	0.00E+00	1.00E+00	1.26E+01	1	-1.26E+01	-1	1.13E+00	0.888388199	-1.13E+00	-0.888388199	5.13E-04
19	95	0.0001	0.00E+00	1.00E+00	1.23E+01	1	-1.23E+01	-1	1.09E+00	0.878511528	-1.09E+00	-0.878511528	5.07E-04
20	100	0.0001	0.00E+00	1.00E+00	1.20E+01	1	-1.20E+01	-1	1.07E+00	0.868789536	-1.07E+00	-0.868789536	5.01E-04

Simulation Results for Cd_RKilm_1.xls

Contaminant:	Cadmium
Receptor:	Kilmastula River

Iterations= 500
Simulations= 1
# Input Variables= 19
# Output Variables= 7
Sampling Type= Monte Carlo
Runtime= 00:00:04
Run on 03/01/02 at 01:58:40 PM

Summary Statistics

[A] Outputs:

Cell	Name		Minimum	Mean	Maximum	5% Perc	50% Perc	95% Perc
G15	Conc. of Contaminant in water at Source	mg/l	0.0321663	0.2521278	2.584042	0.051014	0.150702	0.794836
G41	Dilution Factor at Source	Fraction	84.16666	705.6059	2315.037	152.4279	663.4752	1534.521
G42	Conc. of Contaminant under Source	mg/l	1.18E-04	1.02E-03	0.0166499	0.000244	0.000724	0.002762
G52	Groundwater Travel Time to Receptor	days	219.318	37446.19	483946.5	1065.684	17065.82	151705.1
G54	Contaminant Travel Time to Receptor	days	1.42E+05	9.62E+07	1.64E+09	1994882	33550470	3.98E+08
G65	Concentration at Receptor (without river dilution)	mg/l	9.92E-05	6.39E-04	5.08E-03	0.000195	0.000535	0.001503
G71	Concentration at Receptor (with river dilution)	mg/l	3.65E-06	4.10E-04	9.27E-04	0.000101	0.000385	0.000811

[B] Inputs:

G8	Soil contaminant conc'n	mg/kg	9.51726	21.10185	34.09681	12.28119	20.64192	30.87557
G9	Water filled soil porosity	fraction	0.1145996	0.2514547	0.3963021	0.146773	0.250649	0.356302
G10	Air filled soil porosity	fraction	5.54E-02	0.149488	0.2969711	0.07577	0.139976	0.249126
G11	Bulk density of source substrate e.g. tailings	g/cm3	1.506391	1.824284	2.090985	1.59246	1.834029	2.021908
G12	Henry's Law constant	dimensionless	0	0	0	0	0	0
G13	Soil-water partition coefficient	l/kg	9.090774	158.1355	426.965	26.76125	139.4997	349.248
G19	Effective Rainfall at Source	mm/yr	693.9303	1205.246	1838.371	864.8677	1202.768	1542.734
G20	Run-off Coefficient at Source	dimensionless	0.1007637	0.2508619	0.3999974	0.115087	0.25486	0.381887
G34	Saturated aquifer thickness (active zone)	m	2.057499	12.98459	24.97991	3.097756	12.56013	23.658
G37	Hydraulic Conductivity of aquifer - Log10(K)	m/day	-2.923984	-1.694112	-2.29E-01	-2.66576	-1.75865	-0.58411
G38	Hydraulic gradient	fraction	3.00E-02	4.01E-02	5.00E-02	0.031015	0.040152	0.049082
G39	Background Concentration of Contaminant in Groundwater	mg/l	2.20E-05	4.03E-04	9.43E-04	0.000103	0.000369	0.000803
G46	Soil-water partition coefficient	l/kg	4.859827	168.2436	441.9014	29.58555	154.4186	367.0525
G47	Bulk density of aquifer material.	g/cm3	1.706725	2.023338	2.317108	1.799948	2.017098	2.254848
G48	Porosity of Aquifer material	fraction	5.56E-02	1.32E-01	1.96E-01	0.075575	0.134952	0.178749
G50	Distance to Receptor	m	50.01562	97.71384	149.5017	53.38899	96.90846	143.9011
G58	Half life for degradation of contaminant in water	days	0	0	0	1	10	19
G68	Flow rate in River (low flow)	m3/day	0.1027787	0.2013774	0.2971102	0.131023	0.203071	0.269597
G70	Background Concentration of Contaminant in River	mg/l	3.652E-06	0.0004103	0.0009274	0.000101	0.000385	0.000811

@RISK Sin	Run on 03/	Simulations	Iterations=													
Name	mg/l / (1)@	fraction / (1	mg/l / (1)@	days / (1)@	days / (1)@	mg/l / (1)@	mg/l / (1)@	mg/kg / (1)(	fraction / (1	fraction / (1	g/cm3 / (1)(	dimensionle	l/kg / (1)@I	mm/yr / (1)	dimensionle	m / (1)@Ris
Descriptior	Output	Output	Output	Output	Output	Output	Output	Triang(C8,	Triang(C9,	Triang(C1	Triang(C11	Triang(C12	Triang(C13	Normal(D1	Uniform(C	Uniform(C
Cell	G15	G41	G42	G52	G54	G65	G71	G8	G9	G10	G11	G12	G13	G19	G20	G34
Minimum =	3.22E-02	84.16666	1.18E-04	219.318	142473	9.92E-05	3.65E-06	9.51726	0.1146	0.055405	1.506391	0	9.090774	693.9303	0.100764	2.057499
Maximum =	2.584042	2315.037	1.66E-02	483946.5	1.64E+09	5.08E-03	9.27E-04	34.09681	0.396302	0.296971	2.090985	0	426.965	1838.371	0.399997	24.97991
Mean =	0.252128	705.6059	1.02E-03	37446.19	9.62E+07	6.39E-04	4.10E-04	21.10185	0.251455	0.149488	1.824284	0	158.1355	1205.246	0.250862	12.98459
Std Deviati	0.298286	421.6443	1.26E-03	57842.91	1.77E+08	4.78E-04	2.20E-04	5.635608	6.29E-02	0.054388	0.126543	0	101.2357	203.2633	0.08676	6.728003
Variance =	8.90E-02	177784	1.58E-06	3.35E+09	3.14E+16	2.28E-07	4.85E-08	31.76008	3.96E-03	2.96E-03	1.60E-02	0	10248.67	41315.97	7.53E-03	45.26602
Skewness =	3.787885	0.7918	6.82338	3.441479	4.439553	3.59374	0.391197	0.185587	4.25E-02	0.540973	-0.17328	0	0.543034	0.102385	-7.06E-02	0.117748
Kurtosis =	24.20189	3.260977	69.96745	18.36962	28.75462	25.04219	2.239927	2.221226	2.315645	2.47109	2.358057	0	2.350044	2.694671	1.787483	1.796387
Errors Calc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode =	5.55E-02	879.0802	5.69E-04	1701.297	3959379	2.66E-04	1.95E-04	20.36216	0.171431	0.112947	1.799017	0	133.2441	1253.774	0.12459	14.41862
5% Perc =	5.10E-02	152.4279	2.44E-04	1065.684	1994882	1.95E-04	1.01E-04	12.28119	0.146773	7.58E-02	1.59246	0	26.76125	864.8677	0.115087	3.097756
10% Perc =	5.96E-02	206.2471	3.17E-04	1721.383	2995156	2.29E-04	1.46E-04	13.67149	0.167809	8.72E-02	1.645479	0	35.3052	942.3638	0.126947	4.026954
15% Perc =	6.85E-02	253.8622	3.89E-04	2873.026	4267032	2.66E-04	1.73E-04	14.86832	0.179619	9.34E-02	1.679997	0	45.57874	996.8853	0.139188	4.955812
20% Perc =	7.78E-02	301.5903	4.47E-04	3901.656	6929683	3.24E-04	1.95E-04	15.80873	0.19549	9.89E-02	1.708321	0	55.82587	1030.863	0.154085	5.877338
25% Perc =	8.70E-02	360.4788	5.05E-04	5300.596	9662654	3.49E-04	2.23E-04	16.71452	0.20617	0.107159	1.733285	0	73.3773	1058.167	0.170907	6.858453
30% Perc =	9.70E-02	415.2451	5.60E-04	6682.483	1.36E+07	3.95E-04	2.51E-04	17.49343	0.214669	0.114435	1.757375	0	84.44254	1090.026	0.190382	7.68085
35% Perc =	0.108692	491.8043	5.95E-04	9019.982	1.82E+07	4.33E-04	2.86E-04	18.33683	0.225636	0.11951	1.77832	0	99.35043	1117.027	0.211275	9.55796
40% Perc =	0.124353	543.2205	6.39E-04	10747.47	2.38E+07	4.64E-04	3.19E-04	19.18083	0.234143	0.125248	1.797745	0	112.4372	1147.842	0.228804	10.7592
45% Perc =	0.13874	602.7294	6.76E-04	13596.51	2.84E+07	4.96E-04	3.52E-04	19.98308	0.244823	0.131641	1.814217	0	126.9971	1179.208	0.241498	11.56926
50% Perc =	0.150702	663.4752	7.24E-04	17065.82	3.36E+07	5.35E-04	3.85E-04	20.64192	0.250649	0.139976	1.834029	0	139.4997	1202.768	0.25486	12.56013
55% Perc =	0.160783	695.6945	7.66E-04	21096.22	3.96E+07	5.77E-04	4.19E-04	21.49404	0.258529	0.146119	1.849846	0	160.7849	1219.151	0.267215	13.91776
60% Perc =	0.179822	752.1906	8.19E-04	25185.35	5.58E+07	6.20E-04	4.52E-04	22.48079	0.264759	0.154758	1.867108	0	172.0836	1251.751	0.285222	14.83428
65% Perc =	0.198003	804.2433	8.70E-04	29282.58	7.09E+07	6.59E-04	4.96E-04	23.05934	0.274809	0.16272	1.88417	0	192.861	1276.762	0.298637	16.01438
70% Perc =	0.247461	868.0245	9.53E-04	36078.49	8.73E+07	7.04E-04	5.31E-04	24.21029	0.282791	0.176019	1.89632	0	207.4407	1316.342	0.311284	17.23767
75% Perc =	0.29237	950.025	1.05E-03	44260.26	1.02E+08	7.47E-04	5.65E-04	25.30911	0.29529	0.187131	1.911641	0	226.6662	1353.072	0.321989	18.63666
80% Perc =	0.351895	1039.337	1.18E-03	52650.46	1.22E+08	8.12E-04	6.15E-04	26.31387	0.310451	0.199753	1.936979	0	252.5915	1383.175	0.339322	19.90339
85% Perc =	0.440466	1179.024	1.39E-03	68049.7	1.68E+08	9.36E-04	6.77E-04	27.77789	0.324792	0.213519	1.961592	0	273.9597	1416.932	0.354246	21.76193
90% Perc =	0.568291	1307.866	1.76E-03	90590.09	2.46E+08	0.001114	7.25E-04	29.21746	0.340611	0.231431	1.987507	0	316.1212	1472.032	0.367521	22.80324
95% Perc =	0.794836	1534.521	2.76E-03	151705.1	3.98E+08	1.50E-03	8.11E-04	30.87557	0.356302	0.249126	2.021908	0	349.248	1542.734	0.381887	23.658
Filter Minimum =																
Filter Maximum =																
Type (1 or 2) =																
# Values Fil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenario #1	>75%	>75%	>75%	>75%	>75%	>75%	>75%									
Scenario #2	<25%	<25%	<25%	<25%	<25%	<25%	<25%									
Scenario #3	>90%	>90%	>90%	>90%	>90%	>90%	>90%									

m/day / (1)(	fraction / (1	mg/l / (1)@	l/kg / (1)@	g/cm3 / (1)(	fraction / (1	m / (1)@Ri	days / (1)@	Cumecs / (1	mg/l / (1)@Risk
Triang(C37	Uniform(C	Triang(C39	Triang(C46	Triang(C47	Triang(C48	Uniform(C	Triang(C58	Triang(C68	Triang(C70,D70,E70)
G37	G38	G39	G46	G47	G48	G50	G58	G68	G70
-2.92398	3.00E-02	2.20E-05	4.859827	1.706725	5.56E-02	50.01562	0	0.102779	3.65E-06
-0.22917	5.00E-02	9.43E-04	441.9014	2.317108	0.195679	149.5017	0	0.29711	9.27E-04
-1.69411	0.040109	4.03E-04	168.2436	2.023338	0.131741	97.71384	0	0.201377	4.10E-04
0.618159	5.76E-03	2.14E-04	103.5208	0.13353	3.07E-02	29.26526	0	4.19E-02	2.20E-04
0.38212	3.31E-05	4.58E-08	10716.56	1.78E-02	9.40E-04	856.4553	0	1.76E-03	4.85E-08
0.291063	-2.25E-02	0.4358	0.542165	-1.28E-02	-0.27975	5.43E-02	0	-4.07E-02	0.391197
2.351094	1.810472	2.309456	2.441535	2.444651	2.379003	1.762381	0	2.373435	2.239927
0	0	0	0	0	0	0	500	0	0
-2.06182	4.51E-02	2.81E-04	232.0904	2.008092	0.149952	66.89756	1.40E-45	0.224147	1.95E-04
-2.66576	3.10E-02	1.03E-04	29.58555	1.799948	7.56E-02	53.38899	1	0.131023	1.01E-04
-2.49403	3.20E-02	1.39E-04	43.18191	1.836472	8.89E-02	57.85884	2	0.146407	1.46E-04
-2.34029	3.30E-02	1.78E-04	53.78728	1.878617	9.69E-02	63.12754	3	0.154759	1.73E-04
-2.2522	3.43E-02	2.01E-04	70.04637	1.906729	0.103417	66.97833	4	0.163702	1.95E-04
-2.13956	3.55E-02	2.29E-04	83.6697	1.931552	0.10971	71.44046	5	0.170967	2.23E-04
-2.0652	3.63E-02	2.55E-04	94.06028	1.95454	0.114915	76.20532	6	0.177183	2.51E-04
-1.99331	3.71E-02	2.81E-04	110.1333	1.97631	0.119333	80.702	7	0.182525	2.86E-04
-1.92518	3.78E-02	3.06E-04	121.5361	1.990359	0.1264	86.60998	8	0.189916	3.19E-04
-1.85182	3.88E-02	3.37E-04	138.9464	2.003309	0.130227	92.51134	9	0.195697	3.52E-04
-1.75865	4.02E-02	3.69E-04	154.4186	2.017098	0.134952	96.90846	10	0.203071	3.85E-04
-1.68039	4.10E-02	4.05E-04	168.87	2.037239	0.139112	101.4166	11	0.208142	4.19E-04
-1.61132	4.23E-02	4.38E-04	185.7734	2.052805	0.143975	107.5769	12	0.212771	4.52E-04
-1.46382	4.32E-02	4.79E-04	200.9625	2.076411	0.147362	113.6951	13	0.21951	4.96E-04
-1.37667	0.044177	5.15E-04	218.3729	2.098726	0.150756	118.3424	14	0.224232	5.31E-04
-1.26009	4.51E-02	5.62E-04	235.0764	2.116858	0.154504	122.4584	15	0.231835	5.65E-04
-1.09853	4.60E-02	5.96E-04	260.384	2.14342	0.158749	127.3186	16	0.238604	6.15E-04
-0.9697	4.69E-02	6.57E-04	289.2814	2.172928	0.16375	132.6297	17	0.248938	6.77E-04
-0.80737	4.79E-02	7.04E-04	317.6322	2.200639	0.169075	138.716	18	0.259507	7.25E-04
-0.58411	4.91E-02	8.03E-04	367.0525	2.254848	0.178749	143.9011	19	0.269597	8.11E-04
0	0	0	0	0	0	0	-500	0	0

Calculation of Contaminant Concentration at Receptor.

Receptor: **Water Supply Borehole**
Modelled Contaminant: **Lead (Pb)**

Parameter	Symbols	Minimum	Most Likely / Mean	Maximum / SD	Unit	(1)@Risk	Distribution
1. Calculation of Contaminant Concentration at Source:							
Soil contaminant conc'n	C_s	6162	1.10E+04	1.54E+04	mg/kg	**10863**	Triangular
Water filled soil porosity	q_W	0.1	0.25	0.4	fraction	**0.25**	Triangular
Air filled soil porosity	q_a	0.05	0.1	0.3	fraction	**0.15**	Triangular
Bulk density of source substrate e.g. tailings.	ρ_s	1.5	1.88	2.1	g/cm^3	**1.83**	Triangular
Henry's Law constant	H	0	0	0	dimensionless	**0**	Triangular
Soil-water partition coefficient	K_d	325	550	2814	l/kg	**1229.37**	Triangular
Factor (partitioning between soil and water)	F_1	-	-	-	dimensionless	**1229.50**	-
Concentration of Contaminant in water at Source	$\mathbf{C_w}$	-	-	-	**mg/l**	**8.84**	-
2. Calculation of Dilution Factor (mass balance estimate):							
[A]. Source							
Effective Rainfall at Source	ER_s	-	1197	200	mm/yr	**1197**	Normal
Run-off Coefficient at Source	RC_s	0.1	-	0.4	dimensionless	**0.25**	Uniform
Infiltration	Inf	-	-	-	mm/yr	**898**	N/A
Source Length	L	-	-	-	m	**3.43E-03**	N/A
Source Width	W	-	480	-	m	**480**	N/A
Plume thickness at Source (assume equals aquifer thickness)							
Source Surface Area	As	-	-	-	m^2	**1.65**	N/A
Recharge Rate	Qr	-	-	-	m^3/day	**4.05E-03**	N/A
Check of Recharge Rate using Darcy Equation:							
Combined K of Tailings (5E-8m/s) & Overburden (1E-7m/s)	K	-	-	-	m/day	6.13E-03	N/A
Combined thickness of Tailings (9m) & Overburden (mean: 13.5m)	d	-	-	-	m	22.5	N/A
Vertical Hydraulic Gradient	I	-	-	-	dimensionless	0.45	N/A
	Q	-	-	-	m^3/day	4.59E-03	N/A
[B]. Groundwater							
Saturated aquifer thickness (active zone)	d_a	10	-	34	m	**22.00**	Uniform
Aquifer Cross-sectional Area	Aaq	-	-	-	m^2	**10560**	N/A
Hydraulic Conductivity of aquifer	K	1.00E-02	8.64E-02	1	m/day	**9.52E-02**	N/A
Hydraulic Conductivity of aquifer - Log_{10}(K)	K	-2.00E+00	-1.06E+00	0.00E+00	m/day	**-1.021**	Triangular
Hydraulic gradient	i	0.0011	-	0.0025	fraction	**0.0018**	Uniform
Background Concentration of Contaminant in Groundwater	C_u	-	0.001	-	mg/l	**0.001**	N/A
Aquifer Flowrate	Qaq	-	-	-	m^3/day	**1.81**	N/A
Dilution Factor at Source	$\mathbf{DF_s}$	-	-	-	**fraction**	**447.23**	N/A
Concentration of Contaminant in groundwater under Source (after dilution)	$\mathbf{C_{gw}}$	-	-	-	**mg/l**	**2.07E-02**	N/A

3. Calculation of Travel Time to Receptor:

Soil-water partition coefficient	K_d	32	55	280	l/kg	122.33	Triangular
Bulk density of aquifer material.	ρ_a	1.7	2.3	2.8	g/cm^3	2.27	Triangular
Porosity of Aquifer material	n	0.02	0.05	0.08	fraction	0.05	Triangular
Retardation Factor	Rc	-	-	-	fraction	**5546.78**	N/A
Diatance to Receptor	x	450	-	550	m	500	Uniform
Rate of Groundwater Movement	**v**	-	-	-	**m/day**	**3.43E-03**	N/A
Groundwater Travel Time to Receptor	t_{gw}	-	-	-	**days**	**1.46E+05**	N/A
Rate of Contaminant Movement	**u**	-	-	-	**m/day**	**6.18E-07**	N/A
Contaminant Travel Time to Receptor	t_c	-	-	-	**days**	**8.09E+08**	N/A
					years	**2.22E+06**	N/A

4. Calculation of Contaminant Concentration at Receptor (WITHOUT dilution due to recharge/leakance between Source & Receptor):

Half life for degradation of contaminant in water	$t_{1/2}$	9.9E+99	9.9E+99	9.9E+99	days	9.9E+99	Triangular
Decay Constant	λ	-	-	-	1/days	**7.00E-101**	N/A
(2)Longitudinal dispersivity	a_x	-	-	-	m	**50**	N/A
(2)Transverse dispersivity	a_z	-	-	-	m	**5**	N/A
(2)Vertical dispersivity	a_y	-	-	-	m	**0.5**	N/A
(3)Distance (lateral) to compliance point perpendicular to flow direction	z	-	-	-	m	**0**	N/A
(3)Distance (depth) to compliance point perpendicular to flow direction	y	-	-	-	m	**0**	N/A
(4)Concentration at Receptor	C_{ED1}	-	-	-	**mg/l**	**7.81E-03**	N/A

5. Calculation of Contaminant Concentration at Receptor (WITH dilution due to recharge/leakance between Source & Receptor):

Effective Rainfall between Source & Receptor	ERr	-	1197	200	mm/yr	1197	Normal
Run-off Coefficient on ground between Source & Receptor	RC_r	0.2	-	0.5	dimensionless	0.35	Uniform
Background Concentration of Contaminant in Rain	C_r	0	0.00001	0.0001	mg/l	3.67E-05	Triangular
Infiltration	Inf	-	-	-	mm/yr	**778**	N/A
Total Volume Recharge	Rech	-	-	-	m^3	**2.84E+06**	N/A
Concentration at Receptor	C_{ED2}	-	-	-	**mg/l**	**3.67E-05**	N/A

Notes:

(1). Input highlighted in **RED**; Output highlighted in **BLUE**

(2). Calculated values assume:

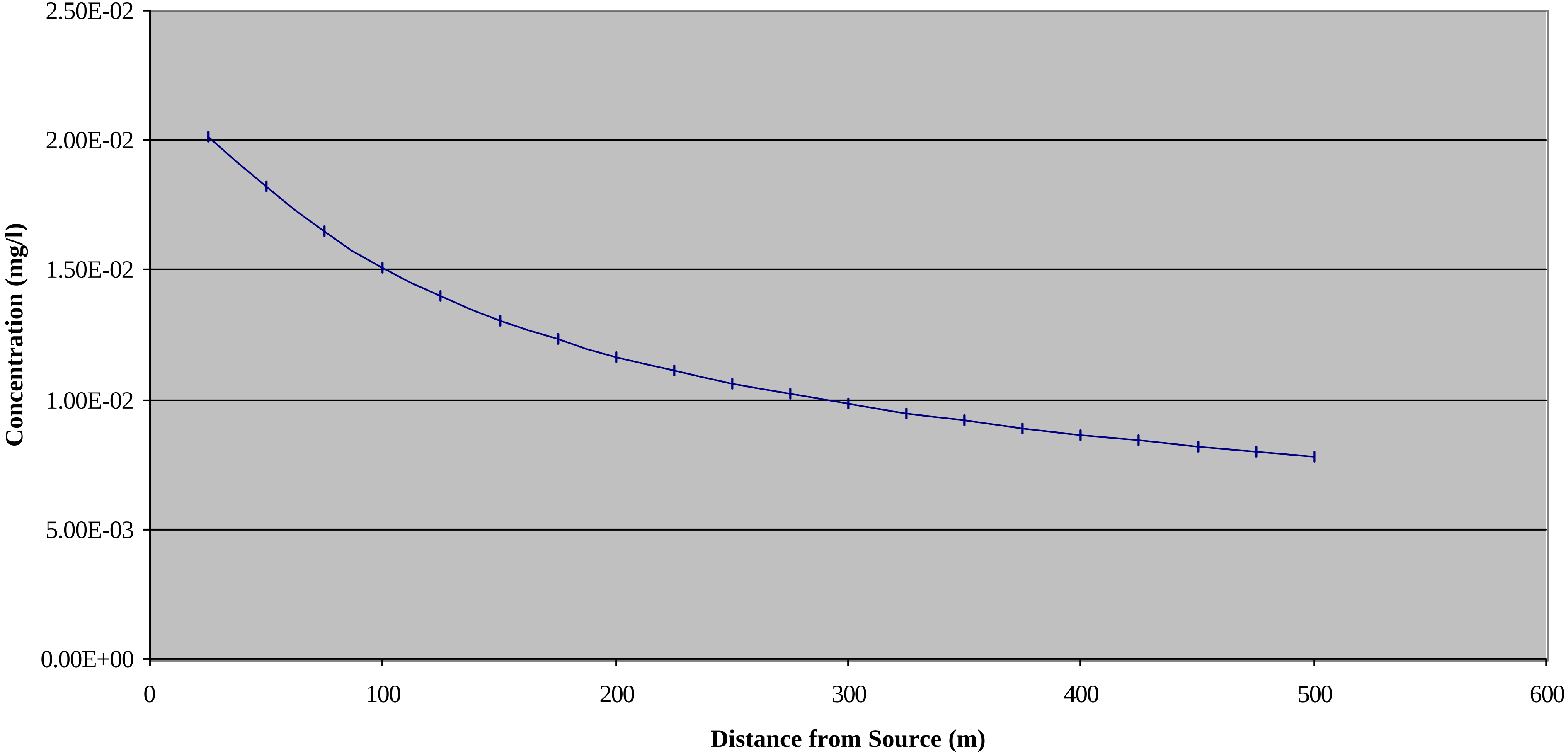
ax = 0.1 *x
az = 0.01 * x
ay = 0.001 * x

(3). These parameters should be set to '0' barring exceptional circumstances. They simulate a point that is offset from the centre of the plume.

(4). Domenico Steady State Solution:

Concentration at Receptor = Cgw*EXP(x/(2*ax)*(1-(1+(4*(decay/Rf)*ax)/u)^0.5))*ERF(b/(4*SQRT(ay*x)))*ERF(W/(4*SQRT(az*x)))

Lead; Water Supply Hole;
Contaminant Concentration using Domenico Steady State Solution
('Most Likely' Concentration)



DOMENICO (STEADY STATE)

Calculations for source located at top of aquifer (ie vertical dispersion in one direction)

	Distance	Term 1	Term 2	EXP	Term 3A	ERF	Term 3B	ERF	Term 4A	ERF	Term 4B	ERF	Concentration
1	25	0.0052	0.00E+00	1.00E+00	1.07E+01	1	-1.07E+01	-1	1.56E+00	0.972193103	-1.56E+00	-0.972193103	2.01E-02
2	50	0.0052	0.00E+00	1.00E+00	7.59E+00	1	-7.59E+00	-1	1.10E+00	0.880205041	-1.10E+00	-0.880205041	1.82E-02
3	75	0.0052	0.00E+00	1.00E+00	6.20E+00	1	-6.20E+00	-1	8.98E-01	0.795976026	-8.98E-01	-0.795976026	1.65E-02
4	100	0.0052	0.00E+00	1.00E+00	5.37E+00	1	-5.37E+00	-1	7.78E-01	0.728667676	-7.78E-01	-0.728667676	1.51E-02
5	125	0.0052	0.00E+00	1.00E+00	4.80E+00	1	-4.80E+00	-1	6.96E-01	0.674820508	-6.96E-01	-0.674820508	1.40E-02
6	150	0.0052	0.00E+00	1.00E+00	4.38E+00	0.999999999	-4.38E+00	-0.999999999	6.35E-01	0.630892407	-6.35E-01	-0.630892407	1.31E-02
7	175	0.0052	0.00E+00	1.00E+00	4.06E+00	0.99999999	-4.06E+00	-0.99999999	5.88E-01	0.594321104	-5.88E-01	-0.594321104	1.23E-02
8	200	0.0052	0.00E+00	1.00E+00	3.79E+00	0.99999992	-3.79E+00	-0.99999992	5.50E-01	0.563323359	-5.50E-01	-0.563323359	1.17E-02
9	225	0.0052	0.00E+00	1.00E+00	3.58E+00	0.99999958	-3.58E+00	-0.99999958	5.19E-01	0.536644848	-5.19E-01	-0.536644848	1.11E-02
10	250	0.0052	0.00E+00	1.00E+00	3.39E+00	0.999998413	-3.39E+00	-0.999998413	4.92E-01	0.513383953	-4.92E-01	-0.513383953	1.06E-02
11	275	0.0052	0.00E+00	1.00E+00	3.24E+00	0.999995275	-3.24E+00	-0.999995275	4.69E-01	0.492877544	-4.69E-01	-0.492877544	1.02E-02
12	300	0.0052	0.00E+00	1.00E+00	3.10E+00	0.999988229	-3.10E+00	-0.999988229	4.49E-01	0.474627213	-4.49E-01	-0.474627213	9.83E-03
13	325	0.0052	0.00E+00	1.00E+00	2.98E+00	0.999974449	-2.98E+00	-0.999974449	4.31E-01	0.458250942	-4.31E-01	-0.458250942	9.49E-03
14	350	0.0052	0.00E+00	1.00E+00	2.87E+00	0.999950238	-2.87E+00	-0.999950238	4.16E-01	0.443450747	-4.16E-01	-0.443450747	9.18E-03
15	375	0.0052	0.00E+00	1.00E+00	2.77E+00	0.999911151	-2.77E+00	-0.999911151	4.02E-01	0.429990534	-4.02E-01	-0.429990534	8.90E-03
16	400	0.0052	0.00E+00	1.00E+00	2.68E+00	0.999852198	-2.68E+00	-0.999852198	3.89E-01	0.417680624	-3.89E-01	-0.417680624	8.65E-03
17	425	0.0052	0.00E+00	1.00E+00	2.60E+00	0.999768072	-2.60E+00	-0.999768072	3.77E-01	0.406366726	-3.77E-01	-0.406366726	8.41E-03
18	450	0.0052	0.00E+00	1.00E+00	2.53E+00	0.999653381	-2.53E+00	-0.999653381	3.67E-01	0.395921908	-3.67E-01	-0.395921908	8.20E-03
19	475	0.0052	0.00E+00	1.00E+00	2.46E+00	0.999502848	-2.46E+00	-0.999502848	3.57E-01	0.386240704	-3.57E-01	-0.386240704	8.00E-03
20	500	0.0052	0.00E+00	1.00E+00	2.40E+00	0.999311486	-2.40E+00	-0.999311486	3.48E-01	0.377234673	-3.48E-01	-0.377234673	7.81E-03

Simulation Results for AgM_Mod.XLS

Contaminant: Lead
Receptor: Water Supply Boreholes

Iterations= 500
Simulations= 1
# Input Variables= 19
# Output Variables= 6
Sampling Type= Monte Carlo
Runtime= 00:00:05
Run on 02/01/02 at 06:03:35 PM

Summary Statistics

[A] Outputs:

Cell	Name		Minimum	Mean	Maximum	5% Perc	50% Perc	95% Perc
G15	Conc. of Contaminant in water at Source	mg/l	2.999592	11.13871	37.40126	4.377695	9.54103	22.47913
G41	Dilution Factor at Source	Fraction	98.42495	476.5325	1311.648	192.1206	440.4081	909.6964
G42	Conc. of Contaminant under Source	mg/l	5.18E-03	2.98E-02	0.2071887	0.008528	0.022835	0.069764
G52	Groundwater Travel Time to Receptor	days	9560.368	245479.2	2124286	29862.73	159843.1	766961
G54	Contaminant Travel Time to Receptor	days	2.76E+07	1.32E+09	1.13E+10	1.22E+08	8.03E+08	4.3E+09
G65	Concentration at Receptor	mg/l	1.98E-03	1.03E-02	4.48E-02	0.003332	0.008626	0.023258

[B] Inputs:

G8	Soil contaminant conc'n	mg/kg	6306.492	10948.74	15163.7	7703.872	11010.88	14022.77
G9	Water filled soil porosity	fraction	0.1081902	0.2513764	0.3941986	0.149628	0.248821	0.353679
G10	Air filled soil porosity	fraction	5.56E-02	0.1460489	0.2893976	0.074139	0.134982	0.243426
G11	Bulk density of source substrate e.g. tailings	g/cm3	1.525791	1.838892	2.092868	1.621057	1.84778	2.021797
G12	Henry's Law constant	dimensionless	0	0	0	0	0	0
G13	Soil-water partition coefficient	l/kg	342.8322	1221.662	2732.857	495.4216	1125.492	2258.638
G19	Effective Rainfall at Source	mm/yr	639.8864	1196.887	1776.39	886.549	1189.291	1540.397
G20	Run-off Coefficient at Source	dimensionless	0.1011805	0.247443	0.3982549	0.11716	0.248739	0.384638
G34	Saturated aquifer thickness (active zone)	m	10.0699	22.28484	33.91808	11.78016	22.56014	32.57848
G37	Hydraulic Conductivity of aquifer - Log10(K)	m/day	-1.945385	-1.038616	-8.65E-02	-1.70019	-1.05417	-0.32757
G38	Hydraulic gradient	fraction	1.10E-03	1.79E-03	2.50E-03	0.001148	0.001791	0.002431
G46	Soil-water partition coefficient	l/kg	38.053	121.6352	270.1549	50.58614	113.0896	227.0867
G47	Bulk density of aquifer material.	g/cm3	1.730399	2.264242	2.754044	1.861457	2.277416	2.632745
G48	Porosity of Aquifer material	fraction	2.11E-02	5.05E-02	7.93E-02	0.029724	0.05001	0.07069
G50	Diatance to Receptor	m	450.2193	499.2548	549.9813	455.1578	497.5883	544.9312
G58	Half life for degradation of contaminant in water	days	0	0	0	1	10	19
G68	Effective Rainfall between Source & Receptor	mm/yr	553.6346	1205.014	1819.916	880.4499	1198.857	1554.17
G69	Run-off Coefficient on ground between Source & Receptor	dimensionless	0.2018388	0.3483682	0.4993838	0.212697	0.353532	0.480283
G70	Background Concentration of Contaminant in Rain	mg/l	1.42E-06	3.58E-05	9.67E-05	6.34E-06	3.16E-05	7.52E-05

@RISK Sin	Run on 03/	Simulations	Iterations=													
Name	Conc. of C	Dilution Fa	Conc. of C	Groundwat	Contamina	Concentrati	mg/kg / (1)(	fraction / (1	fraction / (1	g/cm3 / (1)(	dimensionle	l/kg / (1)@	mm/yr / (1)	dimensionle	m / (1)@Ri	m/day / (1)(
Description	Output	Output	Output	Output	Output	Output	Triang(C8,	Triang(C9,	Triang(C10	Triang(C11	Triang(C12	Triang(C13	Normal(D1	Uniform(C	Uniform(C	Triang(C37
Cell	G15	G41	G42	G52	G54	G65	G8	G9	G10	G11	G12	G13	G19	G20	G34	G37
Minimum =	2.999592	98.42495	5.18E-03	9560.368	2.76E+07	1.98E-03	6306.492	0.10819	5.56E-02	1.525791	0	342.8322	639.8864	0.101181	10.0699	-1.94539
Maximum =	37.40126	1311.648	0.207189	2124286	1.13E+10	4.48E-02	15163.7	0.394199	0.289398	2.092868	0	2732.857	1776.39	0.398255	33.91808	-8.65E-02
Mean =	11.13871	476.5325	2.98E-02	245479.2	1.32E+09	1.03E-02	10948.74	0.251376	0.146049	1.838892	0	1221.662	1196.887	0.247443	22.28484	-1.03862
Std Deviati	5.802346	221.2896	2.23E-02	266423	1.48E+09	6.31E-03	1884.578	6.10E-02	5.19E-02	0.117823	0	550.6946	195.9764	0.088169	6.644916	0.416026
Variance =	33.66722	48969.11	4.95E-04	7.10E+10	2.20E+18	3.98E-05	3551633	3.72E-03	2.69E-03	1.39E-02	0	303264.5	38406.76	7.77E-03	44.1549	0.173078
Skewness =	1.139382	0.939904	2.540709	2.560227	2.576236	1.704292	-0.12437	6.43E-02	0.506896	-0.30867	0	0.569651	5.92E-02	7.68E-02	-5.13E-02	0.120826
Kurtosis =	4.316189	3.785353	14.01895	12.02642	12.15581	7.032007	2.448481	2.395623	2.4677	2.645199	0	2.447601	3.01303	1.737296	1.857204	2.350239
Errors Calc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode =	9.536377	468.8559	1.54E-02	72331.19	2.04E+08	7.44E-03	10806.47	0.291355	0.103352	1.914125	0	562.4208	1254.599	0.198223	31.49571	-1.30701
5% Perc =	4.377695	192.1206	8.53E-03	29862.73	1.22E+08	3.33E-03	7703.872	0.149628	7.41E-02	1.621057	0	495.4216	886.549	0.11716	11.78016	-1.70019
10% Perc =	5.16918	225.0033	1.05E-02	38548.12	1.82E+08	4.04E-03	8378.135	0.170365	8.29E-02	1.678349	0	563.9416	957.0172	0.131264	12.88838	-1.59319
15% Perc =	5.719406	252.2593	1.28E-02	49572.79	2.20E+08	4.82E-03	8781.769	0.184183	9.30E-02	1.706574	0	648.264	1001.282	0.140907	13.99484	-1.48883
20% Perc =	6.15646	283.3968	1.43E-02	61547.27	2.97E+08	5.44E-03	9246.158	0.197836	9.92E-02	1.737044	0	710.3036	1033.09	0.155896	15.26974	-1.40775
25% Perc =	6.625042	303.4051	1.55E-02	74103.66	3.56E+08	6.05E-03	9624.548	0.207376	0.104281	1.75859	0	758.3666	1063.65	0.165767	16.70258	-1.34365
30% Perc =	7.24715	332.527	1.65E-02	90444.09	4.31E+08	6.45E-03	9926.411	0.213948	0.109996	1.778338	0	818.7006	1100.238	0.179861	17.74743	-1.29297
35% Perc =	7.770723	364.3678	1.83E-02	106147.7	5.12E+08	6.95E-03	10321.11	0.226905	0.117511	1.795867	0	894.2084	1117.07	0.197538	18.83346	-1.22864
40% Perc =	8.399938	389.3734	1.97E-02	119627.4	5.97E+08	7.45E-03	10627.06	0.235597	0.124249	1.819539	0	963.9466	1139.637	0.212139	20.2962	-1.17207
45% Perc =	8.918975	411.1349	2.12E-02	139884.9	6.99E+08	8.07E-03	10810.07	0.241593	0.130482	1.836956	0	1054.308	1159.869	0.230242	21.5579	-1.1208
50% Perc =	9.54103	440.4081	2.28E-02	159843.1	8.03E+08	8.63E-03	11010.88	0.248821	0.134982	1.84778	0	1125.492	1189.291	0.248739	22.56014	-1.05417
55% Perc =	10.1909	469.1984	0.024839	179965.6	9.54E+08	9.27E-03	11171.99	0.255523	0.144905	1.865053	0	1181.55	1217.286	0.265161	23.60144	-0.98922
60% Perc =	10.96291	494.8564	2.67E-02	200278.5	1.10E+09	1.00E-02	11458.27	0.26345	0.154035	1.878394	0	1283.183	1248.71	0.276677	24.20825	-0.94883
65% Perc =	12.22821	526.7726	2.97E-02	227651	1.24E+09	0.010708	11703.37	0.275097	0.16245	1.890423	0	1390.996	1269.484	0.285188	25.68472	-0.87616
70% Perc =	13.41588	552.9679	3.30E-02	259243.9	1.48E+09	1.16E-02	12025.06	0.286728	0.170866	1.907484	0	1514.758	1297.127	0.30498	26.74228	-0.81686
75% Perc =	14.63171	594.2281	0.038404	302147.5	1.72E+09	1.29E-02	12334.23	0.29497	0.183984	1.919904	0	1617.409	1322.93	0.324971	27.87647	-0.74093
80% Perc =	15.59631	631.933	4.40E-02	357612.7	2.06E+09	1.43E-02	12652.89	0.30668	0.193903	1.935482	0	1774.211	1358.574	0.342177	29.1256	-0.6617
85% Perc =	17.45116	700.5611	4.84E-02	442905.9	2.40E+09	1.56E-02	12897.94	0.317136	0.206209	1.960406	0	1878.102	1386.919	0.360093	30.05913	-0.58276
90% Perc =	19.36371	783.7288	5.56E-02	573211.5	3.01E+09	1.86E-02	13471.11	0.332666	0.221851	1.99232	0	2027.375	1444.664	0.372777	31.47208	-0.447
95% Perc =	22.47913	909.6964	6.98E-02	766961	4.30E+09	2.33E-02	14022.77	0.353679	0.243426	2.021797	0	2258.638	1540.397	0.384638	32.57848	-0.32757
Filter Minimum =																
Filter Maximum =																
Type (1 or 2) =																
# Values Fil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenario #1	>75%	>75%	>75%	>75%	>75%	>75%										
Scenario #2	<25%	<25%	<25%	<25%	<25%	<25%										
Scenario #3	>90%	>90%	>90%	>90%	>90%	>90%										

fraction / (1	l/kg / (1)@	g/cm3 / (1)	fraction / (1	m / (1)@Ri	days / (1)@	mm/yr / (1)	dimensionl	mg/l / (1)@Risk
Uniform(C	Triang(C4	Triang(C4	Triang(C4	Uniform(C	Triang(C5	Normal(D6	Uniform(C	Triang(C70,D70,E70)
G38	G46	G47	G48	G50	G58	G68	G69	G70
1.10E-03	38.053	1.730399	2.11E-02	450.2193	0	553.6346	0.201839	1.42E-06
2.50E-03	270.1549	2.754044	7.93E-02	549.9813	0	1819.916	0.499384	9.67E-05
1.79E-03	121.6352	2.264242	5.05E-02	499.2548	0	1205.014	0.348368	3.58E-05
4.11E-04	54.54529	0.221703	1.26E-02	28.74471	0	198.5949	8.82E-02	2.20E-05
1.69E-07	2975.188	0.049152	1.58E-04	826.2583	0	39439.95	7.78E-03	4.84E-10
4.46E-02	0.62321	-0.17195	-1.05E-02	5.27E-02	0	0.134661	-1.78E-02	0.539866
1.792384	2.518883	2.573049	2.387522	1.764019	0	3.112523	1.722512	2.41478
0	0	0	0	0	500	0	0	0
1.45E-03	168.9314	2.40017	3.00E-02	526.6024	1.40E-45	1090.837	0.213499	1.60E-05
1.15E-03	50.58614	1.861457	2.97E-02	455.1578	1	880.4499	0.212697	6.34E-06
1.22E-03	56.67865	1.95172	3.32E-02	460.8937	2	950.4831	0.22407	1.04E-05
1.30E-03	62.54791	2.011375	0.036714	464.7183	3	996.48	0.239589	1.30E-05
1.38E-03	69.62663	2.071185	3.97E-02	469.2021	4	1039.824	0.255822	1.49E-05
1.43E-03	77.34503	2.115704	4.18E-02	474.5551	5	1078.398	0.272126	1.69E-05
1.48E-03	84.44533	2.152556	4.34E-02	478.107	6	1103.686	0.282615	1.97E-05
1.57E-03	90.41669	2.198389	4.55E-02	483.2295	7	1131.855	0.296179	2.22E-05
1.64E-03	97.90363	2.227696	4.66E-02	487.6148	8	1156.838	0.312996	2.48E-05
1.69E-03	104.7176	2.252276	4.83E-02	492.7368	9	1177.416	0.33073	2.82E-05
1.79E-03	113.0896	2.277416	5.00E-02	497.5883	10	1198.857	0.353532	3.16E-05
1.86E-03	119.1127	2.301805	5.21E-02	502.9446	11	1229.238	0.367671	3.57E-05
1.92E-03	126.4944	2.32865	5.35E-02	509.5735	12	1246.101	0.38435	3.87E-05
1.98E-03	135.2317	2.359632	0.055432	514.6301	13	1267.009	0.395905	4.34E-05
2.07E-03	144.1972	2.388308	5.74E-02	520.5098	14	1294.249	0.410139	4.87E-05
2.16E-03	158.8677	2.407791	5.96E-02	525.5327	15	1324.979	0.426819	5.34E-05
2.22E-03	172.5879	2.446795	6.19E-02	528.0916	16	1362.601	0.442042	5.67E-05
2.30E-03	186.9189	2.492537	6.49E-02	533.687	17	1403.393	0.452396	6.05E-05
2.36E-03	202.8926	2.537983	6.76E-02	538.9263	18	1471.922	0.46859	6.73E-05
2.43E-03	227.0867	2.632745	7.07E-02	544.9312	19	1554.17	0.480283	7.52E-05
0	0	0	0	0	-500	0	0	0

Calculation of Contaminant Concentration at Receptor.

Receptor: **Kilmastula River**
Modelled Contaminant: **Lead (Pb)**

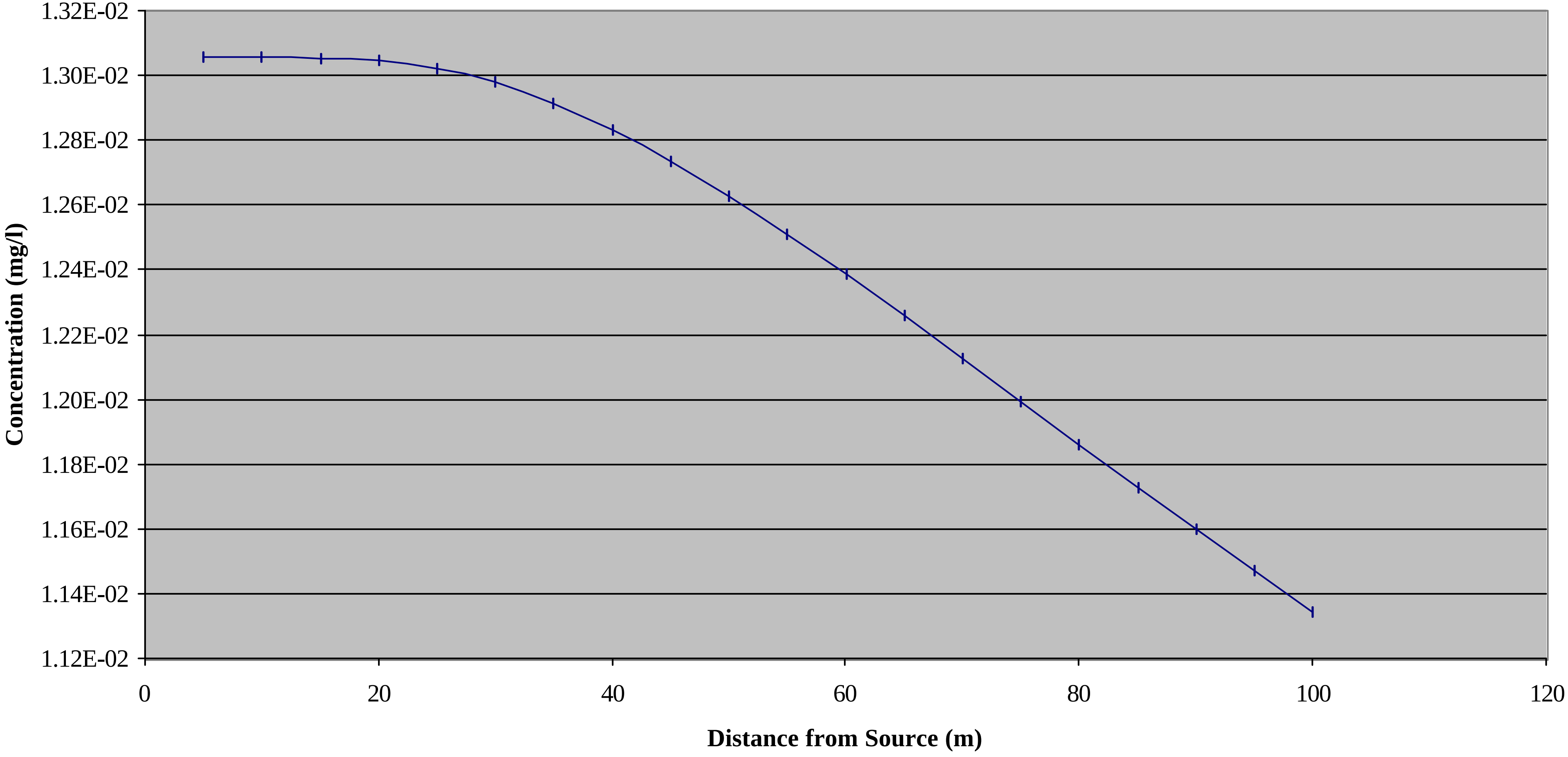
Parameter	Symbols	Minimum	Most Likely / Mean	Maximum / SD	Unit	(1)@Risk	Distribution
1. Calculation of Contaminant Concentration at Source:							
Soil contaminant conc'n	C_s	6162	1.10E+04	1.54E+04	mg/kg	**10863**	Triangular
Water filled soil porosity	q_W	0.1	0.25	0.4	fraction	**0.25**	Triangular
Air filled soil porosity	q_a	0.05	0.1	0.3	fraction	**0.15**	Triangular
Bulk density of source substrate e.g. tailings.	ρ_s	1.5	1.88	2.1	g/cm^3	**1.83**	Triangular
Henry's Law constant	H	0	0	0	dimensionless	**0**	Triangular
Soil-water partition coefficient	K_d	325	550	2814	l/kg	**1229.37**	Triangular
Factor (partitioning between soil and water)	F_1	-	-	-	dimensionless	**1229.50**	-
Concentration of Contaminant in water at Source	$\mathbf{C_w}$	-	-	-	**mg/l**	**8.84**	-

2. Calculation of Dilution Factor (mass balance estimate):							
[A]. Source							
Effective Rainfall at Source	ER_s	-	1197	200	mm/yr	**1197**	Normal
Run-off Coefficient at Source	RC_s	0.1	-	0.4	dimensionless	**0.25**	Uniform
Infiltration	Inf	-	-	-	mm/yr	**898**	N/A
Source Length	L	-	-	-	m	**5.58E-03**	N/A
Source Width	W	-	480	-	m	**480**	N/A
Plume thickness at Source (assume equals aquifer thickness)							
Source Surface Area	As	-	-	-	m^2	**2.68**	N/A
Recharge Rate	Qr	-	-	-	m^3/day	**6.59E-03**	N/A
Check of Recharge Rate using Darcy Equation:							
Combined K of Tailings (5E-8m/s) & Overburden (1E-7m/s)	K	-	-	-	m/day	6.13E-03	N/A
Combined thickness of Tailings (9m) & Overburden (mean: 13.5m)	d	-	-	-	m	22.5	N/A
Vertical Hydraulic Gradient	I	-	-	-	dimensionless	0.45	N/A
	Q	-	-	-	m^3/day	7.47E-03	N/A

[B]. Groundwater							
Saturated aquifer thickness (active zone)	d_a	2	-	25	m	**13.50**	Uniform
Aquifer Cross-sectional Area	Aaq	-	-	-	m^2	**6480**	N/A
Hydraulic Conductivity of aquifer	K	8.64E-04	8.64E-03	0.864	m/day	**1.86E-02**	N/A
Hydraulic Conductivity of aquifer - Log_{10}(K)	K	-3.06E+00	-2.06E+00	-6.35E-02	m/day	**-1.730**	Triangular
Hydraulic gradient	i	0.03	-	0.05	fraction	**0.0400**	Uniform
Background Concentration of Contaminant in Groundwater	C_u	-	0.001	-	mg/l	**0.001**	N/A
Aquifer Flowrate	Qaq	-	-	-	m^3/day	**4.82**	N/A
Dilution Factor at Source	$\mathbf{DF_s}$	-	-	-	**fraction**	**731.83**	N/A
Concentration of Contaminant in groundwater under Source (after dilution)	$\mathbf{C_{gw}}$	-	-	-	**mg/l**	**1.31E-02**	N/A

File Name: Pb_RKilm_1

Lead; Kilmastulla River; Contaminant Concentration using Domenico Steady State Solution ('Most Likely' Concentration)



3. Calculation of Travel Time to Receptor:

Soil-water partition coefficient	K_d	325	550	2814	l/kg	**1229.37**	Triangular
Bulk density of aquifer material.	ρ_a	1.7	2.03	2.35	g/cm^3	**2.03**	Triangular
Porosity of Aquifer material (effective)	n	0.05	0.15	0.2	fraction	**0.133333333**	Triangular
Retardation Factor	Rc	-	-	-	fraction	**18687.37**	N/A
Diatance to Receptor	x	50	-	150	m	**100**	Uniform
Rate of Groundwater Movement	**v**	-	-	-	**m/day**	**5.58E-03**	N/A
Groundwater Travel Time to Receptor	t_{gw}	-	-	-	**days**	**1.79E+04**	N/A
Rate of Contaminant Movement	**u**	-	-	-	**m/day**	**2.99E-07**	N/A
Contaminant Travel Time to Receptor	t_c	-	-	-	**days**	**3.35E+08**	N/A
					years	**9.17E+05**	N/A

4. Calculation of Contaminant Concentration at Receptor (WITHOUT dilution due to recharge/leakance between Source & Receptor):

Half life for degradation of contaminant in water	$t_{1/2}$	9.9E+99	9.9E+99	9.9E+99	days	**9.9E+99**	Triangular
Decay Constant	λ	-	-	-	1/days	**7.00E-101**	N/A
(2)Longitudinal dispersivity	a_x	-	-	-	m	**10**	N/A
(2)Transverse dispersivity	a_z	-	-	-	m	**1**	N/A
(2)Vertical dispersivity	a_y	-	-	-	m	**0.1**	N/A
(3)Distance (lateral) to compliance point perpendicular to flow direction	z	-	-	-	m	**0**	N/A
(3)Distance (depth) to compliance point perpendicular to flow direction	y	-	-	-	m	**0**	N/A
(4)Concentration at Receptor	C_{ED1}	-	-	-	**mg/l**	**1.13E-02**	N/A

5. Calculation of Contaminant Concentration at Receptor (WITH dilution due to mixing with low flows in river):

Flow rate in River (low flow)	Qr	0.1	0.2	0.3	Cumecs	**0.2**	Triangular
					m^3/day	**17280**	N/A
Background Concentration of Contaminant in River	C_r	-	0.001	-	mg/l	**1.00E-03**	N/A
Concentration at Receptor	C_{ED2}	-	-	-	**mg/l**	**1.00E-03**	N/A

Notes:

(1). Input highlighted in **RED**; Output highlighted in **BLUE**

(2). Calculated values assume:

ax = 0.1 *x
az = 0.01 * x
ay = 0.001 * x

(3). These parameters should be set to '0' barring exceptional circumstances. They simulate a point that is offset from the centre of the plume.

(4). Domenico Steady State Solution:

Concentration at Receptor = Cgw*EXP(x/(2*ax)*(1-(1+(4*(decay/Rf)*ax)/u)^0.5))*ERF(b/(4*SQRT(ay*x)))*ERF(W/(4*SQRT(az*x)))

DOMENICO (STEADY STATE)

Calculations for source located at top of aquifer (ie vertical dispersion in one direction)

	Distance	Term 1	Term 2	EXP	Term 3A	ERF	Term 3B	ERF	Term 4A	ERF	Term 4B	ERF	Concentration
1	5	0.0033	0.00E+00	1.00E+00	5.37E+01	1	-5.37E+01	-1	4.77E+00	1	-4.77E+00	-1	1.31E-02
2	10	0.0033	0.00E+00	1.00E+00	3.79E+01	1	-3.79E+01	-1	3.38E+00	0.999998185	-3.38E+00	-0.999998185	1.31E-02
3	15	0.0033	0.00E+00	1.00E+00	3.10E+01	1	-3.10E+01	-1	2.76E+00	0.999902654	-2.76E+00	-0.999902654	1.31E-02
4	20	0.0033	0.00E+00	1.00E+00	2.68E+01	1	-2.68E+01	-1	2.39E+00	0.999261843	-2.39E+00	-0.999261843	1.30E-02
5	25	0.0033	0.00E+00	1.00E+00	2.40E+01	1	-2.40E+01	-1	2.13E+00	0.997461313	-2.13E+00	-0.997461313	1.30E-02
6	30	0.0033	0.00E+00	1.00E+00	2.19E+01	1	-2.19E+01	-1	1.95E+00	0.9941429	-1.95E+00	-0.9941429	1.30E-02
7	35	0.0033	0.00E+00	1.00E+00	2.03E+01	1	-2.03E+01	-1	1.80E+00	0.989266583	-1.80E+00	-0.989266583	1.29E-02
8	40	0.0033	0.00E+00	1.00E+00	1.90E+01	1	-1.90E+01	-1	1.69E+00	0.982989716	-1.69E+00	-0.982989716	1.28E-02
9	45	0.0033	0.00E+00	1.00E+00	1.79E+01	1	-1.79E+01	-1	1.59E+00	0.975551051	-1.59E+00	-0.975551051	1.27E-02
10	50	0.0033	0.00E+00	1.00E+00	1.70E+01	1	-1.70E+01	-1	1.51E+00	0.967201182	-1.51E+00	-0.967201182	1.26E-02
11	55	0.0033	0.00E+00	1.00E+00	1.62E+01	1	-1.62E+01	-1	1.44E+00	0.958169401	-1.44E+00	-0.958169401	1.25E-02
12	60	0.0033	0.00E+00	1.00E+00	1.55E+01	1	-1.55E+01	-1	1.38E+00	0.948651656	-1.38E+00	-0.948651656	1.24E-02
13	65	0.0033	0.00E+00	1.00E+00	1.49E+01	1	-1.49E+01	-1	1.32E+00	0.93880904	-1.32E+00	-0.93880904	1.23E-02
14	70	0.0033	0.00E+00	1.00E+00	1.43E+01	1	-1.43E+01	-1	1.28E+00	0.92877078	-1.28E+00	-0.92877078	1.21E-02
15	75	0.0033	0.00E+00	1.00E+00	1.39E+01	1	-1.39E+01	-1	1.23E+00	0.91863885	-1.23E+00	-0.91863885	1.20E-02
16	80	0.0033	0.00E+00	1.00E+00	1.34E+01	1	-1.34E+01	-1	1.19E+00	0.90849273	-1.19E+00	-0.90849273	1.19E-02
17	85	0.0033	0.00E+00	1.00E+00	1.30E+01	1	-1.30E+01	-1	1.16E+00	0.89839362	-1.16E+00	-0.89839362	1.17E-02
18	90	0.0033	0.00E+00	1.00E+00	1.26E+01	1	-1.26E+01	-1	1.13E+00	0.888388199	-1.13E+00	-0.888388199	1.16E-02
19	95	0.0033	0.00E+00	1.00E+00	1.23E+01	1	-1.23E+01	-1	1.09E+00	0.878511528	-1.09E+00	-0.878511528	1.15E-02
20	100	0.0033	0.00E+00	1.00E+00	1.20E+01	1	-1.20E+01	-1	1.07E+00	0.868789536	-1.07E+00	-0.868789536	1.13E-02

Simulation Results for Pb_RKilm_1.xls

Contaminant: Lead
Receptor: Kilmastula River

Iterations= 500
Simulations= 1
# Input Variables= 17
# Output Variables= 7
Sampling Type= Monte Carlo
Runtime= 00:00:04
Run on 03/01/02 at 11:28:19 AM

Summary Statistics

[A] Outputs:

Cell	Name		Minimum	Mean	Maximum	5% Perc	50% Perc	95% Perc
G15	Conc. of Contaminant in water at Source	mg/l	3.015911	10.83655	35.83723	4.447179	9.204367	23.29523
G41	Dilution Factor at Source	Fraction	68.99925	754.9673	3167.714	169.6474	649.2119	1636.31
G42	Conc. of Contaminant under Source	mg/l	2.93E-03	2.45E-02	0.2973722	0.004994	0.015899	0.07499
G52	Groundwater Travel Time to Receptor	days	336.1664	39527.4	479297.7	890.0237	18161.63	148015.9
G54	Contaminant Travel Time to Receptor	days	3.40E+06	7.33E+08	1.08E+10	13346770	3.21E+08	2.67E+09
G65	Concentration at Receptor (without river dilution)	mg/l	2.74E-03	1.50E-02	8.11E-02	0.00446	0.011885	0.037482
G71	Concentration at Receptor (with river dilution)	mg/l	1.00E-03	1.00E-03	1.00E-03	0.001	0.001	0.001

[B] Inputs:

G8	Soil contaminant conc'n	mg/kg	6342.295	10808.84	15293.83	7602.546	10910.13	13658.88
G9	Water filled soil porosity	fraction	0.1148819	0.2501327	0.3958356	0.15299	0.247024	0.355332
G10	Air filled soil porosity	fraction	5.81E-02	0.1497717	0.2937146	0.074459	0.140695	0.250237
G11	Bulk density of source substrate e.g. tailings	g/cm3	1.510288	1.826137	2.095023	1.609642	1.840094	2.020252
G12	Henry's Law constant	dimensionless	0	0	0	0	0	0
G13	Soil-water partition coefficient	l/kg	363.82	1245.538	2666.534	481.0865	1181.325	2296.038
G19	Effective Rainfall at Source	mm/yr	645.626	1190.028	1736.594	886.549	1178.667	1520.607
G20	Run-off Coefficient at Source	dimensionless	0.1009973	0.2536582	0.3997245	0.116118	0.255441	0.386108
G34	Saturated aquifer thickness (active zone)	m	2.014417	13.20236	24.91825	3.148362	12.03948	24.17873
G37	Hydraulic Conductivity of aquifer - Log10(K)	m/day	-2.970194	-1.703128	-1.63E-01	-2.65142	-1.77575	-0.54839
G38	Hydraulic gradient	fraction	3.01E-02	4.03E-02	4.99E-02	0.030922	0.040533	0.048943
G46	Soil-water partition coefficient	l/kg	383.2939	1200.565	2714.689	487.6111	1114.863	2213.055
G47	Bulk density of aquifer material.	g/cm3	1.725363	2.022718	2.331889	1.799429	2.023118	2.23665
G48	Porosity of Aquifer material	fraction	5.31E-02	1.33E-01	1.98E-01	0.081855	0.137516	0.177113
G50	Distance to Receptor	m	50.14008	99.32626	149.8672	55.87735	99.33208	145.4135
G58	Half life for degradation of contaminant in water	days	0	0	0	1	10	19
G68	Flow rate in River (low flow)	m^3/day	0.1056436	0.2020768	0.2938656	0.133853	0.20026	0.272152

@RISK Sin	Run on 03/	Simulations	Iterations=													
Name	mg/l / (1)@	fraction / (1	mg/l / (1)@	days / (1)@	days / (1)@	mg/l / (1)@	mg/l / (1)@	mg/kg / (1)(	fraction / (1	fraction / (1	g/cm3 / (1)(	dimensionle	l/kg / (1)@I	mm/yr / (1)	dimensionle	m / (1)@Ris
Description	Output	Output	Output	Output	Output	Output	Output	Triang(C8,	Triang(C9,	Triang(C10	Triang(C11	Triang(C12	Triang(C13	Normal(D1	Uniform(C	Uniform(C
Cell	'[Pb_RKilm	'[Pb_RKilm	'[Pb_RKilm	'[Pb_RKilm	'[Pb_RKilm	'[Pb_RKilm	'[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm
Minimum =	3.015911	68.99925	2.93E-03	336.1664	3400585	2.74E-03	0.001	6342.295	0.114882	5.81E-02	1.510288	0	363.82	645.626	0.100997	2.014417
Maximum =	35.83723	3167.714	0.297372	479297.7	1.08E+10	8.11E-02	1.00E-03	15293.83	0.395836	0.293715	2.095023	0	2666.534	1736.594	0.399725	24.91825
Mean =	10.83655	754.9673	2.45E-02	39527.4	7.33E+08	1.50E-02	0.001	10808.84	0.250133	0.149772	1.826137	0	1245.538	1190.028	0.253658	13.20236
Std Deviati	5.784648	476.255	2.65E-02	56211.62	1.18E+09	1.12E-02	2.80E-10	1796.509	0.05978	5.40E-02	0.124188	0	560.9922	194.3695	8.78E-02	6.874609
Variance =	33.46215	226818.9	7.03E-04	3.16E+09	1.39E+18	1.24E-04	7.85E-20	3227443	3.57E-03	2.91E-03	1.54E-02	0	314712.3	37779.49	7.70E-03	47.26025
Skewness =	1.202818	0.911733	3.93967	3.034448	3.78217	2.29135	5.46313	-7.34E-02	0.143351	0.472499	-0.19776	0	0.536277	2.20E-03	-3.31E-02	0.154031
Kurtosis =	4.228777	3.857094	29.47346	16.17247	23.09572	10.06585	47.21529	2.569346	2.408075	2.418882	2.426764	0	2.416777	2.934161	1.737418	1.733827
Errors Calc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode =	7.953549	577.9482	0.01128	611.2174	1.30E+07	5.08E-03	0.001	11289.4	0.24927	0.126039	1.808458	0	1440.685	1239.729	0.162092	19.65205
5% Perc =	4.447179	169.6474	4.99E-03	890.0237	1.33E+07	4.46E-03	0.001	7602.546	0.15299	7.45E-02	1.609642	0	481.0865	886.549	0.116118	3.148362
10% Perc =	4.948963	217.4042	5.86E-03	1696.203	2.34E+07	5.24E-03	0.001	8403.418	0.175268	8.24E-02	1.641253	0	572.9341	950.4444	0.132383	4.081784
15% Perc =	5.391881	264.9926	6.95E-03	2595.326	4.57E+07	6.14E-03	0.001	8829.84	0.1861	9.30E-02	1.683514	0	635.8846	1004.842	0.145745	5.110078
20% Perc =	5.978023	318.2022	8.51E-03	4033.802	5.96E+07	6.72E-03	0.001	9127.309	0.19753	0.100886	1.704762	0	727.371	1032.943	0.161689	6.445863
25% Perc =	6.418929	376.9772	9.85E-03	5329.401	8.36E+07	7.78E-03	0.001	9483.511	0.207863	0.107311	1.739071	0	767.876	1062.078	0.174706	7.474206
30% Perc =	6.885736	435.8186	1.09E-02	7086.089	1.16E+08	8.32E-03	0.001	9807.245	0.215505	0.111138	1.760182	0	837.577	1087.369	0.187255	8.3536
35% Perc =	7.563026	489.8513	1.17E-02	8904.711	1.45E+08	9.44E-03	0.001	10160.05	0.221876	0.118834	1.785228	0	923.4936	1112.442	0.208132	9.233419
40% Perc =	7.969302	544.4269	1.33E-02	11683.4	1.93E+08	1.03E-02	0.001	10480.09	0.231021	0.126214	1.805158	0	984.6476	1137.437	0.221835	10.01789
45% Perc =	8.487002	598.4424	1.44E-02	14444.28	2.44E+08	1.11E-02	0.001	10743.76	0.237047	0.133637	1.817435	0	1065.774	1159.389	0.240424	10.97696
50% Perc =	9.204367	649.2119	1.59E-02	18161.63	3.21E+08	1.19E-02	0.001	10910.13	0.247024	0.140695	1.840094	0	1181.325	1178.667	0.255441	12.03948
55% Perc =	9.841461	730.5718	1.73E-02	22503.48	3.95E+08	1.28E-02	0.001	11087.57	0.253243	0.151514	1.854756	0	1245.329	1206.101	0.272427	13.49493
60% Perc =	10.59514	782.2296	1.94E-02	28942.96	4.88E+08	1.39E-02	0.001	11286.42	0.263142	0.159363	1.871414	0	1337.43	1227.366	0.285148	15.09135
65% Perc =	11.73523	832.2313	2.20E-02	34505.92	5.85E+08	1.49E-02	0.001	11525.89	0.270158	0.169661	1.882571	0	1438.527	1252.123	0.298864	16.5886
70% Perc =	12.96013	930.0616	0.025316	41936.57	6.55E+08	1.63E-02	0.001	11727.18	0.279604	0.179606	1.89381	0	1518.497	1281.544	0.318681	18.28627
75% Perc =	13.88132	1061.601	3.02E-02	50613.05	8.42E+08	1.77E-02	0.001	12057.76	0.29407	0.187704	1.911224	0	1635.365	1311.773	0.329856	19.62812
80% Perc =	14.97312	1208.631	3.39E-02	59292.46	1.08E+09	2.00E-02	0.001	12382.25	0.304752	0.197346	1.93395	0	1745.959	1361.746	0.34816	20.85331
85% Perc =	16.55865	1308.455	4.24E-02	72359.59	1.34E+09	2.31E-02	0.001	12687.13	0.317822	0.209896	1.956534	0	1885.184	1411.165	0.361523	22.02762
90% Perc =	19.12545	1412.976	5.05E-02	106442.7	1.90E+09	2.93E-02	0.001	13126.82	0.336507	0.227646	1.990616	0	2060.169	1452.097	0.371132	23.05366
95% Perc =	23.29523	1636.31	7.50E-02	148015.9	2.67E+09	3.75E-02	1.00E-03	13658.88	0.355332	0.250237	2.020252	0	2296.038	1520.607	0.386108	24.17873
Filter Minimum =																
Filter Maximum =																
Type (1 or 2) =																
# Values Fil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scenario #1	>75%	>75%	>75%	>75%	>75%	>75%	>75%									
Scenario #2	<25%	<25%	<25%	<25%	<25%	<25%	<25%									
Scenario #3	>90%	>90%	>90%	>90%	>90%	>90%	>90%									

m/day / (1)(	fraction / (1	l/kg / (1)@I	g/cm3 / (1)(	fraction / (1	m / (1)@Ri	days / (1)@	Cumecs / (1)@Risk
Triang(C37	Uniform(C	Triang(C46	Triang(C47	Triang(C48	Uniform(C	Triang(C58	Triang(C68,D68,E68)
[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm	[Pb_RKilm_1.xls]1. Contam Transpt Calc Bhole!G68
-2.97019	3.01E-02	383.2939	1.725363	5.31E-02	50.14008	0	0.105644
-0.16279	4.99E-02	2714.689	2.331889	0.197632	149.8672	0	0.293866
-1.70313	4.03E-02	1200.565	2.022718	0.133227	99.32626	0	0.202077
0.637244	5.84E-03	540.9166	0.129243	3.01E-02	29.32922	0	4.14E-02
0.40608	3.41E-05	292590.8	1.67E-02	9.07E-04	860.203	0	1.72E-03
0.346058	-0.10224	0.558407	-4.53E-02	-0.30009	3.69E-02	0	-1.80E-02
2.378632	1.773622	2.486707	2.480823	2.399507	1.731952	0	2.37948
0	0	0	0	0	0	500	0
-1.57579	4.45E-02	798.9711	2.172106	0.154468	59.2733	1.40E-45	0.16867
-2.65142	3.09E-02	487.6111	1.799429	8.19E-02	55.87735	1	0.133853
-2.4917	3.18E-02	554.4939	1.839343	9.08E-02	59.32396	2	0.144518
-2.38581	3.30E-02	602.8132	1.887208	0.099444	63.35236	3	0.156122
-2.2922	3.45E-02	680.1511	1.906313	0.105187	67.75993	4	0.165146
-2.19479	3.50E-02	748.2621	1.927586	0.109162	72.6938	5	0.17235
-2.09301	3.65E-02	817.3405	1.951086	0.114301	78.70405	6	0.178365
-2.02347	3.73E-02	884.3211	1.97893	0.12164	82.95515	7	0.185522
-1.94163	3.84E-02	952.7729	1.997488	0.12847	87.3853	8	0.190542
-1.85274	3.93E-02	1043.095	2.01207	0.133289	92.76904	9	0.196296
-1.77575	4.05E-02	1114.863	2.023118	0.137516	99.33208	10	0.20026
-1.69566	4.18E-02	1187.49	2.038643	0.142295	104.6621	11	0.207315
-1.59608	4.26E-02	1302.602	2.054691	0.145841	109.8641	12	0.213607
-1.51304	4.39E-02	1389.974	2.069416	0.14867	115.4521	13	0.219048
-1.38456	0.044529	1455.781	2.091995	0.151968	120.0866	14	0.226986
-1.25985	4.55E-02	1575.455	2.114577	0.15553	124.8824	15	0.231886
-1.14239	4.63E-02	1700.03	2.13653	0.158941	130.0697	16	0.239726
-0.94579	4.71E-02	1822.434	2.161128	0.164349	133.3086	17	0.246762
-0.75151	4.81E-02	1974.108	2.194299	0.170214	141.3261	18	0.256712
-0.54839	4.89E-02	2213.055	2.23665	0.177113	145.4135	19	0.272152
0	0	0	0	0	0	-500	0

APPENDIX G

ECOLOGY

MANAGEMENT AND REHABILITATION OF THE SILVERMINES AREA

APPENDIX G

Feasibility and Sustainability of Revegetation Options

CONTENTS

1 SOIL REHABILITATION AND REVEGETATION PLAN : OUTLINE PROVISIONAL PROPOSAL FOR SHORT-TERM (2002) ACTION

It is very probable that there will be delays in implementing a management and rehabilitation plan, due to regulatory requirements for choice and design of a facility to take the hazardous mine waste present on-site, and due to the availability of funds. Therefore, it is important to point out what may be possible in the short-term (during 2002) to reduce risks on the site, in an immediate cost-effective manner. These provisional proposals relate to soil rehabilitation and revegetation only, and are presented for discussion.

1.1. Gortmore TMF

Aim: Dust risk reduction; impoundment stability; optimization of risk/environmental benefit/cost ratio; recognition of the reality of administrative/regulatory/financial delays.

1.1.1. Upper tailings slopes: Cover remaining exposed surfaces with gravel, etc., as was undertaken on the south and south-west slopes.

1.1.2. West-facing TMF impoundment lower slope: Tapering double layer timber slope grating, soil-filled, planted with locally-adapted willow (*Salix.*

1.1.3. *Festuca/Bryum* grass/moss tailings cover: Do nothing; monitor main drainage impact, if undertaken during 2002.

1.1.4. *Agrostis/Festuca* grass cover: Establish large zero-fertilizer input trial areas; apply fertilizer elsewhere as per 2001.

1.1.5. Unvegetated acidified tailings surface: Cover with uncontaminated coarse limestone chippings (capillary barrier) from Magcobar site, if available, and if feasible to subsequently traffic without tailings sinking under weight of vehicle.

1.1.6. Establish feasibility trial of soil substitute cover using dredgings from Kilmastulla River and spring-fed drain spoil from agricultural land; establish appropriate vegetation (depends on characterisation and amendment requirements).

1.2. Yellow River Farmland

Aim: Decrease risk of lead toxicity in grazing cattle/sheep; permit field drainage to maintain productivity.

Discharges from the mining sites have resulted in contamination of some fields due to flooding. TNCC have suspended clearance of certain field drains and stream channels in the Yellow River catchment pending the results of this investigation. Excavation of channels which could result in flooding of fields must be done as soon as possible.

2. INTRODUCTION

Rehabilitation plans are presented in the main text and Appendix D of the Final Report. Questions relating to the feasibility and long-term sustainability of soil rehabilitation and vegetation cover, to reduce the risk of metal pollution due to tailings dust-blow, and to reduce water contamination, are addressed here.

2.1. **Brief**

In 2001, SRK Consulting were commissioned by the Department of Marine and Natural Resources (DMNR) to prepare management and/or rehabilitation plans for contaminated mine sites in the Silvermines area. This follows from a series of recommendations from the Inter-Agency Group. These rehabilitation plans are to be presented in the Final Report to the DMNR.

As part of the brief to the consultants, it was necessary to advise the DMNR on the presentation of such plans to the agencies and owners responsible for carrying out and supervising the plans, and to the local people. This report addresses questions which are likely to be raised, relating to the feasibility and the long-term sustainability of revegetation and ecological restoration of the tailings and other wastes, by those who may influence the final decisions for implementation ('stake-holders').

The report has been restricted in its scope by the complexity of interactions between plans for different sites, the conceptual rather than detailed nature of the plans, undecided factors such as the location of (a) waste disposal site(s), and restrictions on the level of detail acquired due to time limitations on the contract.

2.2. **Context**

The management and rehabilitation plan for the Silvermines area must integrate a number of operations, including the following:

(1) Rehabilitation and revegetation of the degraded unvegetated tailings surface of the Gortmore TMF. This will probably require crushed limestone, soil or soil substitute, and an organic matter source, possibly river dredgate or treated sewage sludge.

(2) Disposal of waste from Shallee dump, the Mogul mine tailings lagoon (main settlement pond), the Mogul mine old stock-pile (spillages dump), the Magcobar rock waste producing ARD (acid rock draunage), and mixed kiln clinker waste and tailings from the Ballygown calamine area (currently forming a steep bank over the Silvermines stream). Disposal requirements will have to be agreed with the EPA and TNECC.

(3) The removal of stream sediments with elevated metals in the Kilmastulla catchment, and especially in the Yellow River catchment, to avoid resuspension in future. The excavated sediments may be disposed of in the mine waste disposal site, or be permitted to be used as soil substitute on the Gortmore tailings, depending on their characterisation.

(4) The upgrading and creation of treatment wetlands associated with the Yellow River and discharge from the Gortmore TMF and the Shallee Mine site.

(5) The requirement for soil or soil substitute cover elsewhere in the Silvermines area (e.g. for some of Shallee tailings, TMF embankment slopes, Ballygown area, etc.).

Driving forces for remediation, relevant to revegetation, are:

- Concerns about dust-blow from the Gortmore tailings;
- Concerns about possible future cattle deaths from lead contamination in the Yellow River catchment,
- A general concern about public health risk from exposure to heavy metals (especially near Silvermines village), The development of a mine heritage tourist centre based at Shallee,
- The protection of the mining heritage of the area, and
- Concerns about agricultural productivity and quality.

Taking these concerns from an ecosystem perspective (revegetation requirements and ecological impact), the issues translate as:

(1) Long-term self-sustainability of the vegetation cover on the Gortmore tailings;
(2) Permanent reduction of elevated metal transfer from soils to livestock,
via grazing and silage or hay production;
(3) Long-term restoration of the biological quality of the Yellow River and Kilmastulla River;
(4) Permanent reduction of the risk of metal transfer from mine waste soils to children using the Ballygown mine area;
(5) Landscape revegetation requirements of the proposed mine heritage tourist centre;
(6) Avoidance or control of revegetation of important historical mine sites;
(7) Reduction of the risk of metal transfer to wildlife.
(8) Identification and conservation of any ecologically sensitive areas.

2.3. Remediation approach

Consideration of sustainable development is part of the recommendation of the recent EU CLARINET project on remediation of contaminated land. In particular, the impact of remediation works needs to be clearly assessed (Bardos and Vik, 2001): "If the undesirable impacts of these remediation processes exceed the desired benefits of the core objectives, the core objectives may need to be re-evaluated. If proper risk management procedures have been followed, along with a thorough cost benefit analysis and stakeholder consultation, the risks of such a situation arising should be minimised, depending on the remediation approach selected." Any soil rehabilitation and revegetation proposals presented or considered here are provisional, pending the completion of the above procedures, and completion of final designs and may require modification.

Other aspects of a risk-based remediation approach, recommended by the EU CLARINET project, include risk management, sustainable development, stakeholder's views, cost effectiveness and technical feasibility. These have been addressed in this report where possible.

2.4. Sources of information

Sources of information not directly cited in the relevant sections included SRK Consulting, the Exploration and Mining Division of DMNR, Natural Resource Consultants (2000) characterisation study, Boland (2000), Timpson (1991), local landowners, Sligo Institute of Technology, University of Liverpool, EPA, TNRCC, Teagasc, GSI and Vincent Wildlife Trust.

3 BALLYGOWN SITE

3.1 Revegetation of spoil slopes above Silvermines Stream

Where stream sediment and bank spoil can be safely and feasibly excavated, the following is a rehabilitation option for the spoil bank. Build geotextile layers holding rooting medium fill, and insert willow brush layers between layers. The width of earth layer structure depends on ability of shrubs to root into spoil face material without death or die-back; a small trial can be recommended initially with several plants. The rooting medium will need to be soil or soil substitute which is friable and easily handled. There are a number of potential sources of this material on privately owned land in the Silvermines area, which would require minimal rehabilitation after borrow material removal.

Water diversion and contingency works (sediment traps, etc.) to avoid carrying disturbed sediment downstream to the Silvermines River, with extra impacts on freshwater life, will need to be put in place.

3.2. Revegetation of open-cast area

Revegetation will depend on the final backfill used. The objective would be to create a similar vegetation profile to the adjacent land which comprises principally gorse.

4 MAGCOBAR SITE

4.1. Provisional soil rehabilitation and revegetation plan

Older rock dumps (to the east) have, for the most part, have naturally revegetated fairly well, mainly by a scree moss-based cover. For non-acid-generating scree slopes this natural colonisation should be facilitated. Insufficient time was available to fully characterise the conditions under which such facilitation can be achieved. However, given the scale of the dumps, and the costs involved in slope stabilisation for soil cover, more elaborate restoration may not be justified (with the exception of the excavated face of Rock Dump A; see below). For limestone excavation from waste dumps, it is preferable to avoid north-facing or other slopes visible from the N7 and the surrounding area to the north of Silvermines, because of the great difficulties involved in revegetation of these scree slopes.

The eventual land use of areas of no extractive value may be biodiversity sites (scree habitat).

4.2. Revegetation of excavated face of Rock Dump A

In the excavated face, fresh rock hs been exposed and is clearly visible due to lack of weathering and revegetation. Remedial work will require some limited re-profiling to make safe. Revegetation will occur naturally over time, similar to the other dumps but could be enhanced by placing ridges of soil in front of rehabilitated slope and plant quick-growing deciduous trees, with slower growing native trees and scrub. This will provide screening in medium-term.

4.3. Areas where acid-generating rocks have been consolidated

The vegetation cover, and aftercare, depends on the source type of soil/soil substitute cover, the location of the zones in relation to aspect, rock texture, chemistry, etc. If a reasonably impermeable subsoil barrier is required to reduce infiltration, then control of tree growth may be necessary in the long-term. However, a cover of non acid generating rock, over a low permeability cover would create a similar environment to the bulk of the waste rock.

5. GARRYARD MINE SITE

5.1. Provisional soil rehabilitation and revegetation plan

There are two options: (1) Remove mine waste material from tailings lagoon and settlement pond to another waste facility, and re-create wetland treatment areas in both areas to treat ARD; (2) Establishment of a mine waste landfill to regulatory specifications in the tailings lagoon area, and creation of wetland treatment areas to treat AMD downstream. Both options require isolation of the waste from the receiving environment, and until this is achieved, downstream rehabilitation cannot begin. Artificial water treatment and sediment control structures will be necessary during site works to avoid increased ecological risks to freshwater life in the Kilmastulla River. Following isolation of waste, the re-creation of wetland treatment areas can proceed. The extensive natural rough grassland/wetland area to the west of the site would be suitable subject to detailed design investigations.

5.2. On-site mine waste disposal option

Continuing use of the existing wetland for treatment (i.e. do nothing option) is not recommended due to the high levels of contamination in the stream draining this area to the Yellow River. Upgrading the existing wetland biologically is also unlikely to be successful, given the contaminant load and classification of the adjacent waste.

One option is removal of the hazardous mine and mill waste currently on-site to the Gortmore tailings, the Magcobar pit or elsewhere. The feasibility, difficulties and regulatory requirements of creation of a hazardous waste disposal site on the Gortmore TMF are considered above (3.2). Use of the Magcobar pit for landfill is currently under An Bord Pleanála appeal. Other sites in the area have not yet been specified. The possibility that none of these sites are suitable for the disposal of the Garryard waste exists. Equally, the possibility that the required hazardous waste area could be the Garryard tailings area itself also exists. If it were, then a downstream treatment wetland would be required for treatment of acid mine drainage diverted around the lined waste facility. If the waste material can be removed from the site, then the tailings area can be reconstructed to form a treatment wetland.

5.3. Long-term maintenance of water treatment wetlands

It is likely that excavation of accumulated wetland sediment and sludge will be required periodically. The period is usually a minimum of 20 years but depends on the load input and available area and depth. The loadings at Garryard are low, therefore cleaning out may not be required for many years, especially if the main metal sources are removed. Revegetation will be required following sludge removal. It is likely that this can be achieved through re-use of existing plants.

5.4. Revegetation and land use of the Garryard old stockpile (spillages dump)

The preferred option is the removal of the contaminated material from this site. Because the underlying soil and subsoil will very probably be contaminated, this too may have to be removed. A complete subsoil and topsoil replacement may be required. An impermeable subsoil promoting runoff may be preferable; the availability of clay-rich material locally or from road works is not confirmed. Rehabilitation activities may contaminate some of the imported topsoil, thus an agricultural end-use is not preferable. With sufficient soil depth, tree cover would be feasible, and ash could be planted. In terms of a commercial forestry option, the small size of the area may off-set the benefit of easy access from the road, but a beneficial long-term forestry use may recompense the costs of establishing a 1m deep soil layer.

6. SHALLEE SITE

6.1. Provisional soil rehabilitation and revegetation plan

Much of the tailings mound surfaces are naturally vegetated, but areas which are not should be covered. For the north tailings mound, stripped peat and heather litter held in place by geojute or similar material, to allow heather growth, may be sufficient. For the south mound, a soil or soil substitute cover which holds moisture is required for areas with poor vegetation cover. The extent of soil or soil substitute cover depends on the end use of the area. If public access is fenced off, then sufficient cover is only required to support self-sustaining vegetation growth.

Removal of the dumped mixed waste material from the Shallee site will probably leave residual pockets which will require subsoil and topsoil cover. If, for any reason, the dumped material has to be left *in situ*, there will be a similar requirement for subsoil-topsoil cover. If the site is to be used as a mine heritage centre, then integration of this area into the surrounding landscape will be necessary. A cover of heather, with some gorse would be preferable, limiting the amount of gorse so that it does not represent a fire hazard. If funds are available, then deep (> 1m) soil cover for tree/scrub cover may be necessary in some patches. Final decisions on cover requirements depend on tourist development and waste disposal plans (see EPA, 1999b).

Even after revegetation and stream cleaning, there is likely to be some ongoing transport of metals in solution or suspended solids. This will require a treatment wetland downstream. A marsh and wet grassland area, with some willow growth already exists between the northern tailings mound, the stream and the Yellow River. This already appears to be providing some filtering of metal contaminants in seepage from the tailings, so its existing function would either need to be retained by creating a deeper treatment wetland system near the road, into with the stream would discharge, or by replacing its function with a larger wetland. The excavation of this area may provide material for use as soil substitute in the TMF, but the surface organic layer may be sufficiently enriched with lead and barium in patches that it will need to be disposed of with other hazardous wastes. A detailed site feasibility survey for conversion to deeper wetland will be necessary.

6.2. Feasibility of rehabilitation of stream draining Shallee site

The excavation of sediment from the stream draining the Shallee mine area may necessitate removal of trees and scrub to allow access. This may have negative effects, both in terms of shelter of the tailings slope from the prevailing wind, as well as aesthetically. It may be feasible to access the drains along their channel using a mini-excavator, which would avoid the necessity for tree removal. As a wetland is proposed, along with other remedial works, complete removal of sediment from the stream bed is not necessary, especially if cattle have no access.

6.3. Requirement for soil cover on tailings

Two separate unimpounded deposits of sandy Pb tailings exist at Shallee: One south of the R499 road, and one to the north; both originating from the 1955-58 mining operation. While their contribution to groundwater contamination appears to be minimal (Main Report Section 6.4), there is a potential on-going risk of seepage and erosion to the stream resulting in elevated concentrations of metals in the Shallee stream feeding the Yellow River (Main Report Sect. 7.5.1; Appendix D5). There were reports of dust blow from the tailings in the 1950s and 1960s, as well as possible aerial contamination of mosses in unspecified localities at the Shallee site (Steinbörn and Breen, 1999), so a minor risk exists (Appendix D5) particularly in three areas :

(1) Southern tailings pile plateau (partially vegetated);
(2) Small unvegetated tailings heap near old engine house;
(3) Slopes between tailings benches north of road, which appears to be actively eroding.

6.3.1. *North Tailings Deposit*

In 1991, the lower bench of the tailings deposit north of the road had the best example of self-sustaining soil/vegetation cover recorded for any Irish tailings deposit (Good, 1999a). In 2001, the site had progressed to a willow/birch/heather cover, with the exception of the slope between the two benches, which appears to be actively eroding. For dust control, the site does not require revegetation generally, but does at the crests, the bench slope and some surface-disturbed areas with poor cover. This generally successful cover is probably due to its leached surface (see Main Report Sect. 7.5.4), low pyrite content, soil water retention properties and age.

Dry surface and root-zone conditions may be responsible for the poor cover on the slope, rather than phytotoxicity. Planting to heather would be preferable. If an organic peaty layer (not nutrient-rich) was applied and held in place by geojute, or similar material, then rooting of planted heather into the tailings would be expected, binding the cover after the geojute decays.

A sand martin colony nests in the exposed cliff of the tailings (c. 15m in extent), and has done so for many years. Sloping off and revegetation of this face will require a licence from the Minister for Arts, Heritage, Gaeltacht and the Islands, because it will eliminate the breeding area of the colony. If it is to be left without disturbance, then dust generation from this area will need to be monitored. If no significant generation is occurring, then the exposed cliff should not be disturbed, and plant recolonisation and eventual abandonment by the birds should occur in time. This option, however, requires constant monitoring. Notwithstanding, the above, it may be in the interest of such migratory birds to prevent their breeding in the lead tailings, if they are being subjected to sublethal effects of lead.

6.3.2. *South Tailings Deposit*

The southern tailings deposit, has a much drier, more free-draining surface, parts of the surface is poorly and patchily vegetated. If it is assumed that the surface chemistry is similar to the tailings north of the road, then its lack of cover is probably due to surface drought. The upper (southern) part of the deposit appears to overlie older mine spoil (see 1904 25" map), the lower part is stacked steeply above the stream. There is some colonisation by marram grass (*Ammophila arenaria*), and this site apparently represents its only inland occurrence in Ireland. This is presumably artificially introduced as it is a species normally found in sand dunes. A peaty soil or soil substitute cover placed on the surface, with low nutrient and high moisture retention properties, is required to reduce the risk of dust blow. Heather, already providing patchy cover, can be encouraged; thus, high nutrient inputs are not necessary. Heather litter stripped from further up the Silvermines mountain could supply a source of locally-adapted seed and shoots. Seeding of fescue grasses (*Festuca* sp.) could also be recommended. The aim is for a self-sustaining, native vegetation which blends in with the surrounding area.

The trench which exists on the surface should be examined, by a competent person, for its contribution to drainage and geotechnical stability, prior to finalising revegetation plans. In particular, the in-filling of this trench would probably contribute to surface moisture retention essential for revegetation, and the consequences of such action needs to be assessed.

Given that the beneficial use of the Shallee area is as a heritage centre, public access to the tailings should be restricted by fencing. This cover, if sown to grass without maintenance, will probably be rapidly be colonised by gorse and willow. Too much gorse may represent a fire hazard, so grass maintenance by mowing at least annually will be necessary.

The tailings slopes are mostly vegetated and sheltered by scrub and tree growth. If trees giving shelter from the west are to be removed as part of stream remediation, or site development, then the risk of dust-blow due to increased exposure needs to be re-examined.

7 GORTMORE TMF

7.1. Provisional soil rehabilitation and revegetation plan

All large surface areas of unvegetated acidified tailings should be covered with limestone chippings (200mm depth, or less only if established as self-sustaining by trial or precedent) and soil or soil substitute, sufficiently amended with organic matter (100mm depth). To avoid compaction, loose-tipping and spreading should be carried out using small vehicles with low ground-pressure, and graders should not be used. Unvegetated eroding upper tailings banks should be covered with gravel or similar available material initially to reduce risk of dust-blow, and subsequently with soil or soil substitute, as it becomes available. Both the above areas should be seeded to non-metal-tolerant grass/clover mixture, the composition of which will vary with the soil or soil substitute type. Planting or seeding gorse to increase shelter and reduce desiccation by wind may be necessary. A reserve of grass seed from the tailings surface should be harvested, if signs of acidified 'hot-spots' develop, if the created soil is not very drought-susceptible.

For existing grass cover, management should aim to reduce fertiliser inputs, and encourage a self-sustaining grass cover for *Agrostis/Festuca* areas, and allow *Bryum/Festuca* areas to develop a saturated cover on the tailings.

A trial of river dredge spoil as a soil substitute for the above rehabilitation requirements should be established. If successful, and excess amounts are available, this should be applied to the *Agrostis/Festuca* areas, and not to the *Bryum/Festuca* areas. If monitoring of degraded patches of

Agrostis/Festuca reveals further degradation, limestone chippings will need to be applied as a capillary break to the Agrostis/Festuca areas upon which the dredge spoil is being applied.

It is proposed to stabilise the tailings pond size by engineering works to encourage a denser wetland vegetation cover, and to complex metals to reduce discharge water contaminant loading Organic matter, sources of balanced carbon and nitrogen resources, and other amendments, should be applied to the pond.

The revegetation requirement must take cognisance of the existing surface drainage and any proposed modifications to the drainage. This is necessary to ensure that drought susceptibility, root zone flow and saturation requirements are maintained.

The south-west facing lower slopes should be stabilised using live timber gratings planted with willow. It is assumed that modifications to the various wetlands will not require any revegetation programme beyond natural re-colonisation.

7.2. **Waste disposal on tailings**

Highly metalliferous mine wastes occur at Garryard (settlement pond, tailings lagoon and the old stockpile. A large quantity of mixed waste also occurs at the dump area in Shallee. It may also be necessary to remove kiln clinker and associated waste from adjacent to the Silvermines stream. Stream bed rehabilitation, especially in the Yellow River catchment, may also generate large waste volumes. These wastes will require disposal in designated waste disposal area. The preferred on site area is the Gortmore TMF, but this would require licensing or permitting. The alternative would be an existing landfill site but the type of waste would have to be classified to identify suitable sites.

If mine waste from the Silvermines area is permitted for disposal on the Gortmore tailings,
this may involve the following:

(1) Designating the TMF area as a waste disposal facility, with the requirement for an engineered facility according to regulatory specifications. The difficulties of placement of waste on a liner on potentially thixotropic tailings are not to be underestimated, and carry an increased amount of long-term risk.

(2) The spreading of the waste over an area to say 0.5 m height, preferably over the acidified, unvegetated tailings. For a volume of 15,000 m^2, this would require a disposal surface of 3 ha.

(3) Covering the waste with a low permeability cover, and then with a soil substitute layer, according to standard landfill practice. This will promote surface runoff and minimise leaching of metals and salts from the waste, and permit the establishment of a vegetation cover layer.

(4) The possible requirement and associated costs for a Safety Management System to be in place for the TMF, if the landfill remains active for a number of years, and falls under the Seveso II Directive, as currently proposed for amendment (CEC, 2001). Also the possible requirement for a perpetual discharge licence may result in additional long-term costs.

Because of the very low gradient, some ponding and soil water retention is to be expected over the lined waste on the tailings, especially if further tailings consolidation also occurs. A marsh vegetation cover may therefore be necessary, depending on the cover design.

7.3. **Impact of traffic on tailings**

Compaction of the placed soil layer by machinery traffic must be avoided, otherwise the risk of root-zone contamination by phytotoxic metal salts and upward migration of ARD is much higher. Placement of a soil cover on the tailings will probably require specialised machinery, to minimise compaction.

One of the difficulties to be overcome in placing a stone and soil cover on the degraded tailings surface, is the limitations of access to load-bearing vehicles. Because some of the tailings are surface-saturated and thixotropic (becoming weak under stress), low-ground-pressure adaptations or specialized tracked muskeg-type vehicles may be necessary, such as are used on Bord na Móna bogs. The necessity for a separate machine, the down-sizing of loads from delivery trucks, and the avoidance of traffic compaction on the loose-tipped soil, means that the costs of haulage and spreading of the rock and soil cover will be much greater than normal. A separate, uncontaminated, unloading and reloading area will probably be necessary just outside, or on, the tailings impoundment.

7.4. **Trees as a cover option**

Although timber production from metalliferous soils is an ideal beneficial use (partly because elevated metal concentrations assist preservation of pole timber), it is impractical on uncovered tailings. This is because, *inter alia*, to soil toxicity killing or limiting tree growth, to the risk of wind-blow before maturity, and the difficulties of machine access. Based on trials carried out by Prof. M.S. Johnson and E. Brady at the more benign Tara Mines tailings, tree or shrub cover was not considered a viable alternative to pasture. Other trials on tailings elsewhere have reached the same conclusion., on similar types of tailings.

7.5. **Precedents for a thin soil cover option**

A thin cover of broken rock and soil was successfully used to revegetate Avoca copper tailings in Co. Wicklow, based on revegetation specifications by Prof. M.S. Johnson. However, total metal concentrations are much lower in the surface tailings than they are at Silvermines, and degradation of such a cover remains a long-term risk, due to upward movement of acid-generation products and metals into the soil.

Following a dust-blow event in the early 1980s at the copper tailings impoundment from Avoca Mine near Arkow (Co. Wickow), the tailings were rehabilitated by covering with broken shale and soil. Rehabilitation has been successful; the original agricultural grassland has, for much of the surface, been naturally succeeded by gorse (*Ulex europaeus*). Although soil biological conditions appeared to be initially limited by seasonal surface flooding and drought (Good and Butler, 1999), the vegetation cover has maintained and slowly enhanced itself, without external nutrient inputs, up to 2001. The tailings surface was rehabilitated by covering with limestone chippings, broken shale (specification 200mm depth), and imported soil (specification 100mm depth, and sown to grasses in 1985 (Wardell Armstrong, 1992). Even 'hot-spots' where surface acidification and death of vegetation cover had occurred in the first few years after rehabilitation, have now developed a vegetation cover (mainly willows (*Salix cinerea*)).

The successful revegetation of the Avoca tailings surface may point to a preferred option for the Gortmore tailings. However, when the tailings metal concentrations are compared (Table I2), the considerably greater potentially phytotoxic conditions at Silvermines are apparent. The question remains as to whether upward movement of acidity and potentially phytotoxic metal salts, might occur through a thin soil cover, especially in wetter areas of the tailings surface. A carefully placed capillary barrier of coarse limestone chippings may be necessary to reduce this risk.

TABLE I2. Mean total metal and arsenic concentrations from tailings at Gortmore (Silvermines), compared with Shelton Abbey (Avoca) tailings, and trigger concentrations. Trigger concentrations refer to threshold concentrations above which phytotoxicity or zootoxicity may occur in mine wastes (ICRCL, 1990), and are guidelines only and need to be interpreted relative to prevailing soil conditions.

Site	**Element**					**Source**
	As	**Cu**	**Cd**	**Pb**	**Zn**	
Silvermines (n = 10 samples)	503	272	22.5	9924	7459	DAFRD (2000)
Silvermines (n = 8 samples)	733	143	17.0	11642	4563	SRK (Table 7.13)
(Trigger concentrations	50	250	3.0	300	1000	ICRCL (1990))
(Action threshold	55	190	12.0	530	720	MHSPE (1999))
Avoca tailings (n = 1 sample)	80	700	<0.3	155	79	Good & Butler (1999)
Avoca tailings (n = 2 samples)	-	733	nd	-	55	Dunnells (in litt.)
Avoca tailings impoundment wall (n = 1 sample)	-	5492	nd	-	779	Dunnells (in litt.)
Avoca soil (n = 9 samples)	35	48	<0.3	42	106	Good & Butler (1999)
(Trigger concentrations	50	250	3.0	300	1000	ICRCL (1990))
(Action threshold	55	190	12.0	530	720	MHSPE (1999))

Herbage samples

Site	**Element**					**Source**
	As	**Cu**	**Cd**	**Pb**	**Zn**	
Silvermines tailings (*Agrostis*, *Holcus*, *Poa*)	-	8.2	1.03	29.2	191	DAFRD (2000)
Tara Mines tailings (*Agrostis*)	-	13.5	0.37	16.3	378	Crilly et al. (1998)

7.6. **Self-sustainability of grass and moss cover**

The grass cover occupying >50% of the tailings surface is dominated by *Agrostis stolonifera* and *Festuca rubra* in the more acidic and presumably more saline areas, and by *Festuca rubra* in the wetter areas being invaded by moss (see 3.6.2 below). Although intermixed as patches, partly in response to the textural mosaic characteristic of these tailings (Prendergast, 1991; Tierney, 1998), these two grass cover types must be considered separately.

7.6.1. *Agrostis cover*

Based on information available, there is a higher risk of degradation of the *Agrostis* cover than the *Festuca* cover. This is for three reasons:

(1) *Festuca rubra* appears to be able to reseed and re-establish on the surface of the dense moss matts, where the latter will retain moisture above the saturated tailings, and so inhibit acid-generation by providing an oxygen barrier (see 3.6.2).

(2) *Agrostis stolonifera* is more drought susceptible than *Festuca rubra* (Hubbard, 1968; Williamson, Johnson and Bradshaw, 1982), and grows directly on tailings without an intervening organic layer which could retain moisture. *A. stolonifera* is more tolerant of acidification and maybe of metal salts.

(3) As a species, *Agrostis stolonifera* has a higher nutrient requirement than *Festuca rubra* (Hubbard, 1968; Williamson, Johnson and Bradshaw, 1982); it is assumed that this equally applies to the respective metal-tolerant cultivars.

Where it occurs, the *Agrostis stolonifera*-dominated cover has sustained itself since sowing in 1986-87. This includes a drought period during August/September 1996. Prendergast (1991) reported it as re-establishing itself on the Gortmore tailings by seeding. Good (1999) reported a reduced but developing soil fauna in one *A. stolonifera*-dominated area, indicating the presence of a decomposer community and the beginning of a self-sustaining nutrient cycling system. Nevertheless, the cover must be virtually comprehensively *perpetual* over the whole tailings surface to eliminate the risk of dust-blow.

Neutralization of acidity, by carbonates, in patches currently solely supporting Agrostis, may not last in the medium term (decades) if carbonates are totally consumed. In the absence of a thorough geochemical characterisation of representative parts of the tailings surface, especially for long-term acid-generating and neutralisation potential, the long-term viability of the Agrostis cover cannot be assessed with certainty. In addition, the issue of nutrient cycling and long-term self-sustainability, is difficult to assess because regular fertilizer applications mask the potential of the sward to sustain itself. Climate change and drought susceptibility are also key issues under existing conditions.

Given this uncertainty, but also the fact that degradation would be expected to be a gradual process, some financial provision for rehabilitation could be provided over a medium-term period (say 30 years). Investment of a relatively small initial sum should provide annual maintenance out of income, with the capital sum kept in reserve for rapid unforseen deterioration. If no deterioration occurs, and data on cover self-sustainability accumulates, the financial provision can be returned to its source. This also reduces the requirement for large amounts of cover material in a short space of time, decreasing both environmental and financial costs and achieving an optimum balance between risk, costs and environmental performance.

7.6.2. *Bryum/Festuca* cover

The moss Bryum ?-pseudotriquetrum has extensively colonised many areas of wet tailings surface in the North-east Field, forming a compact saturated layer of c.50mm depth on the tailings. If persistent, this provides an ideal cover of pyritic tailings, inhibiting oxidation due to the maintenance of saturated conditions at and above the tailings surface. This moss exists in a community with Festuca rubra, the latter establishing by seed on the moss surface, and rooting into the organic layer of the moss. In time, birch is expected to colonised this early successional stage. The self-sustainability of this cover type depends on the maintenance of surface hydrological conditions. This needs to be modelled under long-tem climate change and tailings consolidation conditions.

7.7. Seed sources

A commercial seed source for metal-tolerant Agrostis grass apparently no longer exists. Seed would have to be obtained either on contract to a UK seed supplier, or by direct harvesting from the Silvermines tailings.

For the seeds of initial revegetation Agrostis stolonifera, and other grasses and clover were originally purchased from a UK seed supplier in 1985-87. In 1987, when insufficient seed of this grass was available, seed was harvested from the established sward on the tailings.

7.8. Fertilizer application

Compound NPK fertilizer (18:6:12) has been broadcast on the tailings grass surface, almost annually, since sward establishment (Boland, 2000). Fertilizer was applied during 2001, although details of fertilizer composition, rates, timing and areas covered need to be confirmed. There are two issues associated with fertilizer use: acidification and sustainability.

7.8.1. *Soil acidification*

Fertilizers containing ammonium salts, such as ammonium nitrate, will result in soil acidification, if not sufficiently balanced by calcium carbonate in the fertilizer composition, or by buffering in the soil. Because the chemical composition of 18.6.12 fertilizer varies, and because its chemical behaviour interacting with Gortmore pyritic tailings is not known, it is not clear whether there is any tailings surface acidification occurring as a result of its application. It needs to be confirmed, therefore, by a qualified soil chemist, that fertilizer application is not responsible for exacerbating the formation of patches of grass die-back on the tailings surface. Clearly, any further acidification of the Gortmore tailings surface is to be avoided.

7.8.2. *Sustainability of fertilizer-maintained swards*

If fertilizer application ceases, will the grass sward maintain its cover, or will it degrade and expose the tailings surface? At present, even in the presence of fertilizer application, there is evidence of localised grass die-back in small patches of less than 1 m^2, in certain parts of the grass cover. These small, isolated patches appear, in some instances, to be actively degrading, and their geochemical characteristics are not known. Application of lime (calcium carbonate or calcium oxide) to these small patches may inhibit further degradation, but this needs to be formally tested. In the meantime, it cannot be concluded that fertilizer application, in the absence of associated lime application, will inhibit grass cover degradation on its own.

The self-sustainability of the *Agrostis/Festuca* sward, in the absence of fertilizer input, needs to be assessed by zero fertiliser trial in 2002. If the sward will degrade due to nutrient depletion, which cannot be replaced by natural nutrient recycling in the soil, will the sward maintain self-sustaining cover if it receives a set of applications of organic matter to act as a slow-release source of nutrient mineralisation? For reasons of proven efficiency, as well as sustainability (see introduction), the replacement of fertiliser by nutrient-rich organic waste such as sewage sludge, is preferable. Again this needs to be tested in large scale field trials, properly located. It cannot be over-emphasised that long-term cover self-sustainability is the aim, not an aesthetically green sward dependant on perpetual nutrient inputs. Comparisons need to be made with upland *Nardus* grassland, for instance, rather than with agricultural grassland.

7.9. **Sheep grazing**

A flock of c.200 sheep were grazed on the Gortmore tailings grassland for a short period during early winter 1998. They were removed by order of TNRCC, because of concerns that such grazing pressure might degrade the grass cover of the tailings, and thereby increase the risk of dust-blow (DAFRD, 2000). In contrast, at the Zn/Pb tailings at Tara Mines near Navan in Co. Meath, sheep grazing has been used to enhance grass cover by promoting tillering, as well as aiding nutrient cycling via their dung and urine (Crilly *et al*., 1998). There may be benefit in strictly controlled grazing to manage progressive improvement.

Because metal- and salt-tolerance have physiological costs to the plant, such varieties are not very productive under metalliferous soil conditions (Ernst, 1988). Furthermore, *A. stolonifera* as a species is not a preferred forage grass, because it is neither leafy nor very palatable. (Although the more productive ryegrass (*Lolium perenne* cv. Vigor) was originally planted, it failed to persist on the tailings (Tierney, 1998)). Productivity is not important for the objective of dust-prevention, as long as the sward maintains a self-sustaining cover. Equally, productivity is not important, if sheep-grazing is for short periods of several weeks, purely to enhance tillering and maintain plant cover. The questions arising, then , are (1) whether short periods of sheep grazing are necessary to enhance and maintain grass cover, relative to no grazing, and (2) whether such grazing regimes are economically sustainable in the long-term, and thus worthy of R & D investment.

Some of the potential advantages and disadvantages of sheep grazing for the Gortmore tailings grass cover are given in Table I3. As mentioned above, a key question is whether the grass cover at Gortmore TMF *needs* grazing. Little or no grazing has apparently occurred since the establishment of the grass cover in 1986-87 (Boland, 2000). Yet, grass cover has maintained itself over large areas of the tailings, in the absence of grazing, since this period. There is evidence from samples taken in 1991 that a self-sustaining soil decomposer fauna, which can break down dead grass litter in the absence of earthworms, can exist on part of the tailings (Good, 1999b). (Although there is no data on the occurrence of burrowing earthworms in the tailings surface, it is assumed that their populations would be low because of the metal concentrations). However, fertilizer has been regularly applied (Boland, 2000), and, although its future use is a separate question (see above), might sheep grazing be beneficial for sward maintenance in the absence of fertilizer inputs? This is unlikely, for in the absence of fertilizer, both palatability and leaf production will decline. More sensitive management would be necessary to remove the sheep before they start to crop lower down in the sward, and thus increase their susceptibility to mineral soil (and lead, zinc and cadmium) ingestion, and this may not be possible to guarantee. In the Tara Mines experiment, even where fertilizer was applied, there was zero or negative growth of lambs grazing *Agrostis stolonifera* swards over a period of several months.

TABLE I3. Advantages and disadvantages of sheep grazing for sward maintenance on Gortmore (Silvermines) tailings.

	Advantages	***Comments***
1.	Encourage tillering, sward vigour and cover	Can sward cover be maintained adequately in the absence of grazing?
2.	Recycle nutrients through dung & urine	Is there a nutrient recycling problem in the absence of grazing?
3.	A properly managed flock may be a beneficial use for the TMF	Will there always be a market for sheep meat from a publicised contaminated site, given food safety concerns?
4.	Some processes, such as soil aeration and seed dispersal may be enhanced by sheep grazing	Evidence for this needs, if it exists, needs to be quantified
	Disadvantages	***Comments***
1.	Metal accumulation in sheep	Trials at Tara Mines TMF found metal concentrations below threshold limits
2.	Lack of thrive in sheep	Sheep need not graze the area over very long periods, and site can provide a worm-break
3.	Difficulties with lease agreements in the absence of title	It may be possible to overcome this problem
4.	Uncertainty of subsequent sward response if sheep have to be removed for economic, animal health or environmental reasons	A contingency plan can be put in place
5.	Increased costs due to tissue monitoring and compliance inspection	Costs may be outweighed by sward maintenance benefits.
6.	May require fertilizer inputs to be sustainable	
7.	Strict fence maintenance costs to avoid access to more sensitive parts of site (e.g. TMF embankment, areas of moss cover, etc.)	
8.	May not be ecologically sustainable, if there is succession from grass cover to a different vegetation type	

7.10. Sewage sludge application

Sewage sludge, treated or applied in such a way that it does not pose a public health hazard due to pathogenic bacteria, is an ideal organic ameliorant for mine tailings low in organic matter. It has been widely used at other mine sites in Europe and the U.S. If accepted by local residents, then regular low rate applications to the grass sward, under permitted conditions (see Table I4), can provide the essential organic matter upon which a sustainable soil cover can develop. Furthermore, lime treatment of sludge should be beneficial in terms of soil pH. However, it is essential that sludge is not applied to areas where the moss-grass ecosystem is developing, or to areas where excessive loadings to surface water could occur.

While lime-treatment of sludge is feasible for local STPs (sewage treatment plants) at the time of writing, it may not be an option later in the year if TNCC decide to follow other disposal options. The local availability of sludge plus lime would be the preferred option, but the decision to apply it needs to be made urgently. Alternatively, the availability of possible thermally-treated sludge from within the region may have to be examined.

Since the aim is to obtain a self-sustaining vegetation cover, excessive nutrient input from sludge application may not be necessary in some areas, and will need to be carefully controlled. Long-term carbon: nitrogen imbalances and grass thatching need to be avoided. Limitations on application rates will also occur if there are high metal or soluble salt concentrations in the sludge.

In 1997, secondary treated sewage sludge was applied to some of the tailings grassland as an ameliorant. Tertiary treated (e.g. thermally dried, composted or anaerobically digested) sludge is an ideal ameliorant for mine waste, being high in both organic matter and slow-release nutrients and low in pathogenic bacteria, but most currently available sludge is secondarily treated only. At the outset, a demonstration programme and full consultation process, clearly explaining to the local residents, what type, how much, and why sludges are being applied, is seen as critical to the local acceptance of the regular use of sludge on the tailings surface.

If properly treated, sludge has a number of advantages. It adds essential plant nutrients in a slow-release form, complexes metals due to its organic matter content and high CEC, increases water retention during dry periods, raises pH, and physically ameliorates the soil. Sludge and lime are more likely to result in raising long-term soil pH than fertilizer and lime (Sopper and Seaker, 1990). However, sludges are often low in K (Sopper and Kerr, 1982), and some potash amendment may be necessary, if vegetation productivity is constrained by K Soil analysis and trials with and without K amendment are recommended.

TABLE I4. Check list of some of the conditions which may need to be satisfied for the application of sewage sludge to the Gortmore tailings.

1. Explanation to, and consultation with, local community and neighbouring land-owners that sludge is being applied as an organic fertiliser for the grass cover, and not being dumped.
2. Preparation of a map of surface zones on the TMF where sludge application is permitted, avoiding Bryum/Festuca moss/grass areas, and areas adjacent to surface water flows, and marking of the boundary of these areas by posts.
3. Consultation with MWHB public health section as regards recommended application methods and weather conditions to reduce risk of aerosol production (pathogens) and odour.
4. Consultation with EPA as regards recommended application rates to reduce surface water pollution in discharge to Kilmastulla River.
5. Regular mean sludge analysis from each STP for the following parameters: Cu, Cd, Cr, Hg, Ni, Pb, Zn, pH, EC, total N, ammoniacal N, P. Also typical analysis of total and faecal coliforms.
6. Assessment of restrictions on application rates, according to above data, and the physico-chemical characteristics of the receiving tailings, soil or soil substitute, and equipment modifications for traffic on tailings.
7. Assessment of safety, adequacy and environmental compliance of transfer area and access roads for loading application machinery from haulage vehicles.
8. Health and safety assessment for personnel involved in transfer, application, supervision and post-application assessment; spillages notification procedures, etc.
9. Assessment of weather conditions restrictions before, after and during sludge application.
10. Monitoring of bird, fly and rodent use of site after sludge application, in case of queries from public relating to animal transfer of pathogens.
11. Assessment of requirements for integration with other aspects of TMF management and rehabilitation plan, e.g. lime application, bactericide application, etc.
12. Procedure to ensure proper supervision, records and soil and water monitoring.

It must be emphasised that the objective of sewage sludge application is long-term soil maintenance, and not waste disposal. Surface runoff from the tailings surface where sludge has been applied, carrying elevated nutrient and pathogen concentrations, will be intercepted by the wetland treatment systems designed to reduce metal contamination of discharge water. If applications are carried out on a 'little-and-often basis' under suitable weather conditions, and in permitted zones, then there should not be an significant additional nutrient or pathogen loading at discharge to the Kilmastulla River. Surface run-off may be beneficial for enhanced wetland plant growth in the tailings pond on the surface of the tailings. Vigorous plant growth should improve water treatment efficiency in this pond.

It is also essential to ensure that sludge is not applied to areas where the moss-grass ecosystem can develop. That moss has already succeeded from grass in these areas, despite fertilizer nutrient input, shows that grass alone is not the natural endpoint for these areas. It is not known, but very possible, that sludge application could degrade the moss cover.

7.11. **Vegetation monitoring**

A random stratified monitoring of small degrading patches of Agrostis stolonifera and *Festuca rubra*-dominated vegetation should be carried out, using sufficient replication, and associated basic soil chemical characterisation. Performance criterion should be no significant (>10%) mean loss of cover due to death of individual plants at the degraded patch margins, measured by occupancy quadrat subdivisions, and correlated with decrease in soil pH or increase in conductivity. In other words, the degraded patches should not be expanding. This monitoring should be carried out biennially for a period of 10 years.

Where the above performance criterion is not met, a contingency application of ground limestone and organic amendment should be applied to all small patches throughout the *Agrostis/Festuca* areas, and monitoring procedure recommenced, as above.

Where the above performance criterion is still not met after further monitoring, the contingency plan of capillary barrier plus soil and grass cover should be implemented on the patches as they arise, to include downslope drainage pathways if evident.

7.12. **TMF wind-breaks**

The creation of sections of hedgerow on the tailings has two potential advantages: (1) breaking up the visual monotony of the tailings surface vegetation when viewed from the proposed Mine Heritage Centre, and (2) decreasing prevailing wind fetch across the tailings surface. However, the cost of creating even a few sections of hedgerow, orientated SW-NE, composed of uncontaminated rubble and soil/soil substitute (c.2m base width and 1.2 height), and planted to hedgerow shrubs (e.g. hawthorn, blackthorn, gorse, briar) would be very expensive. However, lines of thin-soil cover supporting gorse could be established to visually simulate hedges, and to encourage ongoing development of gorse.

The area of willows on the south-west of the TMF provides important wind control on the most exposed and erosion susceptible slope of the TMF. These should be enhanced by further planting in this area. However, a maintenance access track will be required at the toe of the slope, and some trees may have to be removed to facilitate access. This should be minimal, and avoid individual trees which are making an important contribution to wind protection.

Lines of tall wind break trees also exist on the west side of the tailings. The longevity of these, and their replacement needs to be considered. Exposure to the south and east is significant, however, and it was from winds in these directions that dust blows occurred in 1984, 1985 and 1987. Natural willow and alder growth should be encouraged and integrated with two pedolocks and natural wetland to retain possible erosion from the TMF side walls. The prime function of tree growth will be for visual enhancement rather than preventing dust blow.

Overall, given the extra requirements of perpetual tree maintenance, other than natural willow or alder growth, it is probably preferable to deal with dust-blow prevention by tailings cover rather than by tree shelter belts.

7.13 **Perpetual after-care**

Following best-practice at other tailings facilities in Ireland, for example at the Lisheen Mine, a perpetual management plan is recommended for the Silvermines TMF. This plan will obviously need to be sufficiently flexible to deal with minor unforseen problems of vegetation management and ecological impacts, but a number of issues can be raised at this stage which the plan will need to address. Although it is unwise to attempt to predict the successional pathways that the vegetation cover will take, some possibilities can be examined at this stage. Like weather forecasting, the further one looks into the future, the less accurate the predictions become. However, a period of 1,000 years can be taken as a working period, although geomorphological issues are outside the scope of this report..

7.13.1. *Perpetual fertilizer application and surface drainage*

In terms of cost-benefit and sustainable management practices, the perpetual annual application of NPK fertilizer cannot be recommended unless self-sustaining alternatives cannot be found. Equally, perpetual surface drainage maintenance (to maintain dry grassland), other than for the main drain, is best avoided, and a vegetation cover tolerant of natural local surface-flooding is preferable.

7.13.2. *Thin soil cover on tailings*

A cover of gorse (*Ulex europaeus*) already occurs on a small soil covered part of the Gortmore tailings, near the impoundment wall. This is replacing a grass cover. At the soil-covered Avoca Mine Cu/pyrite tailings (Shelton Abbey near Arklow), gorse has dominated the cover replacing unmanaged grassland at the site. Similarly, at a trial plot of a thin (c. 0.3m) soil cover on HPDE liner at Avoca Mines, gorse has replaced a grass/herb cover. Gorse replacing grassland is to be expected on thin non-alkaline soil covers if they are used on the Silvermines tailings. Two questions arise: (1) What replaces gorse in the ecological succession? (2) What replaces gorse after a fire (accidental or deliberate).

Alder (Alnus glutinosa), willow (Salix spp.), and other trees readily replace gorse in a matter of 10-20 years where there is a nearby source for seeding. A soil cover of >1m is recommended for tree planting. Shallow rooted trees will be more susceptible to wind-throw. Thus, the implications of a thin soil cover may be the long-term control of trees before the reach maturity (by ring-barking, etc.) (see below).

7.13.3. *Moss cover on tailings*

Areas with the same species of moss (Bryum ?-pseudotriquetrum) that is establishing vigorous cover in patches on the Silvermines tailings, have been colonised at other tailings sites by birch (Betula sp.). As a soil organic layer builds up, eventual invasion by ash (Fraxinus excelsior) and sycamore (Acer pseudoplatanus), cannot be ruled out, but because of the exposure to wind, lack of nutrients, and thin soil cover, the first set of trees may remain stunted.

Neither is it possible to rule out localised peat formation, due to water retention, surface acidity and relatively high rainfall. If foci of peat develops, and Sphagnum mosses can establish independent of the metalliferous mineral layer beneath, then eventual horizontal spreading of peat foci may be possible. Peat bogs have formed over metalliferous geochemical anomalies elsewhere in Ireland.

7.12.4 *Tree Growth*

End-point patches of ash and sycamore or ombrotrophic bog may take hundreds of years, if they develop at all. The question is whether there are negative impacts associated with such endpoints. Will it be necessary, for instance, to control tree growth to avoid wind throw of susceptible stands of trees with shallow root-plates? Characteristically, the exposure of the tailings would be expected on the up-turned base of the root-plate. If many trees were blown over, could exposed tailings be blown from the root-plates to surrounding land? It is likely that the density of other vegetation at the time of possible wind blow of trees, will inhibit any dust blow.

Inevitable climate change, of course, whether natural or anthropogenic, will dictate the successional pathways.

7.14. **Preferred land use**

Because of the preference for long-term self-sustaining vegetation cover, with minimum maintenance requirements and costs, and in light of the considerations in section 3.9 above, the preferred land use will not be agriculture or forestry. Also, a land use specified for wildlife conservation may be contradictory, and perhaps in breach of the Wildlife Act, 1976, if birds were attracted into the tailings when there was a risk of their contamination by metals in toxic concentrations. Neither should the TMF be classed as derelict land, or abandoned land if subject to a fully implemented management plan. A land use definition that may be appropriate is *semi-natural pollution control*, where the beneficial use is pollution control, and the processes achieving that are natural, but receiving management intervention to enhance their contribution to pollution control. Wildlife and biodiversity benefits will certainly occur, but they will be secondary, as they are, for instance, on farmland with hedgerows.

All metalliferous tailings impoundments in the State, past, present and future, will have similar perpetual management administrative requirements, and final land-use prioritising pollution control. As the number of impoundments grows, it may be cost-effective to establish the equivalent of a National Tailings Trust, which administers the perpetual management funds necessary for their maintenance as pollution control facilities. Of most importance, in this regard, is the continuity of management at any one site, and the financial ability to deal with emergencies at any one site from aggregate capital reserves.

8. CONTAMINATED AGRICULTURAL LAND AND FARMLAND STREAMS

.8.1. **Agricultural grassland**

Some areas of improved agricultural grassland, used for pasture and for silage and hay production, are susceptible to flooding by streams draining from the mining and process areas. Other fields have been impacted by tailings dust (in the 1980s), and spreading of metal-contaminated drain spoil.

Definition of contamination of soil is usually in terms of action thresholds based on total metal concentrations, but this does not always equate with bioavailability. For instance, based on the Teagasc soil lead concentration data (DAFRD, 2000), many of the fields in the area, even away from the mine sites and Yellow River and its tributaries, could be considered contaminated because they exceed the 530 mg/kg Pb action threshold for soil (Dutch Ministry for Housing, Spatial Planning and Environment). The Dutch threshold limits were derived for particular circumstances in Holland and are known to be very conservative. They are mentioned here in the absence of threshold levels for Ireland. However, a working threshold value of 1,000 mg/kg has been adopted.

8.2. Field drainage and spoil disposal

The need for implementation of remedial measures in the shortest possible time-frame was emphasised by the IAG report (DAFRD, 2000).

Because of the legislative requirements which may apply to disposal of the mine wastes, it is possible that the rehabilitation works may be delayed until these requirements are met. In the meantime, there is an increasing risk of overflow of streams carrying sediment onto grassland soils. This is already happening in the Yellow River north of the road (Gorteenadiha), where a mid-channel bank of sand and gravel is causing deposition of sediment in a grassland field. There is also circumstantial evidence of increasing flooding in some fields, possibly due to a rise in groundwater levels since the Magcobar mine closure. This places further pressure on land-users to excavate field drains. But the disposal of both stream sediment and drain spoil remains a problem.

Recommendation 26 of the Inter-Agency Group (DAFRD, 2000) specifies that "Spoil from drainage and dredging works on the Yellow river and its tributaries should be fenced off and not spread over pastures". Field drains will have a relatively high proportion of organic matter, beneficial for soil recreation on tailings. Thus, the immediate implementation of drainage works on spring-fed field drains which do not contain elevated metals and its disposal as part of cover rehabilitation of the Gortmore tailings surface, appears to be beneficial (weather and soil conditions permitting). Drainage sediment containing elevated metals will also be beneficial due to the low metal content and high organic content. Deposition of all this material will require authorisation.

Excavation of drains and transport of material will require planning and management in terms of potential contamination of fields during material movement.

8.3. Contaminated topsoil as a source for rehabilitation cover

Existing contaminated topsoil on farmland is a burden on the value of the land, but is also sufficiently uncontaminated to support grassland. For the latter reason, it may be a valuable souirce of cover for the Gortmore tailings, which is already metalliferous grassland. If uncontaminated top-soil was used to back-fill excavated contaminated top-soil, rather than being used directly on the tailings, then two problems would be solved together. However, some excess peat from outside the area (e.g. if the N7 construction route proceeds and peat excavate is available) may be needed for efficiency (see Treacy and Timpson, 1999).

8.4. Stream and river sediments

The biological quality of the Kilmastulla, including salmon and trout populations, has improved since mine closure. However, the Yellow River drains from the mining areas and contains elevated metals in solution and presumably in suspension in times of high rainfall. All works to reduce metal loadings in the catchment, will provide continued improvement to the Kilmastulle River.

The Kilmastulla River system provides valuable spawning and nursery habitat for both salmon and brown trout (although it is not part of a designated salmonid water, under Freshwater Fish Directive (S.I. No. 84 of 1988)). Significant numbers of both species were recorded at the confluence of the Foilborrig River, upstream of both the Gortmore TMF and of the discharge of the Yellow River, in 1997 (Quirke, 1998). The Shallee River tributary is also valuable for trout (O'Reilly (1993), cited in Quirke, 1998). Biological quality of the Kilmastulla after confluence with the Silvermines River did not indicate serious pollution when measured during the 1990s (EPA data, in DAFRD, 2000), and salmon have returned to the latter river during the same period (surveyed by Mr Michael Murtagh). However, the Yellow River, draining both the Garryard and Shallee sites, has reduced biological quality indicating moderate toxic pollution, associated with elevated metal levels (DAFRD, 2000), confirmed by metal concentrations of aquatic crustaceans (McCarthy and Breen, 1999). The stream discharging from the Garryard tailings lagoon is the most seriously polluted, with elevated concentrations of arsenic, lead, cadmium and zinc (DAFRD, 2000). Other mine process pollutants, such as xanthates and cyanides, were attributed with pollution of the Kilmastulla during mine operation (Bracken et al., 1991); the current status of xanthates as contaminants in the stream system is not recorded. Sewage effluent was also recorded as a pollutant during mine operation in the early 1980s.

A noticeable feature of the biological quality data after mine closure (1982) is that the quality of the Kilmastulla at Cranna Bridge fluctuates, with toxic effects recorded in 1985, 1993, 1996 but not in 1983, 1987 and 1998 (EPA data, in DAFRD, 2000). The same data records toxic effects at further downstream stations on the Kilmastulla during 1993. The reason(s) for these fluctuations not clear, but disturbance of stream sediment and remobilisation of potentially toxic metals and other contaminants is the most likely cause either during sampling or due to flow conditions at the time. Equally, the future risk of downstream contamination by sediment disturbance cannot be under-rated, and has implication both for remedial works and a 'do-nothing' option.

The extent to which contaminated sediment exists downstream in the main channel river bed of the R. Kilmastulla is not clear. Gravel extraction has apparently occurred since mine closure in 1982. The bed of the Kilmastulla River (below confluence with the Yellow River) was found to be contaminated by lead and zinc, as insoluble precipitates, from the mine in 1975 (Western Health Board and Mogul of Ireland Ltd data from DMNR files). There was a subsequent tailings pipeline spillage into the river of October 1980, and downstream gravel extraction may re-suspend buried tailings and other contaminants.

A key issue is to protect the existing aquatic environment from contaminant loading during any upstream restoration work, whether that is in the mining areas or in the streams and drains. Although there is sediment containing elevated metals in the Kilmastulle River, the water quality downstream of the TMF does not reflect elevated metals. Removal of sediment beyond what is required for maintaining flow, may be counter productive.

Consideration could be given to excavating organic soil from the low lying, wet area to the south of the TMF between the TMF and railway line. This soil would be ideal for soil cover on the TMF or other remediation areas. The resulting ponds could be used as a polishing wetland for the Yellow River, as well as a settlement pond for suspended solids in times of high flow. This would require diverting the Yellow River, prior to its confluence with the Kilmastulle River, through the ponds.

Establishing part of the pond prior to carrying out remedial works and drainage works in the Yellow River catchment, could also provide protection to the Kilmastulle, against accidental release of metal bearing sediment during construction.

The ponds would be restored to a planted wetland after all works is complete.

This restoration scenario relies heavily on two features: (1) The creation of wetland vegetation cover; and (2) the use of gleys and drained fen peat soils as a potential source of soil or soil substitute covers. The development of any such wetlands will take time, and probably at least one year after planting will be necessary before they become fully functional, apart from their function as settlement ponds. Remedial works on waste areas (e.g. the Garryard stock-pile (spillages dump) and tailings lagoon (main settlement pond)) will require some form of remedial works water treatment to control local discharges. Surface run-off and percolate draining fresh waste exposed during remediation will probably carry a greater contaminant load than that currently existing. The potential ecological impact, and feasibility of alternatives, cannot be assessed until final design and construction requirements are known.

The sources of contaminant loading in the Yellow River are, in apparent order of importance: (1) The stream draining the Garryard tailings area; (2) The stream draining the old stockpile; (3) The stream draining the Shallee mine area, including the mixed waste dump; (4) The stream draining the old lead mine at Gorteenadiha; (5) The stream draining the old copper mine at Gorteenadiha; (6) The drainage from the Garryard mine settlement ponds. From the drainage outflow from the Garryard site to the Yellow Bridge, an artificial stream channel was been created separate from the Yellow River and its tributary draining the original Garryard site area. The earth dyke between this stream and the southern field drain has collapsed at a point roughly half way along this route. Similarly, the drainage from the spillages dump (old stockpile) follows an artificial route.

9. ECOLOGICAL RISKS OF REMEDIATION

9.1. Ecological risks

Examples of some ecological receptors that need to be taken into account during remedial works are listed in Table I5.

There are no areas designated, or proposed for designation, in the area of investigation, for species or habitats requiring legal protection (Special Conservation Areas (SACs), Special Protection Areas (SPAs), Natural Heritage Areas (NHAs), Statutory Nature Reserves) under the Habitats Directive (S.I. 94 of 1997), Birds Directive (various S.Is.) or Wildlife Acts (1976-2000). There is an SAC (no. 939) south of Silvermines village in the upland part of Silvermines, designated for *Nardus* grasslands and dry and wet heathlands, but this is some distance from, and upstream of, the mine sites. However, calaminarian grasslands (open semi-natural grasslands with a specialised flora on old terrils or spoil heaps around mines) are listed as a (non-priority) habitat for protection under the Habitats Directive, and some of the metal-tolerant vegetation which has naturally recolonised the old mine spoil areas should be botanically surveyed before being disturbed by rehabilitation works, especially if this is to form part of a nature trail for the Heritage Centre.

Wild fallow deer (*Dama dama*) use the area, and have access to the contaminated streams. A deer carcase was found on the Shallee mine site on 8 January 2002, the same day that recent tracks were observed through the stream draining the mixed waste dump area. While this individual could have died of other causes, deer fatalities due to lead toxicity in the area may be possible.

Unidentified species of bats have been recorded as using the underground workings at Shallee. Because bats are protected under the Wildlife Act, 1976, and Wildlife (Amendment) Act, 2000, before shafts and entrances into underground workings are sealed, it should either be demonstrated that there is no bat use of the workings in question, or grilles should be incorporated into sealed areas. The latter is standard practice at many mine sites in Cornwall and Wales. For further information, see McAney (1999).

9.2. Mitigation and monitoring

Before implementation of rehabilitation works, it needs to be established if an Environmental Impact Assessment is necessary for the works, or can be avoided, e.g. due to the exceptional circumstances of the site. In the absence of an EIS, consideration will need to be given to avoiding negative impact on the ecological receptors in the area, some of which have been referred to above.

Fencing off streams from deer, and use of entrance and exit grills for bats when sealing off shafts known to hold bat roosts, are examples of management which can successfully mitigate wildlife impacts of remedial works.

TABLE I5. Examples of ecological receptors, which could be potentially impacted by inappropriate remedial works in the Silvermines area.

Livestock	
Grazing cattle	(1) Increased contaminated sediment load from excavation of tailings or waste mounds bordering streams. (2) Increased heavy metal availability from excavated stream channels. (3) Increased heavy metal availability after traffic over contaminated pasture soils. (4) Tailings dust generated due to inappropriate cultivation of tailings surface.
Fish	
Salmon	Contamination of water in Kilmastulla River or Silvermines River, as a result of rehabilitation works.
Trout	Contamination of water in Kilmastulla River or Silvermines River, as a result of rehabilitation works.
Wildlife	
Bats	Sealing shafts providing access to roosts in abandoned mines or buildings.
Waterfowl	Lead toxicity due to use of metal-contaminated grit. (Ducks and swans).
Peregrine falcon	Disturbance of potential nesting areas in Magcobar open pit. (Peregrine falcons are protected under the Wildlife Act, 1976, and are a listed species in the Birds Directive,1979).
Badger	Setts disturbed during excavation of scrub areas. (Badgers are a protected species under the Wildlife Act, 1976).
Lampreys	Downstream section of Kilmastulla River (where it flows into the Shannon R.) is a spawning area for these species (Kurz and Costello, 1999).(Likely to be affected only in the case of severe accidental pollution event; the habitats of lampreys are protected under the Habitats Directive).
Habitats	
Metal-tolerant plant & soil communities	Destruction of recolonised habitat during rehabilitiation.

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APPENDIX H

HEALTH HAZARDS

IDENTIFICATION OF SPECIFIC POTENTIAL HEALTH HAZARDS

HUMAN HEALTH

Reference to Appendix A indicates that on the basis of soil, sediment and water geochemistry, a number of exceedences of Irish human health standards have been observed.

As a result a general overview of the human health risks associated with exposure to elevated levels of the following metals has been made.

- Aluminium (Al)
- Arsenic (As)
- Barium (Ba)
- Cadmium (Cd)
- Copper (Cu)
- Iron (Fe)
- Lead (Pb)
- Manganese (Mn)
- Mercury (Hg)
- Zinc (Zn).

Of these elements Cu, Fe, Mn and Zn are essential micronutrients for human health (i.e. a few mg of each are required every day). Nickel may also be a micronutrient, but the other elements are trace contaminants in human beings and exposure to elevated levels may prove toxic.

A brief summary of the health hazards for each element is presented below. This information has been collated from a number of sources including the

- *International Occupational Safety and Health Information Centre International Chemical Safety Cards*, an initiative of the United Nations Environment Program, the International Labour Office and the World Health Organization.
- Environment Agency Research and Development document CLR 10 an associated documents, particularly SGV1, SGV 3, SGV 10 and SGV 5. Department for Environment, Food and Rural Affairs. 2002.
- United States Environmental Protection Agency (USEPA) Preliminary Remediation Goals. (http://www.epa.gov/region09/waste/sfund/prg/)
- Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites. ANZECC / NHMRC Guidelines. 1992.

Aluminium (Al)

Aluminium is poorly absorbed and efficiently eliminated; however, when absorption does occur, Al is distributed mainly in bone, liver, testes, kidneys, and brain (ATSDR, 1990). Aluminium may be involved in Alzheimer's disease (dialysis dementia) and in Amyotrophic Lateral Sclerosis and Parkinsonism-Dementia Syndromes of Guam (Guam ALS-PD complex) (ATSDR, 1990; Goyer, 1991).

The respiratory system appears to be the primary target following inhalation exposure to Al. No decrease in reproductive capacity, hormonal abnormalities, or testicular histopathology was observed in male rats exposed to Al in drinking water for 90 days (Dixon *et al.*, 1979). However, male rats exposed to drinking water containing Al (as Al potassium sulphate) for a lifetime exhibited increases in unspecified malignant and non-malignant tumours (Schroeder and Mitchener, 1975), and similarly exposed female mice exhibited an increased incidence of leukaemia (Schroeder and Mitchener, 1975).

Occupational exposure limits:

10 mg/m³ (as metal dust)

Routes of exposure:

The substance can be absorbed into the body by inhalation.

Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly.

Effects of long-term or repeated exposure:

Lungs may be affected by repeated or prolonged exposure to dust particles. The substance may have effects on the nervous system, resulting in impaired functions.

Arsenic (As)

The toxicity of inorganic arsenic (As) depends on its valence state (-3, +3, or +5), and also on the physical and chemical properties of the compound in which it occurs. Trivalent (As^{+3}) compounds are generally more toxic than pentavalent (As^{+5}) compounds, and the more water soluble compounds are usually more toxic and more likely to have systemic effects than the less soluble compounds, which are more likely to cause chronic pulmonary effects if inhaled. It should be noted that laboratory animals are generally less sensitive than humans to the toxic effects of inorganic arsenic. In addition, in rodents the critical effects appear to be immuno-suppression and hepato-renal dysfunction, whereas in humans the skin, vascular system and peripheral nervous system are the primary target organs.

Water soluble inorganic arsenic compounds are absorbed through the gastrointestinal tract (>90%) and lungs; distributed primarily to the liver, kidney, lung, spleen, aorta, and skin; and excreted mainly in the urine at rates as high as 80% in 61 hr following oral dosing (U.S. EPA, 1984; ATSDR, 1989; Crecelius, 1977). Pentavalent arsenic is reduced to the trivalent form and then methylated in the liver to less toxic methylarsinic acids (ATSDR, 1989).

Epidemiological studies have revealed an association between arsenic concentrations in drinking water and increased incidences of skin cancers (including squamous cell carcinomas and multiple basal cell carcinomas), as well as cancers of the liver, bladder, respiratory and gastrointestinal tracts (U.S. EPA, 1987; IARC, 1987; Sommers *et al.*, 1953; Reymann *et al.*, 1978; Dobson *et al.*, 1965; Chen *et al.*, 1985, 1986). Occupational exposure studies have shown a clear correlation between exposure to arsenic and lung cancer mortality (IARC, 1987; U.S. EPA, 1991).

Occupational Exposure Limits:

0.01 mg/m³

Routes of exposure:

The substance can be absorbed into the body by inhalation of its aerosol and by ingestion.

Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly, when dispersed.

Effects of short-term exposure:

The substance irritates the eyes, the skin and the respiratory tract. The substance may cause effects on the gastrointestinal tract, cardiovascular system, central nervous system and kidneys, resulting in severe gastro-enteritis, loss of fluid, and electrolytes, cardiac disorders, shock, convulsions and kidney impairment. Exposure above OEL may result in death. The effects may be delayed. Medical observation is indicated.

Effects of long-term or repeated exposure:

Repeated or prolonged contact with skin may cause dermatitis. Repeated or prolonged contact may cause skin sensitisation. The substance may have effects on the mucous membranes, skin, peripheral nervous system, liver and bone marrow, resulting in pigmentation disorders, hyperkeratosis, perforation of nasal septum, neuropathy, liver impairment and anaemia. This substance is carcinogenic to humans. Animal tests show that this substance possibly causes malformations in human babies.

Environmental Data:

The substance is toxic to aquatic organisms. It is strongly advised not to let the chemical enter into the environment because it persists in the environment.

Barium (Ba)

The soluble salts of barium are toxic in mammalian systems. They are absorbed rapidly from the gastrointestinal tract and are deposited in the muscles, lungs, and bone. Barium acts as a muscle stimulant at low concentrations but at higher doses may affect the nervous system. Acute and subchronic oral doses can cause vomiting and diarrhoea, followed by decreased heart rate and elevated blood pressure. Higher doses result in cardiac irregularities, weakness, tremors, anxiety, and dyspnea. Death can occur from cardiac and respiratory failure. Acute doses around 0.8 grams can be fatal to humans.

In the Wones *et al* (1990*)* study, human volunteers were given barium up to 10 mg/L in drinking water for 10 weeks. No clinically significant effects were observed. An epidemiological study was conducted by Brenniman and Levy (1984) in which human populations ingesting 2 to 10 mg/L of barium in drinking water were compared to a population ingesting 0 to 0.2 mg/L. No significant individual differences were seen; although a significantly higher mortality rate from all combined cardiovascular diseases was observed with the higher barium level in the 65+ age group.

Subchronic and chronic inhalation exposure of human populations to barium-containing dust can result in a benign pneumoconiosis called "baritosis." This condition is also often accompanied by an elevated blood pressure. Exposure to an air concentration of 5.2 mg barium carbonate/m^3 for 4 hours/day for 6 months has been reported to result in elevated blood pressure and decreased body weight gain in rats (Tarasenko *et al*. 1977). Barium has not been evaluated by the USEPA for evidence of human carcinogenic potential (EPA 1995b).

Occupational exposure limits:

0.5 mg/m^3

Routes of exposure:

The substance can be absorbed into the body by ingestion.

Effects of short-term exposure:

The substance irritates the eyes, the skin and the respiratory tract.

Cadmium (Cd)

Cadmium is absorbed more efficiently by the lungs (30 to 60%) than by the gastrointestinal tract, the latter being a saturable process (Nordberg *et al.*, 1985). Cadmium is transported in the blood and widely distributed in the body but accumulates primarily in the liver and kidneys (Goyer, 1991). Cadmium burden (especially in the kidneys and liver) tends to increase in a linear fashion up to about 50 or 60 years of age after which the body burden remains somewhat constant. Metabolic transformations of Cd are limited to its binding to protein and non-protein sulfhydryl groups, and various macromolecules, such as metallothionein, which is especially important in the kidneys and liver (ATSDR, 1989). Cadmium is excreted primarily in the urine.

Occupational exposure limits:

0.05 mg/m ^{3} (as dust ppm)

Routes of exposure:

The substance can be absorbed into the body by inhalation of its aerosol and by ingestion.

Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly.

Effects of short-term exposure:

The substance irritates the eyes and the respiratory tract. Inhalation of fumes may cause lung oedema. The effects may be delayed.

Effects of long-term or repeated exposure:

Lungs may be affected by repeated or prolonged exposure to dust particles. The substance may have effects on the kidneys, resulting in proteinuria and kidney dysfunction. This substance is probably carcinogenic to humans.

Copper (Cu)

Copper can be absorbed by the oral, inhalation, and dermal routes of exposure. It is an essential nutrient that is normally present in a wide variety of tissues (ATSDR, 1990; U.S. EPA, 1987). In humans, ingestion of gram quantities of Cu salts may cause gastrointestinal, hepatic, and renal effects with symptoms such as severe abdominal pain, vomiting, diarrhoea, hemolysis, hepatic necrosis, haematuria, proteinuria, hypotension, tachycardia, convulsions, coma, and death (U.S. AF, 1990).
No suitable bioassays or epidemiological studies are available to assess the carcinogenicity of Cu.

Occupational exposure limits:

1 mg/m ^{3} (as Cu, dusts & mists).

Routes of exposure:

The substance can be absorbed into the body by inhalation and by ingestion.

Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly when dispersed.

Effects of short-term exposure:

Inhalation of fume may cause metal fever.

Effects of long-term or repeated exposure:

Repeated or prolonged contact may cause skin sensitisation.

Iron (Fe)

There is no health risk at the level found in water around Silvermines but levels of Fe above 1 mg/l can affect colour and taste.

Lead (Pb)

The efficiency of Pb absorption depends on the route of exposure, age, and nutritional status. Adult humans absorb about 10-15% of ingested Pb, whereas children may absorb up to 50%, depending on the source of Pb. More than 90% of Pb particles deposited in the respiratory tract are absorbed into systemic circulation. Inorganic Pb is not efficiently absorbed through the skin; consequently, this route does not contribute considerably to the total body Pb burden (EPA, 1986).

Lead absorbed into the body is distributed to three major compartments: blood, soft tissue, and bone. The evidence shows that Pb is a multi-targeted toxicant, causing effects in the gastrointestinal tract, hematopoietic system, cardiovascular system, central and peripheral nervous systems, kidneys, immune system, and reproductive system. Although similar effects occur in adults and children, children are more sensitive to Pb exposure than are adults. Irreversible brain damage occurs at blood Pb levels greater than or equal to 100 ug/dL in adults and at 80-100 ug/dL in children. Death can occur at the same blood levels in children. Children who survive these high levels of exposure suffer permanent severe mental retardation.

Occupational exposure limits:

0.15 mg/m ^{3}.

Routes of exposure:

The substance can be absorbed into the body by inhalation of its aerosol and by ingestion.
Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly.

Effects of short-term exposure:

The substance may cause effects on the gastrointestinal tract, blood, central nervous system and kidneys, resulting in colics, shock, anemia, kidney damage and encephalopathy. Exposure may result in death. The effects may be delayed. Medical observation is indicated.

Effects of long-term or repeated exposure:

The substance may have effects on the gastrointestinal tract, nervous system, blood, kidneys and immune system, resulting in severe lead colics, paralysis of muscle groups of the upper extremities (forearm, wrist and fingers), anemia, mood and personality changes, retarded mental development, and irreversible nephropathy. May cause retarded development of the new-born. Danger of cumulative effect.

Environmental data:

This substance may be hazardous to the environment; special attention should be given to air and water. In the food chain important to humans, bioaccumulation takes place, specifically in plants and water organisms, especially shellfish

Manganese (Mn)

Manganese is an essential trace element in humans that can elicit a variety of serious toxic responses upon prolonged exposure to elevated concentrations either orally or by inhalation. The central nervous system is the primary target. Initial symptoms are headache, insomnia, disorientation, anxiety, lethargy, and memory loss. These symptoms progress with continued exposure and eventually include motor disturbances, tremors, and difficulty in walking, symptoms similar to those seen with Parkinsonism. These motor difficulties are often irreversible. Based on human epidemiological studies, 0.8 mg/kg/day for drinking water exposure and 0.34 mg/m^3 in air for inhalation exposure have been estimated as lowest-observed-adverse-effect levels (LOAELs) for central nervous system effects.

Effects on reproduction (decreased fertility, impotence) have been observed in humans with inhalation exposure and in animals with oral exposure at the same or similar doses that initiate the central nervous system effects. An increased incidence of coughs, colds, dyspnea during exercise, bronchitis, and altered lung ventilatory parameters have also been seen in humans and animals with inhalation exposure. A possible effect on the immune system may account for some of these respiratory symptoms.

Occupational exposure limits:

0.2 mg/m ^{3}.

Routes of exposure:

The substance can be absorbed into the body by inhalation of its aerosol or fumes, and by ingestion.

Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly when dispersed.

Effects of short-term exposure:

Inhalation of dust may cause bronchitis and pneumonitis. The effects may be delayed.

Effects of long-term or repeated exposure:

The substance may have effects on the lungs and nervous system, resulting in bronchitis, pneumonitis, neurologic and neuropsychiatric disorders (manganism). Animal tests show that this substance possibly causes toxic effects upon human reproduction.

Mercury (Hg)

Absorption, distribution, metabolism, and excretion of Hg are dependent upon its form and oxidation state (ATSDR, 1989; Goyer, 1991). Organic mercurials are more readily absorbed than are inorganic forms. An oxidation-reduction cycle is involved in the metabolism of Hg and Hg compounds by both animals and humans (ATSDR, 1989). The urine and faeces are primary excretory routes. The elimination half-life is 35 to 90 days for elemental Hg and Hg vapour and about 40 days for inorganic salts (Goyer, 1991).

Ingestion of Hg metal is usually without effect (Goldwater 1972). Ingestion of inorganic salts may cause severe gastrointestinal irritation, renal failure, and death with acute lethal doses in humans ranging from 1 to 4 g (ATSDR 1989). Toxicity resulting from subchronic and chronic exposure to Hg and Hg compounds usually involves the kidneys and/or nervous system, the specific target and effect being dependent on the form of Hg (ATSDR 1989).

Occupational exposure limits:

0.025 mg/m^3 (skin).

Routes of exposure:

The substance can be absorbed into the body by inhalation of its vapour and through the skin, also as a vapour.

Inhalation risk:

A harmful contamination of the air can be reached very quickly on evaporation of this substance at 20°C.

Effects of short-term exposure:

The substance irritates the skin. Inhalation of the vapours may cause pneumonitis. The substance may cause effects on the central nervous system and kidneys. The effects may be delayed. Medical observation is indicated.

Effects of long-term or repeated exposure:

The substance may have effects on the central nervous system and kidneys, resulting in irritability, emotional instability, tremor, mental and memory disturbances, speech disorders. May cause inflammation and discoloration of the gums. Danger of cumulative effects. Animal tests show that this substance possibly causes toxic effects upon human reproduction.

Environmental data:

The substance is very toxic to aquatic organisms. In the food chain important to humans, bio-accumulation takes place, specifically in fish.

Zinc (Zn)

Zinc is an essential element with recommended daily allowances ranging from 5 mg for infants to 15 mg for adult males (NRC, 1989). Gastrointestinal absorption of Zn is variable (20-80%) and depends on the chemical compound as well as on Zn levels in the body and dietary concentrations of other nutrients (U.S. EPA, 1984).

Gastrointestinal upset has also been reported in individuals taking daily dietary Zn supplements for up to 6 weeks (Samman and Roberts, 1987). There is also limited evidence that the human immune system may be impaired by subchronic exposures (Chandra, 1984). In animals, gastrointestinal and hepatic lesions, (Allen *et al.*, 1983; Brink *et al.*, 1959); pancreatic lesions (Maita *et al.*, 1981; Drinker *et al.*, 1927a); anaemia (ATSDR, 1989; Fox and Jacobs, 1986; Maita *et al.*, 1981); and diffuse nephrosis (Maita *et al.*, 1981; Allen *et al.*, 1983) have been observed following subchronic oral exposures.

Occupational exposure limits:

Not established.

Routes of exposure:

The substance can be absorbed into the body by inhalation and by ingestion.

Inhalation risk:

Evaporation at 20°C is negligible; a harmful concentration of airborne particles can, however, be reached quickly when dispersed.

Effects of short-term exposure:

Inhalation of fume may cause metal fever. The effects may be delayed.

Effects of long-term or repeated exposure:

Contact with skin may cause dermatitis.

Measures to Reduce Potential Human Health Risks Associated with the Silvermines Area

The measures to reduce potential health risks are an integral part of the proposed remediation works for the Silvermines area and are encapsulated by the following:

1. Removal of the major sources of heavy metals comprising:

    - The tailings from the Garryard Lagoon
    - The waste from the Garryard Old Stockpile
    - The waste from Shallee South/East

    These will be removed to the Gortmore TMF and encapsulated, subject to permitting. If a permit cannot be obtained, the material will have to be sent off-site to a designated disposal area.

2. Treatment of stream flows.

    Flows to the Garryard tailings Lagoon area will be treated in an artificial wetland, and a second wetland will be established for the treatment of flows from Shallee South/East.

3. Prevention of dust

    The establishment of vegetation will be maintained to prevent dust blows from Gortmore TMF and other potential sources.

LIVESTOCK TOXICITY

The following is a general overview of the toxicological risks posed to livestock from exposure to the surface waters at the Silvermines project site. This preliminary assessment has focused on several key chemical elements identified during recent sampling activities.

The concentrations at which inorganic chemical constituents may render a water undesirable for use for livestock is subject to a number of variables, including animal age, sex, species, and physiological state; water intake, diet and its composition, the chemical form of the inorganic element of concern, and the temperature of the environment. Naturally, if livestock feed and water both contain a potentially toxic substance, this must be taken into account. Both short- and long-term effects and interactions with other ions or compounds must also be considered.

Available literature data, combined with an appropriate margin of safety for livestock that drink the waters and to humans who consumes the livestock or their products, were reviewed in order to derive the *Recommendations for Levels of Toxic Substances in Drinking Water for Livestock* (NAS, 1972). The inorganic chemical constituents of concern are compared to these recommended levels in the table below.

Constituent (mg/L)	**Silvermines Surface Water Concentrations (Total)**				**Recommendations for Levels of Toxic Substances in Drinking Water for Livestock** [a]
	GAR 18	GAR 15	GAR 16	01SW4	
Al	3.16				5.0
As	0.06				0.2
Ba		0.19		0.12	No data
Cd				0.02	0.05
Cu		0.37			0.5
Fe	0.26		< 0.05	2.7	No data
Pb	**0.12**	**0.32**	**0.16**	**0.38**	0.1
Mn			0.11	0.2	No data
Hg					0.01
Sulphate (SO_4)	594		369		1,000
Zn		15.99		4.8	24

a – Recommendations published in: Ayers, R.S. and D.W. Westcot. 1976. *Water Quality for Agriculture*. Irrigation and Drainage Paper. Food and Agriculture Organization (FAO) of the United Nations. Date originally presented in: Environmental Studies Board. National Academy of Sciences/National Academy of Engineering. 1972. *Water Quality Criteria*. Prepared for the U.S. Environmental Protection Agency.

b – Lead is accumulative, and problems may begin at thresholds of 0.05 mg/L.

Aluminium

The occurrence of soluble Al in surface waters at concentrations greater than 3 mg/L is rare due to its high tendency to precipitate as the hydroxide (Kopp and Kroner, l970). Most edible grasses contain about 15 and 20 mg/kg of the element. However, there is no evidence that it is essential for animal growth, and very little is found deposited in animal tissues (Underwood, 1971). Aluminium is not considered to be highly toxic (McKee and Wolf, 1963; Underwood, 1971), but Deobald and Elvehjem (1935) found that a level of 4,000 mg Al per kilogram of diet caused phosphorus deficiency in chicks. Its occurrence in water should not cause problems for livestock, except under unusual conditions and with highly acid waters, which will tend to keep the Al in solution at elevated concentrations. Livestock should be protected where drinking waters contain more than 5 mg/L Al.

Arsenic

Arsenic is present in all living tissues in inorganic and certain organic forms. While it may be more commonly regarded as a poison, arsenic has been used medicinally, and is even accepted as a safe feed additive for certain domestic animals. It has not been shown to be a required nutrient for animals, possibly because its ubiquity has precluded the compounding of deficient diets (Frost, 1967).

The toxicity of As depends largely on its chemical form. Inorganic oxides of As are generally considered to be more toxic than organic forms occurring in living tissues or used as feed additives. Differences in toxicities of the various forms are clearly related to the rate of their excretion, the least toxic being the most rapidly eliminated (Frost, 1967; Underwood, 1971).

Wadsworth (1952) gave the acute toxicity of inorganic As for farm animals as follows: poultry, 0.05-0.10 g per animal: swine, 0.5-1.0 g per animal: sheep, goats, and horses, 10.0-15.0 g per animal: and cattle, 15-30 g per animal. To provide the necessary caution, and in view of available data, an upper limit of 0.2 mg/L of As in water was recommended.

Cadmium

Cadmium is normally found in natural waters at very low levels. Research suggests that Cd is not an essential element. It is, on the other hand, quite toxic. Because of the accumulation and retention of the element in the liver and kidney, it was recommended that a limit of 0.10 mg/L, or preferably less, be used for drinking waters.

Parizek (1960) found that a single dose of 4.5 mg Cd/kg of body weight produced permanent sterility in male rats. At a level of 5 mg/L in the drinking water of rats (Schroeder *et al.*, 1963a) or mice (Schroeder *et al.*, 1963b), reduced longevity was observed. Intravenous injection of Cd sulphate into pregnant hamsters at a level of 2 mg Cd/kg of body weight on day eight of gestation caused malformations in the foetuses (Mulvihill *et al.*, 1970).

Miller (1971) studied Cd absorption and distribution in ruminants, such as cattle. He found that only a small part of ingested Cd was absorbed, and that most of what was absorbed went to the kidneys and liver. Once absorbed, its turnover rate was very slow. The cow is very efficient in keeping Cd out of its milk, and Miller concluded that most major animal products, including meat and milk, seemed quite well protected against Cd accumulation.

From the available data on the occurrence of Cd in natural waters, its toxicity, and its accumulation in body tissues, an upper limit of 0.05 mg/L allows an adequate margin of safety for livestock and human consumers.

Copper

Copper is an essential trace element. The requirement for chicks and turkey poults from zero to eight weeks of age is 4 ppm in the diet (NRC, 1971). For beef cattle on rations low in molybdenum and sulphur, 4 ppm in the diet is adequate; but when these elements are high, the Cu requirement is doubled or tripled (NRC, 1970) A dietary level of 5 ppm in the forage is suggested for pregnant and lactating ewes and their lambs (NRC, 1968b). A level of 6 ppm in the diet is considered adequate for swine (NRC, 1968a).

Swine are apparently very tolerant of high levels of Cu, and 250 ppm or more in the diet have been used to improve liveweight gains and feed efficiency. On the other hand, sheep were found to be very susceptible to Cu poisoning (Underwood, 1971), and for these animals, a diet containing 25 ppm was considered toxic. About 9 mg per animal per day was considered the safe tolerance level.

There is limited empirical data on the effects of Cu in the water supply on animals, and its toxicity must be judged largely from the results of trials where Cu was fed to animals. The element does not appear to accumulate at excessive levels in muscle tissues, and it is very readily eliminated once its administration is stopped. While most livestock tolerate rather high levels, sheep do not. Therefore, it was recommended that the upper limit for Cu in livestock waters be 0.5 mg/L.

Lead

A nutritional need for Pb by animals has not been demonstrated, but its toxicity is well known. A rather complete review of the matter of Pb poisoning by McKee and Wolf (1963) suggested that for livestock, the toxicity of the element had not been clearly established from a quantitative standpoint. It has been difficult to establish clearly at what level of intake Pb becomes toxic, although a daily intake of 6 to 7 mg Pb/kg of body weight has been suggested as the minimum that eventually gave rise to signs of poisoning in cattle (Hammond and Aronson, 1964). Apparently, cattle and sheep are considerably more resistant to Pb toxicosis than are horses, being remarkably tolerant to the continuous intake of relatively large amounts of the element (Hammond and Aronson, 1964; Garner, 1967; Aronson, 1971; NRC, 1972). However, there is some tendency for it to accumulate in tissues and to be transferred to the milk at levels that could be toxic to man (Hammond and Aronson, 1964).

There is some agreement that 0.5 mg/L of Pb in the drinking water of livestock is a relatively safe level (McKee and Wolf, 1963), and the findings of Schroeder (1963, 1964, 1965)and his associates with laboratory animals are in agreement with this. Based on these observations, and the information concerning the chronic toxicity of Pb, its apparent role in reducing disease resistance, an upper limit of 0.1 mg/L for Pb in livestock waters was recommended.

Mercury

Natural waters may contain mercury originating from anthropogenic sources or from naturally occurring geological stores. Mercury in solution tends to adsorb readily onto a variety of materials, including the bottom sediments of streams, greatly reducing the levels that might otherwise remain in solution.

Mercury is not essential to animal nutrition and is not readily absorbed. Inorganic Hg salts may be divalent (mercuric) or monovalent (mercurous). Gastrointestinal absorption of inorganic salts of Hg from food is less than 15 percent in mice and about 7 percent in a study of human volunteers, whereas absorption of methyl Hg is on the order of 90 to 95 percent. In comparison to the relative instability of organic compounds such as salts of phenyl Hg and methoxyethyl Hg, alkyl Hg compounds, including methyl Hg, have a high degree of stability in the body resulting in an accumulative effect. This relative stability, together with efficient absorption in the gut, contributes to the somewhat greater toxicity of orally administered methyl Hg as compared to poorly absorbed inorganic Hg salts (Swensson *et al.*, 1959). Brain, liver, and kidney were the organs that accumulated the highest levels of Hg, with the distribution of methyl and other alkyl Hg compounds favouring nerve tissue and inorganic Hg favouring the kidney (Malishevskaya *et al.,* 1966; Platonow, 1968; Aberg *et al.*, 1969).

In cattle and sheep, dietary intake of 0.2 mg/kg Hg will cause uncoordination, unsteady gait, and eventual death. Mortality in poultry begins with Hg levels of 5.0 ppm.

Zinc

Zinc is relatively nontoxic to animals. Swine have tolerated 1,000 ppm of dietary Zn, while 2,000 ppm or more have been found to be toxic (Brink *et al.*, 1959). Similar findings have been reported for poultry where Zn was added to the feed. Adding 2,320 mg/L of the element to water for chickens reduced water consumption, egg production, and body weight. After Zn withdrawal, there were no symptoms of toxicity in chickens (Sturkie, 1956). In a number of studies with ruminants, Ott *et al.* (1996) found Zn added to diets as the oxide to be toxic, but at levels over 500 mg/kg of diet.

While an increased Zn intake resulted in a corresponding increase in Zn in body tissues, the tendency for accumulation was not significant, and tissue concentrations decreased rapidly once Zn dosing was suspended. Zinc is a dietary requirement of all poultry and livestock. There is no established requirement for ruminants, but Zn deficiencies were reported in cattle grazing forage with Zn contents ranging between 18 and 83 ppm (Underwood, 1971). There is also no established requirement for sheep, but lambs fed a purified diet containing 3 ppm of the element developed symptoms of a deficiency that were prevented by adding 15 ppm of Zn to the diet. Based on the low toxicity of Zn and its requirement by most animals, a limit in livestock waters of 25 mg/L is considered to have a large margin of safety.

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APPENDIX I

REMEDIATION ASSESSMENT

TABLE I1 : SUMMARY OF REMEDIAL OPTIONS AND COSTS

Items in bold are the preferred options. (NR = not required; NC= not costed)

AREA	**SITE**	**REMEDIAL OPTIONS**	**COST (Euro s)**
Ballygown	School Playing Field	NR	NR
	Village Field	**1. Cover**	**52,819**
		2. Drainage	**1,610**
		3. Remove stream sediment	NR
	Open Cast	1. Partial re-shaping	4,830
		2. Fence and sign	1,610
		3. Backfill	**8,050**
	Sulphur Mine	1. Cap shafts	NR
		2. Backfill shafts	**3,381**
		3. Fence shafts	**1,052**
	Shafts	1. Fence and sign	**NC**
		2. Capping	NR
		3. Survey and pressure relief	**14,490**
		4. Backfilling	**4,830**
	Underground Mine	NR	NR
	Mine Water Discharge	**1. Silt Trap**	**6,118**
	Waste materials	1. Remove wastes	NR
		2. Partial waste removal	32,460
		3. Gabion protection	**29,000**
		4. Cover	80,500
		5. Intercept run-off	**6,120**
		6. Signs	**3,220**
		7. Remove old tailings N of village	212,440
		8. Fence old tailings N of village	**2,400**
	Mine Buildings	1. Use for livestock	NR
		2. **Conserve Waeltz plant footprint**	**72,730**
		3. Restore Waeltz plant	160,000
		4. Conserve Furnace/Engine House	**15,460**
Magcobar	Open Pit Stability	**1. Signs and Fence**	**12,120**
		2. Backfill	10,000,000
		3. Remove some waste rock and re-profile	193,000
	Subsidence	1. Fencing	Included above
		2. Backfill small sinkhole	**740**
	Pit Lake	**1. Fencing**	**Included above**
		2. Treat in-situ	350,000
		3. Pump and treat capital	800,000
		Operate/yr	160,000
	Old Mine Remains	**1. Fence and sign**	**8,835**
	Visual	**1. Fence to prevent removal of waste rock**	**Included above**
		2. Re-profile	**30,000**
		3. **Dump revegetation**	**25,000**
	Rock Dump Stability	**1. Fencing**	**Included above**
		2. Re-contour slopes	18,000
		3. Remove for fill (progressive)	NC
		4. Maintain stream diversion	**Included above**
	Sulphide Deposits	**1. Consolidate materials**	**4,830**
		2. Cover	**8,920**
		3. **Drainage**	**4,000**
	Mine Buildings	**1. Demolish Plant**	**11,300**
	Settlement Lagoons	**1. Install fence and maintain lagoons**	**1,600**
		2. Backfill lagoons and restore channel	700
Garryard	Settlement Pond	2. Remove material	100,000
		3. Cover	80,000
		4. Drain for treatment	NC
		5. Wetland development	**4,830**
		6. Drain to constructed wetland	NC
		7. Improve fencing	**1050**

	Tailings Lagoon	1. Place cover **2. Remove material** 3. (Contingency) 4. Re-process material 5. Drain to constructed wetland **6. Drainage control** **7. Wetland on site**	410,000 **215,000** 161,000 NC NC **8,000** **453,000**
	Main Shaft	**1. Sign** 2. Drainage	NC
	Underground Mines	**1. Fencing** 2. Backfill **3. Drainage**	**9,400** NC **6,800**
	Old Stockpile	**1. Treat run-off** 2. Cover 3. **Remove Material and restore** - Contingency	**8,000** 180,000 **205,000** 193,000
	Plant site and buildings	1. Remove buildings 2. Retain buildings and site investigation **3. Improve site drainage and treat contaminated areas** **4. Remove Hostel and rehabilitate**	330,000 33,000 **30,000** **23,000**
Gorteenadiha	Mining Heritage	**1. Fencing** **2. Archaeological survey**	**2,415** **8,000**
	Waste Dumps	1. Cover **2. Signage** **3. Drainage and fencing (including gabion wall)** 4. Integrated drainage (contingency)	33,000 **800** **26,000** 15,000
	Open Workings	**1. Fence and signs** **2. Backfilling shafts** 3. **Drainage**	**Included above** **3,500** **Included above**
Shallee	Open Pits – Water Toxicity	None	None
	Open Pits – Scrap and Waste	**Scheduled with waste dumps**	
	Open Pits – Safety	1. Backfill / re-profile **2. Clear vegetation and fence**	NC **48000**
	Shafts	**1. Fence off** 2. Cap (contingency) **3. Safety grill**	**3,400** 12,880 **3,300**
	5.3 Subsidence / Collapse	**1. Fence and sign** 2. Controlled collapse	**Included with open pit costs** NC
	5.3 Safety	**1. Fencing** 2. Rock support	**Included with open pit costs** NC
	5.3 Underground Water Contamination	**1. Intercept and treat in wetland** **2. Divert surface water**	**483,000** **1,810**
	5.4 Tailings : Dust	**1. Cover** **2. Revegetation** 3. Fencing 4. Monitoring and contingency	**13,000** Included above Included above Maintain existing monitoring cost
	5.4 Tailings : Stability	None	No Cost
	5.4 Tailings : Leaching	**1. Cover** **2. Drain to wetland** **3. Revegetate**	**Included in dust** **Included in dust** **Included in dust**
	5.5 Waste Dumps (inbcluding	**1. Integrated drainage**	**Included above**

	Drum dump)	**2. Drainage to wetland** **3. Remove material**	**Included above** **168,420**
	5.6 Mine Buildings	1. Remove buildings **2. Conserve heritage**	NC **305,900**
	5.7 Water Reservoir	**1. Fence**	**4,200**
	5.8 Shallee West safety	1. Backfill 2. Clear vegetation **3. Fence**	NC With 5.9 **6,038**
	5.9 Shallee West Waste Dumps	**1. Backfill waste**	**3,220**
Gortmore TMF	6.1 Dust	1. Signage **2. Improve vegetation** 3. Engineered Cover 4. **Monitoring (5 years)**	Included in 6.3 **622,000** 6,393,500 **20,000**
	6.2 Visual	**1. Revegetate crests** 2. **Tree screen**	**8,300** **81,000**
	6.3 Leaching	**1. Access for animals** **2. Monitoring** 3. Treatment plant **4. Toe wetlands** **5. Information signs**	**Policing** **16,000** NC **With 6.4** **1,600**
	6.4 Erosion	**1. Access for animals** **2. Vegetation cover** **3. Sediment traps** 4. **Monitoring**	**Policing** **With 6.1** **9,390** **with 6.1**
	6.5 Instability	1. Push down slopes 2. **Maintain surface drainage** 3. **Monitoring**	NR **Included with 6.1 and 6.6** **Included with 6.1 and 6.6**
	6.6 Tailings pool	1. Treat water 2. Drain and backfill **3. Upgrade decant** 4. **Prevent access**	NC 66,000 **31,500** **Policing**
	6.7 Retention Ponds	1. Treat water 2. Drain and backfill **3. Upgrade wetland** 4. **Signage**	NC NC **3,220** **Included in 6.3**
	6.8 Delivery Pipeline	None	None
	6.9. Waste disposal site	**1. Liner, topsoil and access road**	**283,000**

NOTE: In some cases costs are consolidated and will therefore not agree with those derived in Phase 3.

I.2 BALLYGOWN AREA (REFER TABLE 14.2)

I.2.1 School Playing Field

Analyses of sediment from the Silvermines school play area (DAFRD 2000), showed levels of lead (Pb), zinc (Zn), cadmium (Cd) and copper (Cu) in excess of prescribed standards i.e. Statutory Instrument No. 294 of 1989 (*ibid.*).

Recorded levels of Pb were in the range of 2,301 mg/kg to 37,850 mg/kg (*ibid.*). The pattern for Zn was similar to that for Pb.

There was immediate concern at the high levels and the field has now been remediated with a limestone ground layer overlain by 1m of borrow material (from 10 km away) and finally grassed. The work was carried out in 2000 and is now in use.

The following assessment is based on the remediated site.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Contaminated soil: Human toxicity.
(b) Contaminated soil: Decreased receiving stream water quality.

ASSESSED RISK (LIKELIHOOD x CONSEQUENCE)

(a) Contaminated soi1: human toxicity

The *likelihood* of toxicity event occurring was assessed as *low*, based on the cover over the original material and the fact that blood Pb concentrations of people in Silvermines Village were not raised despite possible exposure prior to remediation.

The *consequence* for human toxicity from contaminated sediments in the Village playing field was assessed as *low* due to very low possible exposure from this site.

The assessed risk is Lp x Lc = Low risk.

No remedial actions are required.

(b) Contaminated soil: decreased stream water quality

The *likelihood* of contaminated sediments migrating from the playing field to the tributaries of the Silvermines River was assessed as *low*.

The *consequence* of decreased stream water and sediment quality as a result of migration of sediment from the Village playing field to the tributaries of the Silvermines River was assessed as having *low* significance, given the ambient quality of the water and the very low levels of metals which could arise from the site.

The assessed risk is Lp x Lc = Low risk.

No remedial actions are recommended.

NOMINATED END USE

The nominated end use is a school playing field.

REMEDIATION OPTIONS CONSIDERED

None.

RECOMMENDED ACTIONS

None.

I 2 BALLYGOWN AREA (REFER TABLE 14.2)

I.2.2 Village Field

Based on the findings of analyses of sediment from the Silvermines school play area (DAFRD 2000) and the samples of the same waste material taken in the adjacent fields (Section 7.2.3), the Village playing field material has been assumed to be of a similar geochemical character with levels of lead (Pb), zinc (Zn), cadmium (Cd), Arsenic (As) and copper (Cu) in excess of prescribed standards i.e. Statutory Instrument No. 294 of 1989 (*ibid.*).

It is understood that the field is not used as present due to the poor surface and lack of grass cover. It is clear that some of the waste is acid generating. If it were decided that the field is to be used in the future remedial work would be required in the form of a soil cover.

The following is based on the nominated end land-use as a village playing field.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Contaminated soil: Human toxicity.
(b) Contaminated soil: Decreased receiving stream water quality.

ASSESSED RISK (LIKELIHOOD x CONSEQUENCE)

(a) Contaminated soi1: human toxicity

The *likelihood* of toxicity event occurring was assessed as *low*, based on the findings of a number of studies summarised in DAFRD (2000). Evidence has been identified of lead ingestion by children via the soil-dust-hand/mouth pathway, however it was found that blood Pb concentrations of people in Silvermines Village were not raised. The conclusion was that low solubility of Pb might have contributed to low human bioavailability of soil Pb. It is recognised that bioavailability is not necessarily a consideration of potential impact.

Other metals were not assessed in the IAG study so there is no report on blood levels apart from Pb. Cd and Zn can cause health problems by long term inhalation or ingestion (Appendix F), in a similar way to lead.

The *consequence* for human toxicity from contaminated sediments in the Village playing field was assessed as *high*. The principle route of human exposure to Pb is food, but it is usually environmental sources that produce excess exposure (US National Parks Service [US NPS] 1997). Primary sources include Pb in air from combustion, Pb-based paints, hand-to-mouth activities of children living in contaminated areas (*ibid.*).

If released or deposited on soil, Pb will be retained in the upper 2 - 5cm of the soil particularly soils with greater than 5% organic matter or a pH 5 or above. The US EPA has set a National Generic Soil Screening Level (SSL) of 400mg Pb/kg soil for the ingestion pathway. The US NPS also note that human risk management criteria, developed by the US Bureau of Land Management (1995), for children living adjacent to contaminated sediments for Pb is also set at 400mg/kg.

The assessed risk is Lp x Hc = medium risk. Therefore it has been determined that remedial actions are required.

(b) Contaminated soil: decreased stream water quality

The *likelihood* of contaminated sediments migrating from the playing field to the tributaries of the Silvermines River was assessed as *high*.

The *consequence* of decreased stream water and sediment quality as a result of migration of sediment from the Village playing field to the tributaries of the Silvermines River was assessed as having *low* significance, given the ambient quality of the water and the small area relative to the remaining area of source material.

This assessment was based on the results of Irish EPA monitoring of stream water and sediments in 2000, which indicated increased levels of Pb, Cd, Zn and Fe downstream of the playing fields.

The assessed risk is Hp x Lc = medium risk. However, relative to the area of exposed waste at Ballygown, specific remedial works to reduce the risk here are not recommended. There will be a beneficial improvement if remedial works are carried out to reduce the risk of ingestion as described in 1(a) above.

NOMINATED END USE

The nominated end use for the Village playing field is a recreational area or derelict land.

End use compliance criteria are to be developed and would normally be integrated with the monitoring needs following remediation works in the general area.

Post-remediation monitoring of stream water and sediment quality would be required over 3 years and would be part of a regional monitoring programme.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for Pb concentrations in soil (DAFRD 2000). However, given that the high consequence of human toxicity and the high likelihood of stream water and sediment quality deterioration as a result of the soils of the Village playing field and the surrounding area, some remedial actions are deemed necessary to achieve compliance with the nominated end land use. A critique of the remedial options considered is as follows.

(i) Placement of Appropriate Cover on Village Field

The objectives of covering the playing field are to:

- significantly reduce the potential for physical contact with contaminated soils;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

This topsoil would then be seeded to grass, but the quantity of the grassing and subsequent maintenance would be subject to after use requirements.

To achieve these objectives approximately 1500 m^3 of suitably benign material would be required to provide a cover of no less than 0.2 m across the field.

Suitable borrow material could be obtained from the M7 road construction or a site to be identified equating to a haulage distance of around 10 km.

A 150 mm layer of limestone aggregate should be placed over the existing surface to provide under-drainage for the field and to provide alkalinity to help 'fix' metals. This could be obtained from Magcobar. Approximately 1900 m^3 would be required at a haulage distance of 2 km.

The total cost would be €52,819.

(ii) Drainage Works

Lateral drainage channels exist but would require improvement by excavation and placement of some limestone aggregate in the bottom of the channel.

The cost of this would be €1,610.

(iii) Partial Removal of Contaminated Sediment from the Receiving Stream

The objective of removing contaminated sediment from portions of the receiving stream is to eliminate or significantly reduce the potential for re-suspension of heavy metals within stream sediments. Appropriate erosion and sediment control works would also be required for this option.

The contribution to the stream from the playing field will be relatively small and such work would be done as part of a remediation plan for the area and not specifically for the playing field.

(iv) No Specific Action

No specific action is required if it is to be left as derelict land, except to provide information signs**.**

RECOMMENDED ACTIONS

It is recommended that remediation options (i) and (ii) be adopted. Contingency planning should include the use of soil amelioration and growth additives to encourage re-vegetation. Some institutional controls may be required to manage use and maintenance.

Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Identify cover material source(s), confirm haul distances and costs;
- Draft a conceptual integrated erosion and sediment control plan;
- Confirm extent of drainage works required and costs;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (cover material geochemistry, receiving stream water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

Capital Works : €54,430.

I.2.3 OPEN CAST

As noted in the Phase I report the open pits of the Silvermines area do not pose a major hazard, based on the relatively small-scale nature of the open pits.

The following refers to the main open pit and not to the arcuate shaped pit. The latter poses no danger and can be left as part of a derelict mining landscape. (Refer Figure 3.1)

The main pit intersects groundwater and has a permanent water filled sump sometimes used for domestic waste disposal.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Open pit (stability): Danger to humans & livestock/wildlife;
(b) Open pit (leaching metal): Human toxicity;
(c) Open pit (leaching metal): Livestock toxicity;
(d) Depth of water.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Open Pit Stability

The *consequence* of the open pit at the Ballygown area representing a danger to humans and livestock/wildlife was assessed as *low* based on the physical dimensions of the void and hence the minor nature of associated possible dangerous situations.

The *likelihood* of the pit being a danger to humans and livestock/wildlife was assessed as *low* given the relative inaccessibility of the area and the lack of human and/or livestock contact with the open pit.

The assessed risk is Lc x Lp =Low risk.

Notwithstanding it has been determined that some remediation actions are required.

(b) Open Pit Leaching : Human Toxicity

The *consequence* of the pit wall generating leaching products that are toxic to humans was assessed as *low*.

The *likelihood* of a human toxicity event as a result of pit wall leaching was assessed as *low* given the physical dimensions of the pit (and hence the extent of leaching possible) and the relative inaccessibility of the area and the lack of human contact with the open pit.

The assessed risk is Lc x Lp = Low risk.

Therefore no specific remediation actions are required.

(c) Open Pit Leaching : Livestock Toxicity

The *consequence* of the pit wall generating leaching products that are toxic to livestock was assessed as *low*.

The *likelihood* of a livestock toxicity event as a result of pit wall leaching was assessed as *low* given the physical dimensions of the pit and the relative inaccessibility of the area and the lack of livestock contact with the open pit.

The assessed risk is Lc x Lp = Low risk.

Therefore no specific remediation actions are required.

(d) Depth of Water (Human and Livestock Drowning)

The consequence of drowning must be assessed as high. The likelihood is low given the shape, depth of water and limited access.

The assessed risk is Hc x Lp = Medium risk.

Some remediation should be considered.

NOMINATED END USE:

The end use for the area of the Ballygown open void is a Pit Lake or as backfill to derelict land.

End use compliance criteria are to be developed and would be based on geotechnical stability pit water quality and safety.

REMEDIATION OPTIONS CONSIDERED

Irish legislation pertinent to disused quarries (i.e. *Mines and Minerals Act 1931* and the *Mines and Quarries Act 1965*) appears to make no specific reference to completed open pit wall stability.

Nevertheless a critique of the remedial options considered in terms of open pit wall stability is presented below.

(i) Partial Re-shaping and Stabilise Open Pit Wall Slopes

The objective of stabilising the open pit wall would be to limited the potential for pit wall failure.

The most practical stabilisation techniques would be controlled slope reduction works by re-profiling the waste materials on the crest and the pit sides by partial backfill.

Reprofiling would necessitate movement of approximately 2,000m^3 of material from waste around the open pit at a total cost of €4,830. Alternatively, the pit could be used to dispose of concrete from the Waeltz plant and covered with local waste to profile and vegetated with local shrubs (gorse).

(ii) Institutional Controls

The objective of opting for institutional controls would be to restrict and control public and livestock access to the open pit area. Institutional controls typically focus on fencing and signage. The perimeter of the open pit is approximately 150 m and would be required to be fenced and appropriate signage erected.

Costs associated with fencing and signage would be in the vicinity of €1,610.

(iii) Backfilling

The objective of backfilling the open pit would be to eliminate issues associated with an open void and to use the void space for disposal of suitable material, cover and revegetate with local species.

The source of material would be based on a re-profiling of the surrounding waste dumps.

The costs for backfilling with local material, re-profiling and vegetating would be €8,050.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use(s);
- findings of void hydrology/hydrogeology studies;
- availability of borrow material;
- geotechnical assessment;
- associated cost estimates

It is recommended that remediation option (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Identify suitable backfill material;
- Survey waste material to be re-contoured and costs;
- Develop a re-contouring plan including nomination of slope gradients, stockpile heights and drainage features;
- Specify revegetation plans;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Integrate with remediation actions for other areas in the vicinity;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €8,050.

I.2.4 SULPHUR MINE

INTRODUCTION

There are two open shafts in the Sulphur Mine open pit. They are fenced but the fences are in poor condition. There are two backfilled shafts, one of which shows signs of subsidence. There are two adits in the hangingwall, one of which has overhanging, dangerous rocks. The hanging wall is a near vertical rock face up to 15m high in places.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Shafts: Danger to humans & livestock/wildlife.
(b) Rock face : Danger to humans and livestock.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Shafts and Adits : Danger to Humans/Livestock

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as medium. Two shafts are open but access is limited.

The consequence of the underground workings in terms of a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the shafts.

The assessed risk is Mp x Hc = High risk.

Therefore it has been determined that remediation actions are required.

(b) Rock Face : Danger to Humans and Livestock

The consequence is assessed as medium and the likelihood is low due to the presence of a fence and trees along the crest of the face and access only through a farm field.

The assessed risk is Mc x Ll = Low risk.

No remedial work is required.

NOMINATED END USE;

The nominated end use for the area of the underground workings is rough grazing; controlled public use; and/or derelict land. Controlled public use would be based on using the site for educational interest.

End use compliance criteria are to be developed and would be based on geotechnical stability verification of any areas proposed for human and livestock access, as well as structural survey of any potentially affected dwellings.

Routine post-remediation monitoring of subsidence and shaft stability would be required over 4 years.

(i) Capping of Shafts

The main objective of this option is to eliminate the potential for unauthorised and unsafe entry to the shaft openings. The shafts are shallow and access to the site is limited. Concrete capping is considered unnecessary.

(ii) Backfilling

Backfilling of a shaft was typically undertaken in the past as a means of making the shaft safe.

Settlement of backfilled material can occur and has occurred on Shaft A (Figure 3.1).

It is recommended that the open shafts are backfilled and all shafts are signed. The quantity of backfill is small and can be obtained from mine waste within the pit within 100m of each shaft.

The total quantity is estimated at ± 300 m^3 and the cost would be €3,381.

(iii) Fencing

All four shafts should be fenced. A steel grill should be placed over the eastern adit and the area around the western adit (Molly's hole) should be fenced off to prevent approach to overhanging rocks.

The cost would be approximately €1,052.

RECOMMENDED ACTIONS

It is recommended that remediation options (ii) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

Immediate action should be taken on these shafts

RECOMMENDED KEY ACTIONS

- Survey and position all shafts and adits;
- Identify extent of fencing (metres) and signage (number to be installed and costs);
- Confirm end use compliance criteria (geotechnical stability; areas proposed for human and livestock access; structural survey of any potentially affected dwellings) and incorporate into post-remediation monitoring programme;
- Prepare an overall subproject budget.

TOTAL ESTIMATED COST OF WORKS

- €4,433.

I 2.5 SHAFTS

INTRODUCTION

In the Ballygown Calamine/Knockanroe areas there are a number of ventilation and access shafts indicated on plan. Identifying all the shafts in the field has proved difficult. Most of the shafts identified have been backfilled. On Knockanroe, the shafts are backfilled, have shrub growth cover but often have depressions within the backfill mound. Additional fill should be placed to fill the voids and promote drainage off the mound.

There is one shaft indicated adjacent to the road in Silvermines Village. This needs to be specifically located, due to the proximity to housing. This may require topographic survey, possible geophysics and trenching.

Two capped shafts have been identified, the Russell shaft south of the Cornish engine house and one adjacent to the Waeltz Plant.

There are two open shafts in the Sulphur Mine open pit. They are fenced but the fences are in poor condition. (Section I 2.4).

There is evidence of settlement in a backfilled shaft in the Sulphur Mine open pit. Many of the shafts can be identified as small mounts with clumps of trees and shrubs, but often with depressions in the centre of the mounds suggesting subsidence or incomplete filling.

Three shafts in meadows in the village can be identified by dense shrubs and perimeter fencing.

One of these shafts immediately north of the new school playing field is reported to discharge water during heavy rain.

The mine workings themselves have not shown signs of collapse or subsidence on the surface but it is difficult to confirm this from the present day terrain. The main hazard is from the shafts, many of which were backfilled in an uncontrolled manner. This risk is particularly on the shafts along the line of the drainage adit. Erosion from below the shaft fill can progressively remove material and induce collapse.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) Shafts: Property damage.
(b) Shafts: Danger to humans & livestock/wildlife.
(c) Mine workings subsidence : danger to humans and livestock.
(d) Discharge of mine water from Shafts.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a): Shafts: Property damage

The *likelihood* of property damage occurring has been assessed as *Medium* given the proximity of shafts to housing in one particular place. The proximity of the Silvermines drainage adit to the road requires investigation and may require restoration below the road to maintain adit drainage and avoid possible future road damage. This will require survey to establish the position relative to the road and properties and geophysical survey to confirm the position of the tunnel and adit entrance.

The *consequence* of the underground workings resulting in property damage as a result of subsidence, collapse, flooding, etc. has been assessed as *High*.

The assessed risk is Mp x Hc = High risk

Therefore it has been determined that remediation actions are required.

It is unlikely that the particular shaft adjacent to the house in Silvermines village will constitute a significant risk but the exact position should be located and the awareness of the shaft established with the landowner. Subsidence in the road due to subsidence over the tunnel could be a risk to traffic.

(b) Shafts : Danger to Humans/Livestock

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as medium.

The consequence of the underground workings in terms of a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the shafts.

There are no open shafts outside of Sulphur Mine but some shafts require additional fill and re-profiling to make safe.

The assessed risk is Mp x Hc = High risk.

Therefore it has been determined that remediation actions are required.

(c) Discharge of Mine Water from Shafts

The likelihood of discharge from the ventilation shafts in Silvermines village is high. It is known to occur in heavy rain. This could occur due to blockage of the drainage adit and the loosely backfilled shafts providing a preferred drainage path. The consequence would be local flooding and erosion of the shaft backfill, creating a safety issue. The consequence is assessed as medium.

The assessed risk is Hp x Mc = Medium risk.

Limited remedial works are required.

NOMINATED END USE

The nominated end use for the area of the underground workings is rough grazing and/or derelict land (Sulphur mine area).

End use compliance criteria are to be developed and would be based on geotechnical stability verification of any areas proposed for human and livestock access, as well as structural survey of any potentially affected dwellings.

Routine post-remediation monitoring of subsidence and shaft stability would be required over 4 years.

REMEDIATION OPTIONS CONSIDERED:

(i) Institutional Controls

The objective of opting for institutional controls would be to increase control of public and livestock access to the same shafts.

Institutional controls typically focus on fencing and signage. Approximately 10 shafts would be required to be fenced and appropriate signage erected. At other shaft sites where there are mounds of waste material sudden collapse is not likely. There are 34 shaft sites in total.
The total cost of this item is included with I.2.8.

(ii) Capping of Shafts

The main objective of this option is to eliminate the potential for unauthorised and unsafe entry to the shaft openings. This would comprise a reinforced concrete slab on concrete foundations or a well founded shaft lining.

However, the nature and shallow depth of remaining shafts in the area do not warrant formal capping.

(iii) Water Pressure Release and Drilling Investigation

During heavy rainfall groundwater is known to discharge from at least one of the backfilled shafts in Silvermines. It is essential that drainage from the adit continues and additional water pressure relief is provided by boreholes into the adit. This would require two boreholes of maximum 15m, with a discharge pipeline to the Silvermines stream. Holes should also be drilled to assess position and condition of the tunnel and adit to the north.

The total cost of this option is estimated to be €14,490.

(iv) Backfilling

Backfilling of a shaft was typically undertaken in the past as a means of making the shaft safe.

Settlement of backfilled material can occur and implications on future land use and safety need to be considered. Additional stabilisation of the infill material (e.g. drilling and stage pressure grouting and/or placement of reinforced concrete plug/cap) is often used but is not considered necessary at Ballygown.

It is recommended that all shafts are checked and additional backfill placed to re-profile the surface.

The cost of additional backfilling would be €4,830. The material can be sourced from adjacent ground.

RECOMMENDED ACTIONS

It is recommended that remediation option (i), (iii) and (iv) be adopted. Key actions for the implementation of these remedial measures are summarised below.

Priority should be given to geotechnically checking the shafts in the Silvermines Village. This will require accurate survey, geophysics and trenching or drilling, unless local residents can provide good information on the shafts. Two boreholes should be drilled into the drainage adit to assess pressure release requirements. Discharge from the boreholes in high rainfall periods should be discharged to the stream through a pipeline. The pressure release is to prevent back-up of water in the drainage adit in case of blockage or high flows. Back-up water could then break out in uncontrolled manner in the village area.

RECOMMENDED KEY ACTIONS

- Survey and position all shafts and adits (topographic and geophysics);
- Drill pressure release holes into drainage adit and assess drainage needs;
- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Confirm end use compliance criteria (geotechnical stability, areas proposed for human and livestock access; structural survey of any potentially affected dwellings) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €19,320.

I 2.6 UNDERGROUND MINE

INTRODUCTION

The underground mine works at Ballygown comprise both Calamine and Sulphur Mine. The workings were not extensive although fairly shallow and sometimes within 10m of surface. There are a number of development drives which do not constitute a significant hazard due to their limited size. It is known that some collapses occurred in some developments. Some of the drives were backfilled and it is likely that most collapse would have already occurred due to the age of the workings.

Any further settlement will be small and localised and is not likely to constitute a danger.

HAZARD/ISSUE AND POTENTIAL IMPACT

(a) Land use.
(b) Property damage.
(c) Humans and livestock.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

In all three cases the consequences of collapse and the likelihood is assessed as low and no remedial works are required.

NOMINATED END USE

The nominated end use for the area of the underground workings is rough grazing; controlled public use; and/or derelict land.

End use compliance criteria are to be developed and would be based on geotechnical stability verification of any areas proposed for human and livestock access, as well as structural survey of any potentially affected dwellings.

Routine post-remediation monitoring of subsidence and shaft stability would be required over 4 years, based on visual inspection.

RECOMMENDED ACTIONS

No specific actions are required except to place information notices at strategic positions across the site. These may form part of heritage information signs.

I.2.7 BALLYGOWN: MINE WATER DISCHARGE

INTRODUCTION

The discharge refers to that water discharging from the drainage adit in the village.

As part of the Phase II assessment, further *in situ* and laboratory analyses were undertaken to help characterise the quality of the discharge water from an adit (refer Section 7.2.1 of this report). In comparison with Irish surface water standards, the results indicate that groundwater within the underground workings is likely to contain elevated levels of metals and salts although only Ba, Cu and Cd slightly exceed Irish Standards. This is based on two sets of samples and some additional seasonal monitoring of quality and flow should be done.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Sulphides/Oxidation products: Human toxicity.
(b) Sulphides/Oxidation products: Livestock toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Sulphides/Oxidation Products : Human Toxicity

The *consequence* of a discharge of sulphide oxidation products was assessed as *low* in terms of human toxicity due to the fact that the water is not used for domestic purposes.

The *likelihood* of a human toxicity event occurring was assessed as *low* based on the relative inaccessibility of the area and opportunities for contact.

The assessed risk is Lp x Lc = Low risk.

Therefore it has been determined that no remediation actions are required.

(b) Sulphides/Oxidation Products : Livestock Toxicity

The *consequence* of a high metal load discharge occurring in terms of livestock toxicity (sediment & water) was assessed as *medium*. The water quality of the discharge is generally within limits (Table 7.3) but can be expected to rise with silt load after heavy rain.

The *likelihood* of a livestock toxicity event occurring was assessed as *medium* considering the very limited access and proximity of the Silvermines stream.

The assessed risk is Mc x Mc = Medium risk.

It has been determined that remediation action is required.

NOMINATED END USE

End use compliance criteria are to be developed and would be based on adit discharge rates, receiving stream water and sediment quality and public/livestock access restrictions.

Post-remediation monitoring of stream water and sediment quality would be required over 4 years.

Contingency planning will be required in the event of continued non-compliant water quality and sediment quality. Plans could include institutional controls and diversionary drainage works.

The adit discharge flows in a small stream in thick undergrowth for 30 m, after which it enters the Silvermines River. Dilution in the river will significantly reduce the impact of the adit discharge and the opportunity for exposure to animals and humans in the adit discharge itself, is low. There is likelihood of increased sediment load during heavy rain periods, which is likely to contain metals. This silt should be collected in a silt trap and combined with works to maintain an open discharge (see I 2.5). There is potential for future underground blockage of the adit, which is understood to be very small. This could impede drainage and increase discharge from the ventilation shafts along the adit.

REMEDIATION OPTIONS CONSIDERED

Given that the consequence of human and livestock toxicity is high some remedial actions are deemed necessary to achieve compliance with the nominated end land uses.

(i) Silt Trap and Adit Works

A silt trap should be constructed to collect sediment from the adit discharge which may arise in periods of high flood. This should be combined with improvement works to the adit. The exact position of the adit is not clear due to collapse material and fallen trees. The area will need excavation to establish detailed requirements. This should be integrated with I 2.5.

Silt accumulation is not expected to be large but will need removal on an annual or bi-annual basis. It is assumed this can be removed to the TMF.

The cost of clearing the adit area and construction of a silt trap would be €6,118 but additional works will be required around the adit and road once it is exposed.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & sediment;
- availability of suitable disposal sites;
- availability of wetland or water treatment plant site;
- associated cost estimates;
- monitoring of seasonal flow and chemistry variability.

It is recommended that remediation option (i) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Detailed survey of the site to establish construction requirements;
- Design and implement remedial works;
- Monitor flow (monthly) silt load and water chemistry in terms of lead, zinc, cadmium, TDS and pH (quarterly) for four years.

TOTAL ESTIMATED COST OF WORKS

- €6,118.

I.2.8 WASTE MATERIALS

INTRODUCTION

This includes all the areas of surface waste on the Calamine and Sulphur mine areas.

As part of the Phase II assessment, further *in situ* and laboratory analyses were undertaken to help characterise the waste material of the Calamine area at Ballygown. The results indicate highly elevated levels of As, Cd, Cu, Pb & Zn (*cf.* Irish agricultural soils - McGrath & McCormack 1999, in DAFRD 2000). (See Section 7.2.3). However, runoff water quality is generally good due to buffering. The resultant impacts on the streams is generally not significant but it is reasonable to assume that suspected solids in times of high runoff will be more significant.

There is a field containing low banks of old tailings to the north east of the village. A cattle death was reported and Teagasc have investigated. A number of fields show high metals in soils apparently not related to the brewers tailings field. The tailings have been disused for many years, are well vegetated and there is no risk of erosion or dust blow. It has been decided that these tailings should be fenced.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Sulphides/Oxidation products: Human health.
(b) Sulphides/Oxidation products: Livestock toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Sulphides/Oxidation Products : Human Toxicity

Calamine Area

The *likelihood* of a toxicity event occurring was assessed as *Medium* based on the current public usage of the Calamine area (e.g. dog walking, mountain-biking, etc.). It is understood that the area is used by children for mountain biking. This could expose them to dust and inhalation.

The *consequence* of human toxicity from the Calamine area was assessed as *Medium* particularly for Pb, Zn, As & Cd, all of which exceeded the respective US EPA SSL for the ingestion pathway. There were no exceedances of the SSL for the inhalation pathway (where given).

The assessed risk is Mp x Mc = Medium risk

Therefore it has been determined that some remedial actions are required.

Old tailings to North of village

The likelihood of a toxicity event occurring was assessed as low based on the current lack of public access to the old tailings.

The consequence of human toxicity was assessed as Medium particularly for Pb, Zn, As & Cd, all of which exceeded the respective US EPA SSL for the ingestion pathway. There were no exceedances of the SSL for the inhalation pathway (where given).

The assessed risk is Lp x Mc = Low risk

Therefore it has been determined that some remedial actions are required.

(b) Sulphides/Oxidation Products : Livestock Toxicity

Calamine area

The *likelihood* of a livestock toxicity event occurring was assessed as *Low* given the general lack of a vegetative cover across the area and hence the absence of grazing.

The *consequence* of livestock toxicity as a consequence of oxidation products from waste material was assessed as *Medium*.

The assessed risk is Lp x Lc = Low risk.

Therefore it has been determined that no specific remediation actions are required.

Old tailings to North of village

The likelihood of a livestock toxicity event occurring was assessed as Medium as cattle have recently died. In the vicinity, though not at the tailings.

The consequence of livestock toxicity was assessed as Medium.

The assessed risk is Mp x Mc = Medium risk

Therefore it has been determined that remediation actions are required.

(c) Sulphides/Oxidation Products : Erosion of Contaminants

Calamine area

The *likelihood* of erosion occurring and transporting oxidation products was assessed as *Medium*. More than 50% of the area is covered by grass and gorse but there are areas that are poorly vegetated. There is evidence of local gullying and sheet flow during heavy rain and material can be transported into the drainage system. This is a particular concern on the west bank of the Silvermines stream where waste products cover the bank.

The *consequence* of erosion of particulates and oxidation products was assessed as m*edium* given the relative low heights and grades of the waste material structures.

Therefore the assessed risk is Mp x Mc = Medium risk.

Limited remedial works would be beneficial, namely:

- the west bank of the Silvermines stream;
- the derelict land north of Sulphur Mine.

The bank of the Silvermines stream would benefit from removal of existing waste material and placement of soil to encourage vegetation growth.

Similarly, the derelict land at Sulphur Mine would benefit from placement of soil and seeding to encourage vegetation growth.

The non-vegetated areas at Calamine around the engine houses, reflect various phases of old mining and should not be disturbed.

Old tailings to North of village

The likelihood of erosion occurring and transporting oxidation products was assessed as Medium. The area is covered by grass, but adjacent to the Stream.

The consequence of erosion of particulates and oxidation products was assessed as Low given the relative low heights and grades of the old tailings deposits.

Therefore the assessed risk is Mp x Lc = Low risk.

No action is required with respect to erosion of the old tailings.

NOMINATED END USE

The nominated end use for the Calamine area is Open Space. The area north of Sulphur Mine is derelict land but could be used for rough grazing with some improvement works.

The area to the north of Silvermines cottage has been restored by the village as open amenity and trail areas. Ownership of much of the Ballygown area is uncertain.

End use compliance criteria are to be developed and would be based on performance of the contaminant disposal site(s), cover material geochemistry, receiving stream water and sediment quality and public access restrictions.

Routine monitoring of stream and stream sediment quality should be done and contingency planning may be required in the event of increased erosion or decreased water or sediment quality.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils (DAFRD 2000). However, given the high consequence of human toxicity some remedial actions are deemed necessary to achieve compliance with the nominated end land use. A critique of the remedial options considered is as follows.

There are some important archaeological features of early mining in the areas of ore dressing. These will need to be identified and recorded, and would be suitable for a detailed archaeological survey and mapping by a University.

(i) Remove Contaminated Material

The main objective of this option is to eliminate the potential for uncontrolled exposure to contaminated waste material.

This would necessitate the excavation, removal of waste and replacement with suitable growing medium. This option is not considered necessary. Some of the site represents mineral dressing areas and should be maintained for heritage.

(ii) Partial Removal of Contaminated Sediment from the Receiving Stream and Banks

The objective of removing contaminated sediment from portions of the receiving stream is to eliminate or significantly reduce the potential for re-suspension of heavy metals within stream sediments. Some waste should be removed from the bank and placed elsewhere on the site to fill. Appropriate erosion and sediment control works would also be required for this option. This would necessitate the excavation, removal of about 1600m^3 and replacement with approximately 1200m^3 of growing medium to establish vegetation. Removal could be to the open pit area to the south. (400m). Potentially suitable disposal sites can be identified at the south end of the site.

Estimated costs associated with excavation, road haulage, emplacement, topsoil and seeding would total €32,460.

(iii) Protection of Stream Bank with Gabions

A gabion wall would be erected in the Calamine area where stream banks, are steep and seasonal erosion occurs. It may be necessary to remove a small quantity of waste as part of the preparatory process. The estimated cost of a gabion wall is €16,500. It has been assumed that excavation and replacement of 900m^3 will be required during the preparation and execution of the works, and that the cost of preparatory and restoration works is €10,000. The total including some preliminaries and earthworks is €29,000.

(iv) Placement of Appropriate Cover

The objectives of applying a cover over the waste material area are to:

- significantly reduce the potential for physical contact with contaminated material;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

To achieve these objectives approximately 6,000 m^3 of suitably benign material would be required to provide a cover of no less than 0.2 m across the area north of Sulphur Mine, assuming about 40% of the area would need to be covered. Suitable borrow material sources can probably be found within about 10 km.

It is estimated that this option would cost in the vicinity of €80,500.

(v) Intercept Runoff

During heavy rain, runoff can carry some silt due to flow northwards across the waste. An interception channel should be constructed immediately north of the engine house and furnace house. This would drain to a small interception settlement pond before the river. Annual clearance of the silt would be required and removed to the TMF.

Approximate cost of this would be €6,120.

(vi) Institutional Controls

The objective of opting for institutional controls would be to inform the public with signs.

An allowance of €3,220 should be made.

(vii) Remove old tailings North of village

This option would involve removing the old tailings, depositing them on top of the Gortmore TMF and re-vegetating the area excavated.

An allowance of €212,440 should be made.

(viii) Fence old tailings North of village

A perimeter fence and signage be installed to restrict access at a cost of €2,400.

RECOMMENDED ACTIONS

It is recommended that remediation options (iii), (v), (vi) and (viii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Archaeological survey to define areas to be conserved;
- Assess storm flows and design sediment catchment;
- Identify area(s) for stream sediment and bank excavation and costs;
- Identify disposal site for excavated material, confirm haul distances and costs and licence requirements;
- Identify source and cost of local replacement/cover material for stream bank;
- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (receiving stream water and sediment quality; public access restrictions) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Monitor stream water quality on a quarterly basis prior to and after remedial works;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €44,200.

I.2.9 MINE BUILDINGS

INTRODUCTION

According to the findings of the industrial archaeological assessment for the Silvermines area the Ballygown area, contains remnant buildings of heritage value. These comprise the engine house, furnace building and Waeltz plant.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Engine House and Furnace Building : Danger to humans & livestock/wildlife.
(b) Waeltz plant : Asbestos toxicity to humans.
(c) Waeltz plant : Asbestos toxicity to livestock.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Engine House and Furnace Building

The *consequence* of the remnant structures representing a danger to humans and livestock/wildlife was assessed as *low* based on the physical dimensions of the structures and hence the minor nature of associated possible dangerous situations.

The *likelihood* of the structures being a danger to humans and livestock/wildlife was assessed as *low* given the condition of the structures. However, some conservation works would be required.

Therefore it has been determined that no specific remediation actions are required apart from conservation works.

(b) Waeltz Plant

The *consequence* of the Knockanroe remnant plant and buildings resulting in human toxicity was assessed as *high* given the known affects of asbestos on human health.

The *likelihood* of a human toxicity event occurring from contact/exposure to the asbestos was assessed as *low* given the small quantity of asbestos in the area and the relative inaccessibility of the area and the lack of unauthorised contact with the structures.

The assessed risk is Hc x Ll = Medium risk.

Therefore it has been determined that some remediation actions are required.

(c) Waeltz Plant : Livestock Toxicity

The *consequence* of the Knockanroe remnant plant and buildings resulting in livestock toxicity was assessed as *medium* given the known affects of asbestos.

The *likelihood* of a livestock toxicity event occurring from contact/exposure to the asbestos was assessed as *low* given the small quantity of asbestos in the area and the relative inaccessibility of the area and the lack of unauthorised contact with the structures.

The assessed risk is Mc x Ll = Low risk.

Therefore it has been determined that some remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the remnant structures is as part of a heritage site.

End use compliance criteria are to be developed and would be subject to the specialist industrial archaeological assessment.

REMEDIATION OPTIONS CONSIDERED

Relevant to the structures at Knockanroe, the *European communities (Asbestos Waste) Regulations 1994* state that:

“ A person who carries on an activity ….. which gives rise to the production of asbestos waste shall take the measures necessary to ensure that the asbestos waste arisings are, as far as reasonably practicable, reduced at source or prevented.

Remedial options considered to address this requirement are as follows:

(i) Use of Waeltz Plant

Some of the buildings are being used as winter shelter for livestock. This could be continued as an option, without any further work although the buildings will deteriorate and become unsafe.

(ii) Conservation of Waeltz Plant (Heritage)

Remove asbestos roof covering and dispose in licensed site and cut all walls down to window height to leave for heritage purposes. The cost would be approximately €40,530 with an additional estimated €32,200 to dispose of the asbestos. Assuming the concrete can be disposed at Magcobar dumps or used as construction fill a total cost for this option would be €72,730.

(iii) Restore the roof

Replace the asbestos covering, remediate concrete where damaged and brace walls where necessary. This would mean removing the asbestos to a licensed site at an estimated €32,200 and replacing the entire roof and bracing. The estimated total cost is €160,000.

The preferred option is the first for economic reasons but the second option would allow the full plant to be retained.

(iv) Conservation of Engine House and Furnace Building

These buildings need to be archaeologically and structurally surveyed. Remedial work to be limited to conservation of existing structure, by consolidation pointing.

Estimated cost is €15,460.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- Assessed risk;
- Applicable statutory requirements;
- Nominated post-closure end use(s);
- Findings of industrial archaeological study;
- associated cost estimates.

It is recommended that remediation options (ii) and (iv) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Confirm desire of local people, and heritage interest groups with respect to Waeltz Plant;
- Identify items for dismantling and removal and costs thereof;
- Obtain quotation from and select a specialist contractor for removal and disposal of asbestos materials;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (statutory heritage site regulations) and incorporate into post-remediation monitoring programme;
- Identify heritage management requirements;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €88,190.

I 3 MAGCOBAR: OPEN PIT (REFER TABLE 14.3)

I 3.1 Open Pit Stability

INTRODUCTION

As noted in the Phase I report the Magcobar open pit is the largest in the Silvermines area and although fenced, constitutes a potential hazard due to deep water and possible slope failure or erosion in the longer term, which could extend beyond the fencing.

HAZARD/ISSUE & POTENTIAL IMPACT)

(a) Open pit (stability): Danger to humans & livestock/wildlife.
(b) Open pit (stability): Failure of waste dump.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Danger to Humans and Livestock

The *consequence* of the open pit at Magcobar representing a danger to humans and livestock/wildlife was assessed as *high* based on the physical dimensions of the void and hence the nature of possible dangerous situations.

The *likelihood* of the pit being a danger to humans and livestock/wildlife was assessed as low given the relative accessibility of the area and the potential for human and/or livestock contact with the open pit.

The assessed risk is Hc x Ll = Medium risk.

Therefore it has been determined that some remediation actions are required.

(b) Failure of Pit causing Failure of Adjacent Waste Dump

The *consequence* of pit wall failure resulting in failure of the waste dump was assessed as *low*.

The *likelihood* of such an event occurring was assessed as *High* given the physical dimensions of the pit and the proximity of the dump to the pit perimeter.

The assessed risk is Lc x Hl = Medium risk.

It has been determined that some remediation actions are required.

NOMINATED END USE

The nominated end use for the Magcobar open void is a pit lake or a landfill site. The proposal for using the areas as a landfill is the subject of an EIS currently before the determining authority.

End use compliance criteria are to be developed and would be based on geotechnical stability pit water quality and predictive modelling (re: final water level, flux rates, strata layering, turn-over, etc.). For the landfill option, end-use compliance criteria would focus on geochemical stability of the site (including methane gas issues), ground and surface water quality, atmospheric emissions and aesthetics.

Post-remediation monitoring of pit wall movement and void water quality would be required over 12 months.

Environmental monitoring associated with a landfill would be expected to cover a wider range of parameters and extend over a longer time frame.

Contingency planning will be required in the event of major pit wall failure beyond predicted zones of affectation and in the event of significant reductions in void water quality.

Contingency planning for a landfill would be expected to cover a range of potential hazards and issues associated with such an activity.

REMEDIATION OPTIONS CONSIDERED

Irish legislation pertinent to disused quarries (i.e. *Mines and Minerals Act 1931* and the *Mines and Quarries Act 1965*) appear to make no specific reference to completed open pit wall stability. Nevertheless a critique of the remedial options considered in terms of open pit wall stability is presented below.

(i) Institutional Controls

The objective of opting for institutional controls would be to restrict and control public and livestock access to the open pit area.

Institutional controls typically focus on fencing and signage. The perimeter of the open pit is already fenced with a 7’ diamond mesh fence with appropriate signage. Some routine inspection and maintenance would be required. The fence is close to the pit edge on the west side and it is recommended that the fence is relocated and extended over a length of about 200m with an additional 200m.

The cost would be €12,120.

(ii) Backfilling

The objective of backfilling the open pit would be to eliminate issues associated with an open void.

Backfilling of an open pit is a common method of disposing of waste rock or other suitable material such as domestic refuse.

Costs associated with backfilling vary but assuming the waste dumps are used, it would cost an estimated €10,000,000 to backfill the Magcobar open pit.

Pit backfilling via the creation of landfill requires greater technical input, planning and supervision as noted in the EIS (M C O'Sullivan 2001) and this has not been costed as it would be a commercial operation.

(iii) Removal of Waste Rock from the Open Pit Edge

The objective of re-profiling the surface of the open pit perimeter would be to limit the possibility of pit wall collapse or movement resulting in major failure of existing waste material stockpiles located on the periphery of the top of the open pit.

Re-profiling earthworks in this area would necessitate movement of an estimated 60,000m^3 of material (e.g. backfill to open pit, re-contouring/moving material away from open pit edge). The total cost of the earthworks would be approximately €193,000.

RECOMMENDED ACTIONS

The preferred remedial action is (i) based on maintaining the peripheral fencing.

Final actions can only be determined once the proposed use of the pit for waste disposal is determined.

TOTAL ESTIMATED COST OF WORKS

€12,120 to move fence and add section.

Annual maintenance of whole fence : €1,500.

I 3.2 SUBSIDENCE OF UNDERGROUND WORKINGS

INTRODUCTION

The underground workings comprise bord and pillar workings of limited extent below the south west pit wall. The access was via single inclined adit from the pit floor. The bords are up to 40m wide but in competent rock. Geotechnical conditions are unknown but if the roof or pillar rock was weak it is likely that collapse would have already occurred. If the rock is strong, then collapse is unlikely. If collapse of the workings occurred the bulking and arching effect would limit the amount of subsidence that would occur at surface. Such movement may result in local instability of the pit sidewall.

HAZARD/ISSUE AND POTENTIAL IMPACT

(a) Surface subsidence : Health and Safety.
(b) Open Pit Stability.

(a) Surface Subsidence : Health and Safety

The consequence of subsidence representing a danger to humans or livestock was assessed as low based on the limited subsidence that could possibly occur.

The likelihood of danger was assessed as low due to limited access and likely limited subsidence.

The assessed risk is Lc x Ll = Low risk.

No remedial action is required.

(b) Open Pit Stability

The consequence of pit wall failure was assessed as low.

The likelihood of failure was assessed as low given the low likelihood of significant collapse of the workings.

The assessed risk is Lc x Ll = Low risk.

No remedial action is required.

(c) **Small Sinkhole Safety**

The existing small sinkhole represents a danger to humans and livestock.

The likelihood of a human or livestock falling into the sinkhole is assessed as low because of the location of the sinkhole.

The consequence of the sinkhole representing a danger to humans or livestock was assessed as high, because of the size and depth.

The assessed risk is Lc x Hl = Medium.

NOMINATED END USE

The nominated end use for the land potentially affected by subsidence is derelict mine land with some use as rough pasture. The small sinkhole is in pastureland.

REMEDIATION OPTIONS CONSIDERED

(a) Magcobar Pit

(i) Institutional Controls

These controls would be limited to extending the pit peripheral fencing to the west. This is recommended under items I3.1 and I3.4.

No other options have been considered.

(b) Small Sinkhole

(i) Institutional Controls

These would be limited to the maintenance of the fence to prevent access.

(ii) Backfilling

Fill material will be placed in the sinkhole, the surface levelled and vegetated, and the area returned to pasture.

RECOMMENDED ACTIONS

No action is recommended for the Magcobar pit and underground workings. It is recommended that the small sinkhole be backfilled at an estimated cost of €740 as the risk is low.

I 3.3 PIT WATER (Pit Lake)

INTRODUCTION

Water in the Magcobar pit is near neutral (O'Sullivan 1998 in Aslibekian 2000). Concentrations of Zn and Cd exceed maximum acceptable concentrations (MAC) while Fe, Ni and Mn are particularly high in the deeper portion of the water column (>40 m) (Aslibekian 2000).

As noted in the Phase I report (SRK 2001) this data indicates that with depth the pit water becomes increasingly acidic and contains higher levels of metals (Fe, Mn, Zn & SO_4). These vertical chemical variations may indicate that seasonal or permanent stratification has occurred in the pit lake (*ibid.*).

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Open Pit (void pit lake): Danger to humans & livestock/wildlife.
(b) Open pit (void pit lake): Human toxicity.
(c) Open pit (void pit lake): Livestock toxicity.
(d) Open pit (void pit lake): Groundwater contamination.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Danger to Humans and Livestock

The *consequence* of the void waterbody at Magcobar endangering humans and livestock/wildlife was assessed as *high* based on the physical dimensions of the void and hence the nature of possible dangerous situations.

The *likelihood* of the pit being a danger to humans and livestock/wildlife was assessed as *medium* given the relative accessibility of the area and the potential for human and/or livestock/wildlife contact with the open pit.

The assessed risk is Hc x Ml = High risk.

Therefore it has been determined that some remediation actions are required.

(b) Human Toxicity

The *consequence* of the void waterbody resulting in human toxicity was assessed as *high*.

The *likelihood* of such an event occurring was assessed as *low* given the chemistry of the void waterbody.

The assessed risk is Hc x Ll = Medium risk.

Therefore it has been determined that some remediation actions are required.

(c) Livestock

The *consequence* of the void waterbody resulting in livestock toxicity was assessed as *medium*.

The *likelihood* of such an event occurring was assessed as *low* given the chemistry of the void waterbody.

The assessed risk is Mc x Ll = Low risk.

It has been determined that no remediation actions are required.

(d) Groundwater Contamination

The *consequence* of the void waterbody resulting in groundwater contamination was assessed as *medium*.

The *likelihood* of such an event occurring was assessed as *low* given the groundwater system in the Magcobar area and the modelled static nature of the pit lake level over time.

The assessed risk is Mc x Ll = Low risk.

Therefore it has been determined that no remediation actions are required.

NOMINATED END USE

The nominated end use for the Magcobar open void is a pit lake or a landfill site. The proposal for using the areas as a landfill is the subject of an EIS currently before the determining authority.

End use compliance criteria are to be developed and would be based on pit water quality and predictive modelling (re: final water level, flux rates, strata layering, turn-over, etc). For the landfill option, end-use compliance criteria would focus on geochemical stability of the site (including methane gas issues), ground and surface water quality, atmospheric emissions and aesthetics.

Post-remediation monitoring of void water quality would be required over an initial period of 5 years to assess the pit lake water quality profile.

Environmental monitoring associated with a landfill would be expected to cover a wider range of parameters and extend over a longer time frame.

Contingency planning will be required in the event of significant reductions in void water quality.

For a landfill contingency planning would be expected to cover a range of potential hazards and issues associated with such an activity.

REMEDIATION OPTIONS CONSIDERED

Irish legislation pertinent to disused quarries (i.e. *Mines and Minerals Act 1931* and the *Mines and Quarries Act 1965*) appear to make no specific reference to abandoned open pits. Nevertheless a critique of the remedial options considered in terms of open pit wall stability is presented below.

(i) Institutional Controls

The objective of opting for institutional controls would be to restrict and control public and livestock access to the open pit area.

Institutional controls typically focus on fencing and signage. This is covered under 3.2.

(ii) In-Pit Water Treatment

The objective of this option is to reduce the potential of the quality of the void waterbody deteriorating to a level that poses a serious threat to humans, livestock and wildlife.

Methods for *in situ* treatment include chemical and biological, which would require treatment over a few years at minimum. Costs are difficult to estimate without detailed geochemical modelling but could be of the order of €350,000.

(iii) Directing Void Water to a Water Treatment Plant

The objective of directing void water via a water treatment plant would be to provide treated effluent to comply with regulatory or other prescribed standards for water quality.

The cost of a treatment plant would depend on the design flow rate. Treatment plants of suitable capacity cost around €800,000 to construct and entail annual running costs of around €160,000.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure end use(s);
- determination of the landfill proposal;
- associated cost estimates.

It is recommended that remediation option (i) be adopted. Key actions for the implementation of this remedial measure are summarised below.

RECOMMENDED KEY ACTIONS

- Determine status of landfill proposal;
- Confirm fence maintenance costs and responsibilities;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Establish quarterly water quality monitoring regime and responsibility including depth sampling (monitoring for 3 years);
- Notwithstanding the landfill proposal nominate end use compliance criteria (pit lake water quality) and incorporate into post-remediation monitoring programme;
- Integrate with other monitoring programmes;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

Costs are covered under 3.2 for fence maintenance.

Monitoring costs based on depth sampling quarterly for 4 years would be approximately €20,000.

[1] All recommended actions are subject to the final determination of the landfill proposal.

I 3.4 DESTRUCTION OF OLD MINE REMAINS

The remnant walls and the workings of the old copper mining are interspersed in the waste rock dumps. These must be conserved. There is risk of loss or damage during other remedial works on the site. They comprise remnant walls of buildings below waste dump C, remnant walls and lagoon structures below dump B and workings and small waste dumps below waste dump A.

The assessed risk of loss has to be considered as high.

Immediate action is required to fence the areas and carry out archaeological surveys.

The estimated cost is €8,835 comprising 1100m of fencing, most of which can be 3 strand barbed wire. This should be combined with item I3.1.

I 3.5 VISUAL

INTRODUCTION

Section 7.3.3 of the Phase I report notes that few concerns have been raised regarding the impact of the Magcobar waste dumps on the visual landscape character of the area. Nevertheless it is included here to ensure all potential impacts and issues of concern are covered.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Aesthetics: Negative visual impact

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Aesthetics

The *consequence* of the waste rock piles resulting in a negative visual impact has been assessed as *low* based on the existing viewshed of the Silvermines area.

The *likelihood* of the dumps posing a negative intrusion on the visual landscape was assessed as *medium* given the dimensions and the lack of a vegetative cover over most of the dumps.

It has however, been determined that some remediation actions are required.

NOMINATED END USE

The nominated end use for the Magcobar waste dumps is revegetated derelict land.

Post-remediation monitoring of dump revegetation would be required over 3 years.

Contingency planning will be required in the event of inability to establish a vegetative cover on the dumps, slope failure and/or other substantial changes to dump profiles. Plans could include application of soil ameliorants, growth additives, etc. to encourage revegetation and/or re-contouring works.

REMEDIATION OPTIONS CONSIDERED

(i) Institutional Controls to Prevent Uncontrolled Removal of Waste Material

The objective of opting for institutional controls would be to control public access to the whole or portions of the area to reduce unauthorised removal of waste material and thence, the potential for exposure of large areas of bare rock face.

Institutional controls typically focus on fencing and signage. For the Magcobar waste dumps it is estimated that approximately 200 m of fencing would be required. This is costed under I3.1.

(ii) Re-profiling Dump Slopes to Integrate with Surrounding Viewsheds

The objective of re-profiling the waste dumps would be to assist in reducing the visual impact of the dumps on the landscape. Re-profiling works have been estimated to cost around €30,000. However, this would destroy much of the existing vegetation and minimum disturbance is recommended.

(iii) Dump Topsoiling and Revegetation

Topsoiling and revegetation would assist in reducing the visual impact of the waste rock dumps by providing less aesthetic contrast with the background landscape.

A lump sum estimate of €25,000 is given for limited revegetation.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure end use;
- geotechnical character of the dumps;
- the potential for use of the material as aggregate;
- associated cost estimates.

It is recommended that remediation options (i), (ii) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Undertake aggregate feasibility study;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (slope stability) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €55,000.

I 3.6 ROCK DUMP STABILITY

INTRODUCTION:

As noted in the Phase I report there are several engineered waste rock piles at Magcobar, located around the open pit. Excavation of material from the toe of a dump has occurred recently, resulting in potential instability problems.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Dump instability: Danger to humans

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

The *consequence* of the waste rock piles representing a danger to humans has been assessed as *Medium* based on potential risk for serious injury as a result of slope failure, particularly the removal of material from the toe of Dump A.

The *likelihood* of the dumps posing a danger to humans was assessed as *Medium* given the limited public access to and use of the area but known removal of stone from dumps.

The assessed risk is Mc x Ml = Medium risk.

It has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the Magcobar waste dumps is derelict land. Some controlled use of dump material for construction could be allowed but this should be done under controlled conditions for health and safety and environmental reasons.

End use compliance criteria are to be developed and would be based on slope stability assessment.

Post-remediation monitoring of slopes would be required over 3 years.

Contingency planning will be required for the event of slope failure. Plans could include re-contouring works, diversionary drainage, and/or application of soil ameliorants, growth additives, etc. to encourage revegetation.

REMEDIATION OPTIONS CONSIDERED

Remedial options considered are as follows.

(i) Institutional Controls to Prevent Uncontrolled Removal of Waste Material

The objective of opting for institutional controls would be to control public access to the whole or portions of the area, to reduce unauthorised removal of waste material and thence, the potential for slope destabilisation and subsequent slope failure.

The cost is covered under I3.5.

(ii) Re-contour Dump Slopes

The objective of re-contouring or flattening the waste dumps would be to limit the possibility of major slope failure particularly in areas where the toe has been removed.

The total cost including some filling and seeding would be € 18,000.

(iii) Remove Dump Material for use as Aggregate/Fill

This objective would enable waste dump piles to be depleted/lowered in a controlled manner whilst achieving some financial gain on any earthworks. This option would need to be subject to an assessment of the viability of the material as an aggregate. The use of the material would be costed for the end use.

(iv) Maintain Surface Water Diversion

This is to maintain the existing drainage system to ensure no accumulation of water behind the dumps. Costs included under I 3.7.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure end use;
- geotechnical character of the dumps;
- the potential for use of the material as aggregate; and
- associated cost estimates

it is recommended that remediation options (i), (iii) and (iv) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Undertake aggregate feasibility study;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (slope stability) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site.
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

(i) and (iii) included under I3.5 and (iv) included under I 3.7.

I 3.7 SULPHIDE/OXIDATION PRODUCTS

INTRODUCTION:

The Phase I report notes that in relation to the waste rock dumps, there is often the presence of highly pyritic material which results in ARD. Drainage from individual waste rock dumps has not been characterised nor has the reactivity of the material and the potential to generate acid drainage been assessed.

As part of the Phase II assessment, further *in situ* paste pH and EC analyses were undertaken to help characterise the waste material of the Magcobar area. The results indicate acidic conditions (pH 1.6 - 6.7) at five of the 10 sample sites. The most acidic sites (pH 1.6 & 3.9) were located on waste dump surfaces with massive marcasite and pyrite boulders. However the sampling was focussed on some of the acid generating material which appears to represent a small percentage of the waste material. It is particularly evident on the top of dump A and top of dump C (Figure 3.2).

Analysis of stream sediment immediately downstream of the Magcobar dumps (DAFRD 2000) indicated elevated levels of Mg, Al, Fe, Mn, Zn, Ba & Pb; only Ba and Zn were above the Dutch standards in a couple of cases. However, surface water samples from the various streams around the dumps, showed elevated metals but only Ba and Cu were slightly above the standards (see Section 7.3 and Table 7.5).

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Sulphides/Oxidation products: Human toxicity.
(b) Sulphides/Oxidation products: Livestock toxicity.
(c) Sulphides/Oxidation products: Decreased stream water quality.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Human Toxicity

The *consequence* for human toxicity as a result of ARD from the Magcobar waste dumps was assessed as *Medium*.

The *likelihood* of a toxicity event occurring was assessed as *low* given the results of *in situ* sampling and the level of current public usage of the area.

The assessed risk is Mc x Ll = Medium risk.

Therefore it has been determined that remediation actions are required.

(b) Livestock Toxicity

The *consequence* of livestock toxicity as a consequence of oxidation products from waste material was assessed as *high*.

The *likelihood* of a livestock toxicity event occurring was assessed as *low* given the general lack of a vegetative cover across the area and hence the absence of grazing, although animals can access the area and can ingest solid matter from grazing or stream beds.

The assessed risk is Hc x Ll = Medium risk.

Therefore it has been determined that remediation actions are required.

(c) Decreased Stream Water Quality

The *consequence* of decreased stream water and sediment quality as a result of ARD from the Magcobar dumps was assessed as *medium*, given the ambient quality of the water and sediment in the upstream of the dumps.

The *likelihood* of receiving water and sediment quality being adversely affected by ARD from the dumps was assessed as *medium*.

This assessment was based on the results of Irish EPA monitoring of stream water and sediments in 2000, which indicated increased levels of Pb, Cd, Zn and Fe downstream of the playing fields.

The assessed risk is Mc x Ml = Medium risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the Magcobar waste dumps is derelict land. End use compliance criteria are to be developed and would be based on performance of the contaminant disposal site(s), cover material geochemistry, as well as receiving stream water and sediment quality.

Post-remediation monitoring of stream water and sediment quality would be required over 3 years.

Contingency planning will be required in the event of non-performance of contaminant disposal site(s), loss of cover material, inability to establish vegetative covers, continued non-compliant water quality and sediment quality. Plans could include institutional controls, diversionary drainage works, placement of additional/ alternative cover material, application of soil ameliorants, growth additives, etc to encourage revegetation.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

Stream sediment immediately downstream of the Magcobar waste dumps contains levels of nickel (Ni), cobalt (Co), copper (Cu), Arsenic (As) and cadmium (Cd) above target values[1] but below intervention values[2]. Measured levels of zinc (Zn), barium (Ba) and lead (Pb) were above the MHSPE intervention values.

A critique of the remedial options considered is as follows.

(i) Consolidate Potentially Acid Forming Material

The main objective of this option is to eliminate the potential for further generation of acid drainage from the waste dumps.

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[1] The target values indicate the level at which there is a sustainable soil quality. It is the level that has to be achieved to fully recover the functional properties of the soil for human, plant and animal life. This level also provides an indication of the benchmark for environmental quality in the long term on the assumption of negligible risks to the ecosystem (MHSPE Circular 2000).

[2] The soil remediation intervention values indicate when the functional properties of the soil for humans, plant and animal life is seriously impaired or threatened. They are representative of the level of contamination above which there is s serious case of soil contamination (*ibid*).

This would necessitate the excavation, and consolidation in one dump of approximately 1,000 m^3 of contaminated material. The volume is uncertain until surveyed. For budgeting purposes, a volume of 1000m^3 has been assumed.

Estimated costs total approximately €4,830.

(ii) Placement of Appropriate Cover

The objectives of applying a cover over the Magcobar waste dumps are to:

- reduce the potential oxidation of pyritic material and the generation of ARD;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

For the purpose of estimating, an area of 1,250 m^2 has been assumed. To achieve these objectives approximately 500 m^3 of non sulphide bearing limestone rock waste overlain by a soil cover of no less than 0.5 m across the sulphide bearing material will be required at a cost of €2,700.

375 m^3 of borrow material will be required at a placed cost of €5,820. This will then be seeded at a cost of €400. The total cost of this option is 8,920.

(iii) Integrated Drainage Control

The objectives of improved drainage control would be to divert upstream 'clean' water and intercept 'dirty' water, to reduce the potential for contaminated surface runoff. Intercepted 'dirty' water would be directed via a treatment facility (e.g. constructed wetland, water treatment plant, retention basin, etc.), the nature of which would be dependent on the quality of the water and the required level of treatment.

Works required to achieve these objectives would entail the establishment and improvement of upstream diversionary drainage and such works would cost an estimated €4,000. Maintenance on an annual basis should allow €800/year.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- availability of suitable disposal sites and borrow material;
- associated cost estimates

It is recommended that remediation options (i), (ii) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Identify extent and volume of material to be consolidated;
- Identify cover material source(s), confirm haul distances and costs;
- Confirm extent of drainage works required and costs;
- Prepare a schedule of remediation works including identification of milestones, cost and responsible parties;
- Confirm end use compliance criteria (cover material geochemistry, receiving stream water and sediment quality) and incorporate into post-remediation monitoring programme for 3 years;

- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €18,550;
- Ongoing maintenance €800/year.

I 3.8 MINE BUILDINGS AND PLANT SITE

The plant comprises crusher and associated screen houses and conveyor (poor condition), the storage shed and workshop in good condition, prefabricated office building and oil storage tanks.

The plant site will rapidly deteriorate and will become dangerous in the future.

There is a low risk to humans and livestock at present due to limited access.

There is no heritage value in keeping any of these structures but the workshop is in good condition on its own hardstanding and could be utilised for commercial or farm purposes.

It is recommended that the workshop be evaluated for future use and the other structures are demolished.

The cost of demolishing and removing the materials is estimated at €11,300.

I.3.9 SETTLEMENT LAGOONS NORTH OF MAGCOBAR PIT

The settlement lagoons north of the Magcobar Pit are long, shallow, narrow ponds of approximately 25m x 5m, and it is assumed that they were used to settle silt from the diversion canal during the operational life of the mine.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Settlement Lagoons, depth of water.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Depth of Water (Human and Livestock Drowning)

The consequence of drowning must be assessed as low. The likelihood is low given the shallow depth of water and limited access.

The assessed risk is Lc x Lp = Low risk.

NOMINATED END USE

The end use for the lagoons is to continue as silt traps.

REMEDIATION OPTIONS CONSIDERED:

(i) Partial backfilling

The lagoons could be backfilled, leaving a channel for the passage of water. The backfilling would involve the placement of approximately 200m^3 of suitable fill. Cost for backfilling and construction of a channel would be approximately €1200.

(ii) Institutional Controls

The objective of opting for institutional controls would be to restrict and control public and livestock access to the lagoon area. Institutional controls typically focus on fencing and signage. The perimeter of the lagoons is approximately 70 m and would be required to be fenced and appropriate signage erected. Costs associated with fencing and signage would be in the vicinity of €700.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- availability of borrow material;
- associated cost estimates.

it is recommended that remediation option (ii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Erect fences and signage.

TOTAL ESTIMATED COST OF WORKS

- €700.

I 4 : GARRYARD (MOGUL): INCLUDING SUBSIDENCE ZONE (REFER TABLE 14.4)

I 4.1 SETTLEMENT POND

INTRODUCTION

The discharge from the ponds shows slightly elevated sulphate but metals are within acceptable limits. The inflow shows slightly elevated Pb and Mn which presumably settle out in the ponds and sulphate (369 mg/l) (see Section 7.4.1). Pond B is to be left as it is. The following description refers to Pond A. (See Figure 3.3).

In 1999 sediment with elevated metal concentrations was found throughout the area and was particularly pronounced in a small stream draining the Garryard settlement pond.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) High dissolved metals in sediment & water: Elevated TDS & metals in local streams.
(b) High dissolved metals in sediment & water: Human toxicity.
(c) High dissolved metals in sediment & water: Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Elevated TDS and Metals in Local Streams

The *consequence* of increased TDS & metals in local streams via flows from the settlement pond was assessed as *medium* based on water quality data available for areas upstream and downstream of the pond.

The *likelihood* of this occurring was assessed as *medium* given the area of the catchment and dimensions of the pond, combined with local rainfall patterns and visual confirmation, which indicate the likely frequent outflow from the pond.

The assessed risk is Mc x Ml = Medium risk.

Remediation actions are required.

(b) Human Toxicity

The *consequence* of human toxicity as a consequence of high dissolved metals in the settlement pond was assessed as *Medium.*

The *likelihood* of human toxicity occurring was assessed as *low* given the general lack of public access and use of the pond area.

The assessed risk is Mc x Ll = Medium risk.

Some remediation actions are required.

(c) Livestock/Wildlife Toxicity

The *consequence* of livestock toxicity associated with high dissolved metals in the settlement pond was assessed as *medium.*

The *likelihood* of such an event was assessed as *high* given the quality of the sediment and the water and the potential for livestock to access the pond and areas immediately downstream.

The assessed risk is Mc x Hl = High risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use for the Garryard settlement pond is wetland for water treatment.

End use compliance criteria are to be developed and would be based on water balance data for the pond, inflow and outflow water quality, statutory discharge water quality requirements and any future public use of the area.

Post-remediation monitoring of wetland discharge water and sediment quality would be required over 4 years.

Contingency planning will be required in the event non-compliant discharge water and sediment quality. Plans could include institutional controls, diversionary drainage works and adoption of an alternate treatment system.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

Given the high consequence and likelihood of human and livestock toxicity (respectively) some remedial actions are deemed necessary to achieve compliance with the nominated end land uses. A critique of the remedial options considered is as follows.

(i) Remove Contaminated Material From the Settlement Pond

The main objective of this option is to eliminate the potential for further contamination of downstream waterbodies sediments. This would necessitate the excavation, removal and emplacement of approximately 10,000 m^3 of material from the pond.

The excavated material could be disposed of in Gortmore TMF, Magcobar open pit or any other on-site area deemed appropriate, subject to disposal permission.

Excavation works, haulage and disposal costs could be around €100,000.

(ii) Placement of Appropriate Cover

The objectives of applying a cover over the pond would be to:

- reduce the potential for mobilisation of sediment laden with elevated levels of TDS and metals;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

To achieve these objectives approximately 5,000 m^3 of suitably benign material would be required to provide a cover of no less than 0.5m across the pond area.

The cost would be approximately €80,000.

(iii) Drain Pond to a Water Treatment Plant

The objective of directing pond discharge via a water treatment plant would be to treat influent to an extent that effluent complies with regulatory or other prescribed standards for water quality.

Considering the ongoing requirement for treatment, this is not a practical option.

(iv) Encourage Wetland Growth

Converting the settlement pond to a wetland provides a means of 'treating' inflow and thence, lowering the system effluent TDS and metals loads.

There is some wetland development in the second pond (Figure 3.3) but some earthworks would be required to establish suitable aquatic macrophyte growth zones and together with plantings, this could cost around €4,830 to create, together with some minor fence repairs at €1,000.

(v) Drain Pond to Constructed Wetland

The objective of directing pond discharge via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended soilds retention. The discharge quality is presently acceptable and an alternative method to redeveloping the existing ponds is not a practical option.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & pond sediment
- availability of suitable disposal sites;
- availability of wetland or water treatment plant sites; and
- associated cost estimates

It is recommended that remediation option (iv) be adopted. Key actions for the implementation of this remedial measure are summarised below.

RECOMMENDED KEY ACTIONS

- Prepare preliminary pond water balance;
- Monitor inflows and quality (3 years);
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for the tailings lagoon;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €5,830.

I 4.2 TAILINGS LAGOON

INTRODUCTION:

The water in the lagoon contains elevated Cd, Fe, Mn, Pb, SO_4, As and Al, particularly as particulates greater than 0.45µm.

Refer to comments above for the Garryard Settlement Pond.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) High dissolved metals in sediment & water: Elevated TDS & metals in local streams.
(b) High dissolved metals in sediment & water: Human toxicity.
(c) High dissolved metals in sediment & water: Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Elevated TDS and Metals in Local Streams

The *consequence* of increased TDS & metals in local streams via flows (& seepage) from the tailings lagoon was assessed as *high*.

The *likelihood* of this occurring was also assessed as *high* given the area of the catchment and dimensions of the pond, combined with local rainfall patterns and visual confirmation, which indicate the likely frequent outflow from the lagoon.

The assessed risk is Hc x Hl = High risk.

Remediation actions are required.

(b) Human Toxicity

The *consequence* of human toxicity as a consequence of high dissolved metals in the lagoon was assessed as *high*.

The *likelihood* of human toxicity occurring was assessed as *low* given the general lack of public access and use of the area.

The assessed risk is Hc x Ll = Medium risk.

Some remediation actions are required.

(c) Livestock / Wildlife Toxicity

The *consequence* of livestock toxicity associated with high dissolved metals in the settlement pond was assessed as *high*.

The *likelihood* of such an event was assessed as *high* given the quality of the sediment and the water and the potential for livestock to access the lagoon and areas immediately downstream.

The assessed risk is Hc x Hl = High risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use for the Garryard tailings lagoon is a wetland for water treatment.

End use compliance criteria are to be developed and would be based on water balance data for the lagoon, inflow and outflow water quality, statutory discharge water quality requirements and any future public use of the area.

Post-remediation monitoring of wetland discharge water and sediment quality would be required over 4 years.

Contingency planning will be required in the event of non-compliant discharge water and sediment quality. Plans could include institutional controls, diversionary drainage works and adoption of an alternate treatment system.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

A critique of the remedial options considered is as follows.

A water treatment plant is an option but was not considered further as it is impractical as an ongoing solution.

(i) Placement of Appropriate Cover

The objectives of applying a cover over the lagoon would be to:

- reduce the potential for mobilisation of sediment laden with elevated levels of TDS and metals;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff and increased seepage.

To achieve these objectives approximately 11,000m^3 of suitably benign material would be required to provide a cover of no less than 0.5m across the pond area, together with a 200mm limestone drainage layer and geotextile. This would then be topsoiled and seeded.

It is estimated that this option would cost in the vicinity of €410,000 but would not provide any ongoing water treatment.

(ii) Remove Contaminated Material From the Tailings Lagoon

The main objective of this option is to eliminate the potential for further contamination of downstream waterbodies. This would necessitate the excavation, removal and emplacement of approximately 22,000 m^3 of material from the pond.

The excavated material could be disposed of in Gortmore TMF, Magcobar open pit or any other on-site area deemed appropriate.

Excavation works, haulage and disposal costs could be around €215,000. However, if a hazardous formal waste facility is used then a contingency cost of €160,000 should be allowed.

(iii) Reprocess Tailings as Ore

There is potential for processing the tailings to extract any residual ore. This option would necessitate haulage of the material to a suitable plant such as at Lisheen or Galmoy. It is suggested that likely returns from reprocessing this material would not be sufficient to warrant further investigation of feasibility.

(iv) Drain Lagoon to Constructed Wetland

The objective of directing lagoon discharge via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended soilds retention. This option would still leave the existing sediment and ongoing generation of contaminated water to pass through the wetland.

It is considered not to be a sustainable long term option.

(v) Integrated Drainage Control

The objectives of an integrated drainage system for the lagoon would be to segregate 'clean' and 'dirty' water and direct the 'dirty' water to a treatment facility (e.g. wetland, treatment plant, via sedimentation basins, etc.). This would have the effect of reducing the potential for contaminated seepage and surface runoff from discharging from the lagoon to downstream waterbodies.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such works would cost an estimated €8,000. The ‘dirty’ water would then pass through a developed wetland (Item vi).

(vi) Develop Wetland on the site after removal of contaminated material

This would require design of earthworks and sizing to treat discharge from the plant site. The estimated total cost of wetland development after removal of the sediment (Item ii) is approximately €453,000. There will be opportunities to simplify design requirements and reduce costs after detailed design.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & pond sediment
- availability of suitable disposal sites;
- availability of wetland or water treatment plant sites; and
- associated cost estimates

it is recommended that remediation option (ii), (v) and (vi) be developed. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Survey volume of materials to excavate and identify suitable disposal site;
- Prepare preliminary lagoon water balance and diversion requirements;
- Determine the required size and type of wetland to treat the predicted inflows/outflows;

- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site.
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €676,000, plus a contingency of €161,000 for hazardous waste disposal elsewhere.

Periodic cleaning of sediment and precipitated ore will be required. This interval will be a minimum of 20 years at a present day estimate of €20,000.

I 4.3 MAIN GARRYARD SHAFT

INTRODUCTION

The main shaft at the plant site has a concrete cap but also has a discharge pipe for water which flows into a drain under the buildings and ultimately into the tailings lagoon.

The discharge occurs particularly after heavy rain but the continuity of flow is unknown. Based on field measurements, the discharge contains elevated TDS. It is important to maintain this discharge to prevent uncontrolled overflows elsewhere.

The details of the shaft cap construction are unknown but it is assumed that there is no risk of failure of the cap foundations as the shaft was the main hoist shaft and foundations will be well designed. Shaft collapse or cap failure is not considered an issue but the site should be clearly identified.

Detailed water quality data is not available because there was no discharge at the time of sampling. Field measurements showed elevated TDS.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Shaft cap damage: Human safety.
(b) Shaft discharge: Contamination of local streams.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Human Safety

The *consequence* of human injury occurring as a result of shaft cap damage was assessed as *medium*.

The *likelihood* of damage occurring was assessed as *low* based on the relative inaccessibility of the area and knowledge of the existence of the shaft.

The assessed risk is Mc x Ll = Low risk.

Nevertheless it has been determined that remediation actions is required.

(b) Contamination of Streams

The *consequence* of shaft discharge resulting in contamination of local streams was assessed as *medium*. The discharge will enter the tailings lagoon, where it will be remediated as part of the lagoon works.

The *likelihood* of shaft discharge resulting in contamination of local streams was assessed as *high* based on the quality of the shaft discharge and downstream water quality data.

The assessed risk is Mc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the Garryard shaft is continued light industrial use.

End use compliance criteria are to be developed and would be based on shaft discharge rates, receiving stream water and sediment quality and public/livestock access restrictions.

Post-remediation monitoring of stream water and sediment quality would be required over 12 months.

Contingency planning will be required in the event of continued non-compliant water quality and sediment quality. Plans could include institutional controls and diversionary drainage works.

REMEDIATION OPTIONS CONSIDERED:

In terms of the shaft cap, practical remediation is limited to ensuring that the cap and shaft are clearly identified and should be protected from damage.

For the discharge, discussions with the Irish EPA indicate that there are currently no Irish groundwater standards, however the EPA are currently working on producing a set of standards for groundwater. In the interim in areas prior to any anthropogenic influences, the EPA advise that reference is made to drinking water standards i.e. SI No. 81 of 1988, which will be revoked by SI No 439 of 2000 but not until 1st January 2004. For example standards in drinking water for Pb are 0.05 mg/l, Zn 1 mg/l, Cd 0.005 mg/l and Fe 0.2 mg/l. However the implications of the background levels of metals (*in situ* mineralogy) and the effects of mining need to be considered.

The remedial options considered are as follows.

(i) Install clear warning sign on the shaft cap

(ii) Drain Shaft Discharge to Constructed Wetland

The objective of directing shaft discharge via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended solids retention.

Discharge rates are variable but the available wetland area will be sufficient to achieve suitable levels of residence and metals uptake, based on discontinuous inflows.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & sediment;
- availability of wetland or water treatment plant site;
- associated cost estimates.

It is recommended that remediation options (i) and (ii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Install warning sign;
- Determine shaft discharge flow rates;
- Determine the required size of the constructed wetland and costs;
- Identify constructed wetland site;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;

- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

Drainage works to be maintained by occupier. Signage as part of other cost items.

I 4.4 UNDERGROUND MINES

INTRODUCTION

The early mined areas of Garryard have suffered significant collapse in the area of steeply dipping orebody in the outcrop area, which is clearly visible on the hillside.

Later workings were backfilled with cemented, pyrite-rich tailings, which limited the potential for collapse. There is a collapse feature adjacent to the road at the entrance to the Magcobar site, but this may not be attributed directly to mining subsidence. It is more likely to have been a palaeo sinkhole which has developed due to erosion of underlying fill material during the period of dewatering of Magcobar or Mogul mines

The source of pyrite, oxidation products and presence of groundwater, could result in the migration of groundwater with elevated TDS and metals in solution.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) Mine workings: Subsidence/Collapse (loss of productive land use);
(b) Mine workings: subsidence (property damage);
(c) Mine workings: Danger to humans & livestock/wildlife;
(d) Mine workings: seepage of contaminated groundwater.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Loss of Productive Land Use

The *consequence* of subsidence resulting in the potential loss of productive land resources, has been assessed as *medium* based on the historic and current land capability of the area.

The *likelihood* of subsidence occurring has been assessed as *high* over a limited area where subsidence has been observed and where further subsidence is possible.

Therefore it has been determined that remediation actions are required.

(b) Surface Dwelling

The consequence of subsidence resulting in damage to dwellings has been assessed as low based on relationship of workings to dwellings and likely damage.

The likelihood of damage is also low based on relationship of dwellings to undermined areas.

The assessed risk is Lc x Ll = Low risk.

No remediation is required.

(c) Danger to Humans and Livestock

The *consequence* of the underground workings being a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the openings.

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as *medium* given evidence of public access and use of the area.

The assessed risk is Hc x Ml = High risk.

Therefore it has been determined that remediation actions are required.

(d) Contaminated Ground Water

The consequence of contaminated ground water seepage is considered low as flows will be low due to low hydraulic gradient and relatively low hydraulic conductivity.

The likelihood is medium based on the fact that the source of contaminants exists but the process should be slow in a largely anaerobic environment.

The assessed risk is Lc x Ml = Low risk.

No specific remedial measures are proposed apart from surface water diversion.

NOMINATED END USE:

The nominated end use for the area of the underground workings is as farmland or derelict land.

End use compliance criteria are to be developed and would be based on geotechnical stability and verification of any areas proposed for human and livestock access.

Post-remediation monitoring of subsidence and shaft stability would be required over 12 months.

Contingency planning will be required in the event of major subsidence and shaft collapse beyond predicted zones of affectation. Plans could include further institutional controls and acquisition of adversely affected property.

REMEDIATION OPTIONS CONSIDERED:

(i) Fencing

Upgrading and augmenting the existing fencing would enable greater control on public and livestock access to the whole or portions of the area of the underground workings, thus significantly limiting the potential for an accident.

Institutional controls typically focus on fencing and signage. The Mogul shafts appear to have been capped but the construction is unknown.

There is an existing fence which is in poor condition in some areas and would require extending. An increase in warning signs would be appropriate.

Total cost would be of the order of €9,400 plus ongoing inspection and maintenance of €500 / year.

(ii) Backfilling

Backfilling of subsidence areas may be considered to stabilise them, however this is not a realistic option in terms of the volume of backfill and the uncertainty of future integrity of the surface.

The mine and process waste material in the Gorteenadiha area may be potentially suitable as backfill material.

Due to the large area concerned and potential land use, this is not considered to be a viable option.

(iii) Integrated Drainage Control

The objectives of improved drainage control would be to divert 'clean' water around the subsidence areas to reduce the potential for contaminated seepage and discharge.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such works would cost an estimated €6,800.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use(s);
- findings of geotechnical assessment;
- findings of heritage value assessment;
- discharge water flow & quality data;
- associated cost estimates

It is recommended that remediation options (i) and (iii) be adopted. Key actions for the implementation of this remedial measure are summarised below.

RECOMMENDED KEY ACTIONS

- Survey positions of all shafts and adits;
- Detailed topographic survey to plan surface drainage;
- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Assess Requirement for specialist geotechnical assessment of shaft/adit stability;
- Incorporating the findings of the geotechnical assessment (where required), prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Design and install surface drainage measures;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €16,300 plus annual maintenance and inspection of €1,000.

I 4.5 OLD STOCK PILE

INTRODUCTION

The old stockpile contains a mixture of sulphide ore and plant process residues as well as other unknown plant wastes.

As part of the Phase II assessment, *in situ* paste pH and EC analyses were undertaken to help characterise the material. The results indicate that the material is reactive and contains leachable constituents.

Analysis of stream water and sediment quality downstream of the old stock pile indicated elevated levels of Fe, Mn, Zn, Pb, Cd, and Ba (EPA 2001 data).

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Sulphides/Oxidation products; Mill concentrate spillage & unknown materials: Elevated TDS & metals in local streams.
(b) Sulphides/Oxidation products; Mill concentrate spillage & unknown materials: Human toxicity.
(c) Sulphides/Oxidation products; Mill concentrate spillage & unknown materials: Livestock toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated TDS, Solids and Metals

The *consequence* of elevated TDS & metals in local streams as a result of sulphide oxidation from the Old Stockpile was assessed as *high*, given the reactive nature of the waste material and the results of downstream water quality analysis.

The *likelihood* of receiving water and sediment quality being adversely affected by poor quality drainage from the dumps was also assessed as *high*.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that specific remediation actions are required.

(b) Human Toxicity

The *consequence* for human toxicity as a result of poor quality drainage from Old Stockpile was assessed as *high*.

However the *likelihood* of a toxicity event occurring was assessed as *low* given the level of current public access/usage of the area.

The assessed risk is Hc x Ll = Medium risk.

Therefore it has been determined that specific remediation actions are required.

(c) Livestock Toxicity

The *consequence* of livestock toxicity as a consequence of oxidation products from waste material was assessed as *high*.

The *likelihood* of a livestock toxicity event occurring was assessed as *high* also based on potential for livestock access to the area and to streams downslope of the dump.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the old stockpile is pasture.

End use compliance criteria are to be developed and would be based on performance of any contaminant disposal site(s), cover material geochemistry, as well as receiving stream water and sediment quality.

Post-remediation monitoring of stream water and sediment quality would be required over 4 years.

Contingency planning will be required in the event of non-performance of contaminant disposal site(s), loss of cover material, inability to establish vegetative covers, continued non-compliant water quality and sediment quality. Plans could include institutional controls, diversionary drainage works, placement of additional/ alternative cover material, application of soil ameliorants, growth additives, etc. to encourage revegetation.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

Stream sediment immediately downstream of the site contains levels of Fe, Mn, Pb, Cd and Ba above target values and intervention values.

Remediation work will consider ecological and environmental management. The ecological considerations are discussed in Appendix G.

A critique of the remedial options considered is as follows.

(i) Intercept and Treat Surface Runoff and Seepage

The objectives of an integrated drainage system would be to segregate 'clean' and 'dirty' water and direct the 'dirty' water to s treatment facility (e.g. wetland, treatment plant, via sedimentation basins, etc.). This would have the effect of reducing the potential for contaminated seepage and surface runoff from discharging to downstream waterbodies.

The ‘dirty’ water could be culverted under the road to the settlement pond. The total cost of drainage would be €8,000, due mainly to the requirement for road culverts. This option is not acceptable on its own as it would still leave exposed stockpile.

(ii) Placement of Appropriate Cover

The objectives of applying a cover over the dumps are to:

- reduce the potential oxidation of pyritic material and the generation of ARD;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

It is estimated that this option would cost in the vicinity of €180,000, but this would not remove the risk of long term erosion and contaminated seepage.

(iii) Remove Potentially Acid Forming Material

The main objective of this option is to eliminate to potential for further generation of acid drainage from the waste dump.

This would necessitate the excavation, removal and emplacement of approximately 14,000m^3 of contaminated material. The proposed disposal site would be the TMF. There is uncertainty as to the content of the stockpile and care will be required to identify and segregate any non ore or process material for alternative disposal as necessary.

Some restoration would be desirable in the form of a cover for a growth medium over a layer of limestone aggregate (0.2m).

Estimated costs associated with excavation, haulage and emplacement with topsoil replacement would be €205,000. This option is preferred because it removes the same material which would otherwise remain as a potential risk. A contingency of €193,000 should be allowed for hazardous waste disposal elsewhere.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- availability of suitable disposal sites and borrow material;
- associated cost estimates

it is recommended that remediation options (i) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Survey quantity of material to remove and confirm disposal site;
- Identify cover material source(s) and growing medium;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (cover material geochemistry, receiving stream water and sediment quality) and incorporate into post-remediation monitoring programme (3 years);
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget and schedule.

TOTAL ESTIMATED COST OF WORKS

- €213,000.

Allow contingency of €193,000 for hazardous waste disposal at licensed site.

I 4.6 MINE BUILDINGS AT PLANT SITE

INTRODUCTION

The Mogul plant site at Garryard contains a number of large buildings and concrete structures but all of the plant has been removed. The site is currently used by a haulage contractor who is using the buildings and the open yard space. Some aspects of the site have some value as part of an integrated heritage site.

It must be expected that the subsoil below the site is contaminated in some areas. The majority of the site is paved and while this is not disturbed, potential leaching of contaminants off site will be minimised. Effluent from the site will currently arrive in the tailings lagoon or settlement pond. Any exposed areas of fill should either be covered or removed to a licensed site.

The overall site must be cleaned and landscaped to acceptable visual appearance.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Remnant buildings: Danger to humans & livestock/wildlife.
(b) Contaminated land.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Remnant Buildings

The *consequence* of the remnant structures representing a danger to humans and livestock/wildlife was assessed as *medium* based on the physical dimensions of the structures and hence the minor nature of associated possible dangerous situations.

The *likelihood* of the structures being a danger to humans and livestock/wildlife was assessed as *low* given the condition of the structures, and general public access.

The risk was assessed as Mc x Ll = Low risk.

Nevertheless it has been determined that some specific remediation actions are required.

(b) Contaminated Land

The consequence of exposure to potentially contaminated land to humans and livestock as well as leaching or erosion to surface water must be considered as *medium*. This is based on the likely high ground contamination of parts of the site.

The likelihood of exposure is considered as *medium* based on the fact that some ground works are being conducted at present by the occupants of the site. There are also some areas of exposed waste materials adjacent to the settlement pond.

The assessed risk is Mc x Ml = Medium risk.

Remedial action is required.

NOMINATED END USE

The nominated end use for the area of the remnant structures is alternative commercial use (e.g. workshops, visitor centre, etc.).

End use compliance criteria are to be developed and would be based on the findings of the heritage value assessment.

REMEDIATION OPTIONS CONSIDERED

Subject to possible conservation of some structures as heritage value, some specific remediation is proposed to limit, to the extent possible, any residual safety and environmental issues.

A critique of the remedial options considered to address these issues is as follows.

(i) Removal of Infrastructure and Site Rehabilitation

The objective of this option would be to ensure to the extent possible that the area is left in a state that would not pose a serious or likely risk to human and/or animal health as a consequence of the presence of the plant and infrastructure.

Site rehabilitation could cost in the order of €330,000

(ii) Retention of Plant & Infrastructure for an Alternative Use & Site Rehabilitation

Some of the infrastructure in place at the site may be retained for an alternative post-closure use. Some site rehabilitation works should be carried out to clean up and landscape peripheral areas. Depending on the after use, an investigation should be carried out to characterise the level of risk from contaminated ground. Investigation costs would be of the order of €33,000.

(iii) Site Drainage and Contaminated Areas

Existing site drainage must be maintained and any additional sources of potential contamination controlled. Exposed contaminated areas should be covered or removed and drained to engineered specification. No earthworks should be carried out without prior investigation of underlying materials and potential contaminants.

Estimated costs are €30,000.

(iv) Removal of Hostel Building

Estimated cost of €23,000.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- findings of the heritage assessment;
- nominated post-closure conceptual end use(s); and
- associated cost estimates

it is recommended that options (iii) and (iv) be adopted in the first instance, with consideration of the final end use. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Itemise existing infrastructure and evaluate potential for re-use;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Prepare detailed plan of site drainage and develop modification and maintenance plan;
- Prepare detailed site plan to show areas for upgrade of cover, new cover and drainage works;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Define site investigation programme to characterise contamination and risks;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF THE WORK

Costs estimated to be €53,000 for remedial works and €33,000 site investigation.

The site investigation may reveal a need for more remedial works if specific hazards are identified. A contingency of €164,000 should be allowed.

I 4.7 GORTEENADIHA MINING HERITAGE

Below the open cast workings there are a series of stone dressing structures from the early phase of working the open pit (Plate 4.5.2). These occur within the waste piles and are of archaeological interest. They should be protected until they can be surveyed.

HAZARD/ISSUE AND POTENTIAL IMPACT

(a) Destruction of Structures

There is no impact apart from the high risk of losing the structures if the area is accessed for other remedial works or any other purpose.

They should be protected as heritage and archaeological interest.

REMEDIAL OPTIONS CONSIDERED

The area should be fenced and conserved for heritage.

ACTIONS

The area should be fenced and surveyed, excavated and recorded as soon as possible.

The survey could be allocated to a University group and a cost of €8,000 should be allowed.

The cost of fencing the area is €2,415.

I 4.8 GORTEENADIHA: WASTE DUMPS

INTRODUCTION:

The site comprises the area of waste disposal and former ore processing around and north of the open cast mine.

It must be expected that the dumps contain sources of material which can result in elevated metals and salts due to sediment erosion and dissolved solids. The site is also of archaeological and heritage value.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) Surface waste & process dumps: Human toxicity.
(b) Surface waste & process dumps: Livestock toxicity.
(c) Surface waste & process dumps: Contamination of surface water.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Human Toxicity

The *consequence* for human toxicity as a result of poor quality drainage from this area was assessed as *high*.

The *likelihood* of a toxicity event occurring was assessed as *low* based on the potential for contact with the material to an extent to be toxic.

The assessed risk is Hc x Ll = Medium risk.

Remediation actions are required.

(b) Livestock Toxicity

The *consequence* of livestock toxicity as a consequence of oxidation products from waste material was assessed as *high*.

The *likelihood* of a livestock toxicity event occurring was assessed as *medium* given the general lack of a vegetative cover across the area and hence the absence of grazing, but there is access for animals.

The assessed risk is Hc x Ml = Medium risk.

Therefore it has been determined that remediation actions are required.

(c) Contamination of Surface Water

The *consequence* of erosion of contaminated sediment to surface water is *medium* due to cattle grazing downstream.

The *likelihood* of erosion is *high* due to existing gully erosion and lack of vegetation.

The assessed risk is Mc x Hl – Medium risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use for the Gorteenadiha surface waste and process dumps is a heritage site.

End use compliance criteria are to be developed and would be based on the findings of relevant heritage value assessments.

REMEDIATION OPTIONS CONSIDERED:

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However, the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline. As noted above, no data are available on the geochemistry of the Gorteenadiha waste material.

A critique of the remedial options considered is as follows.

(i) Placement of Appropriate Cover

The objectives of applying a cover over the waste material are to:

- reduce the potential oxidation of pyritic material and the generation of poor quality drainage;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

To achieve these objectives approximately 2000 m^3 of suitably benign material would be required to provide a cover of no less than 0.2 m across the area.

It is estimated that this option would cost in the vicinity of €33,000.

(ii) Institutional Controls

The objective of opting for institutional controls would be to control public access to the whole or portions of the area and to establish warning signs.

Institutional controls typically focus on fencing and signage. It is considered that only signage is required at a nominal cost of €800.

(iii) Drainage Works

The objective of remedial drainage works would be to control surface runoff from the area of the waste material. This could be achieved via the establishment of drainage channels and retention basins to provide residence time for sediment-laden runoff to settle. This would include cleaning of the drain along the roadside, and fencing with a drain along Cromwell’s road.

The estimated costs associated with this option are in the vicinity of €26,000.

(iv) Integrated Drainage Control

The objectives of an integrated drainage system would be to segregate 'clean' and 'dirty' water and direct the 'dirty' water to the Garryard wetland. This would have the effect of reducing the potential for contaminated seepage and surface runoff from discharging to downstream waterbodies.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such works are included under I 4.9 (iii). Cost estimates for conveying the dirty water through a culvert under the road to the wetland would cost in the order of €15,000, if required, and a contingency for this should be allowed.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- water balance data;
- heritage value assessment;
- availability of suitable disposal sites and borrow material; and
- associated cost estimates

It is recommended that remediation options (ii), (iii) and (iv) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Fence, excavate and record archaeology as soon as possible;
- Identify cover material source(s), confirm haul distances and costs;
- Draft up a conceptual integrated erosion and sediment control plan;
- Confirm extent of drainage works required and costs;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (cover material geochemistry, receiving stream water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL COST

- €26,800 plus a contingency of €15,000 to take drainage to the Garryard wetland if required.

I 4.9 UNDERGROUND AND SURFACE WORKINGS

INTRODUCTION

In the Gorteenadiha area there are some open pit workings and shallow, underground workings that are believed to date back to the early 19th century. The area is known to be dangerous due to small, open shafts in thick undergrowth and uncertain stability of the shallow open pit workings.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Open pit & underground workings: Subsidence/Collapse (loss of productive land use).
(b) Open pit & shafts: Danger to humans & livestock/wildlife.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Subsidence or Collapse

The *consequence* of subsidence resulting in the potential loss of productive land resources, has been assessed as *medium* based on the historic and current land capability of the area.

The *likelihood* of subsidence occurring has been assessed as *high* given the current extent of subsidence observed across much of the area of the underground workings.

The assessed risk is Mc x Hl = Medium risk.

Therefore it has been determined that remediation actions are required.

(b) Danger to Humans and Livestock

The *consequence* of the underground workings in terms of being a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the openings.

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as *high* given evidence of public access and use of the area, the lack of restrictions on grazing and the absence of institutional controls.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the underground workings is derelict land.

End use compliance criteria are to be developed and would be based on geotechnical stability and verification of any areas proposed for human and livestock access.

Post-remediation monitoring of subsidence and shaft stability would be required over 3 years.

Contingency planning will be required in the event of major subsidence and shaft collapse beyond predicted zones of affectation. Plans could include further institutional controls and acquisition of adversely affected property.

REMEDIATION OPTIONS CONSIDERED

Remedial options considered to address these requirements are as follows:

(i) Institutional Controls

The objective of opting for institutional controls would be to control public and livestock access to the whole or portions of the area of the underground workings.

Institutional controls typically focus on fencing and signage.

Costs associated with fencing and signage would be included with item I4.8.

(ii) Backfilling

Backfilling of a shaft is typically undertaken to permanently increase the safety of underground mine workings by stabilising shafts and adits.

Settlement of backfilled material can occur and implications on future land use need to be considered. Each shaft should be fenced.

Detailed survey is required to accurately locate and evaluate shaft remediation requirements. An allowance of €3,500 should be made for backfilling or local fencing as required.

The mine and process waste material in the Gorteenadiha area may be potentially suitable as backfill material, which would reduce costs.

(iii) Drainage Control

The objectives of improved drainage control would be to divert 'clean' water around the open void/underground workings.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such would be included in item I4.8.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- water balance data;
- heritage value assessment;
- availability of suitable disposal sites and borrow material;
- associated cost estimates

It is recommended that remediation options (i), (ii) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Survey all shafts and adits;
- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Investigate feasibility of backfilling shafts and selected surface workings with surface waste material;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €3,500 (plus items considered as part of I4.8).

I 5 SHALLEE SOUTH : (REFER TABLE 14.6)

INTRODUCTION

In the 19th and 20th centuries a number of workings were established to exploit Pb-bearing veins in the Shallee area. At Shallee South & West 14 veins were worked with surface excavations up to 80 m long and 10 m deep. Some areas are flooded and there is danger to humans and livestock by falling into voids and falling into flooded pits.

Upstream of the Shallee complex metal levels were elevated particularly for Pb and thallium (Tl). Downstream levels were also elevated, notably Pb, As and Zn.

Analysis of surface and sump waters from the Shallee (South & West) indicates elevated metals (Ba, Fe, Pb & Mn).

I 5.1 OPEN PITS : TOXICITY OF PONDED WATER

The ponds represent groundwater within the bottom of the open pits.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Open pits: Human toxicity.
(b) Open pits: Livestock toxicity.
(c) Groundwater and Surface Water.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Human Toxicity

The *consequence* of the open pits (waterbodies) resulting in human toxicity was assessed as *medium*.

The *likelihood* of such an event occurring was assessed as *low* given the chemistry of the waterbodies and remoteness.

The assessed risk is Mc x Ll = Low risk.

Nevertheless it has been determined that some remediation actions are required.

(b) Livestock Toxicity

The *consequence* of the open pit waterbodies resulting in livestock toxicity was assessed as *medium*.

The *likelihood* of such an event occurring was assessed as *low* given the chemistry of the waterbodies and difficult access.

It has been determined that some remediation actions are required.

(c) Surface Water and Groundwater Quality

The consequence of seepage to groundwater or leakage to surface water resulting in decreased water quality is assessed as low.

The likelihood of leakage is *medium* based on moderate to low permeability of the rocks and possibility of occasional over spill to surface water in heavy rain.

The assessed risk is Mc x Ll = Low risk.

No remedial measures are required.

NOMINATED END USE

The nominated end use for the Shallee (south & west) open pits is as derelict land or as part of a heritage site.

End use compliance criteria are to be developed and would be based on pit water quality and predictive modelling (re: final water level, flux rates, strata layering, turn-over, etc.

REMEDIATION OPTIONS CONSIDERED

No measures required. The pit water is in hydraulic continuity with the underground water and any remediation would form part of 5.3.

RECOMMENDED ACTION

None.

I 5.1 OPEN PITS : SCRAP AND WASTE

HAZARD / ISSUE AND POTENTIAL IMPACT

(a) Visual impact of Waste.
(b) Toxicity to humans and animals.
(c) Toxicity to groundwater and streams.

(a) Visual Impact

The consequences of the scrap and waste in the open pits is assessed as *medium* based on limited access. (Plate 5.3.2).

The likelihood is *low* based on the fact that it is not visible from outside the mine area and on the very small numbers of people who would enter the mine.

(b) Toxicity to Animals and Humans

The consequences are assessed as high as the content of some of the scrap drums is unknown.

The likelihood is low due to limited access for humans and animals.

The assessed risk is Lc x Ll = Medium risk.

Some remediation is required.

NOMINATED END USE

The nominated end use is as a heritage site.

REMEDIATION OPTIONS CONSIDERED

Remove the scrap and waste production materials to a licensed site.

RECOMMENDED ACTION

Remove scrap.

The costs are integrated with I 5.5.

I 5.1 OPEN PITS : SAFETY (PONDS AND ROCK FACES)

The nature of the various open pits and trenches is that most faces are dangerous in terms of animals or humans falling into them. Drowning could occur in the ponds. (Plates 5.1.1 to 5.1.5).

HAZARD/ ISSUE AND POTENTIAL IMPACT

(a) Injury and Death

The consequence of falling over the edge or in to the water is high.

The likelihood is *medium* to *low* due to the limited access.

The assessed risk is Hc x Ml = Medium risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use is as a heritage site.

End use compliance criteria are to be developed and would be based on accessibility.

REMEDIAL OPTIONS CONSIDERED

i) Backfill or Re-profile

This would cover the ponds and re-shape the rock faces and trenches to make safe. This would entail drilling and blasting all the edges as well as importing rock fill. Not considered necessary.

ii) Clear Vegetation

This would entail clearance of vegetation for 5m around the face edges to ensure visibility. This would also require ongoing bi-annual maintenance. This would be included in (iii) below.

iii) Fence Off

This would require a 7’ diamond mesh fence all around the open pit areas. This would entail a length of 1,500m at a cost of €48,000, with annual maintenance of €800.

RECOMMENDED ACTIONS

It is recommended that option (ii) and (iii) be adopted. Key actions are:

- Survey length of fencing required together with number of notices required;
- Prepare a schedule of works integrated with other remedial options for the site;
- Nominate end use compliance criteria;
- Define a maintenance programme;
- Prepare subproject budget.

TOTAL ESTIMATED COST OF WORK

The total cost is estimated at €48,000 with annual maintenance of €800.

I 5.2 SHAFTS

INTRODUCTION

There are four main shafts at Shallee, namely :

Kings Shaft
Whim Shaft
Field Shaft
Engine Shaft

There is an open shaft with a wide metal grid set in concrete at the edge of the drum dump. It appears to be an ore shoot or possibly a vent shaft. The field shaft is flooded and discharges water from the mine to the stream, north of the plant site.

The condition of the other shafts is unknown, as they have not been identified. It is assumed that they are capped but that some protection measures will be required. A detailed survey will be required to identify the exact position.

HAZARD / ISSUE AND POTENTIAL IMPACT

(a) Open shaft (human and livestock safety).
(b) Shaft Collapse.

(a) Open Shaft Human and Livestock

The consequences of the shafts being a danger is *medium* due to the nature of the shafts and their access.

The likelihood of the shafts being a danger is *medium* due to limited access to the site and ease of access to the shafts.

The assessed risk is Mc x Ml = Medium risk.

Remedial works are required.

(b) Shaft Collapse

The consequences are *low* due to limited access.

The likelihood is *low* due to the shaft construction and in a competent sandstone.

The assessed risk is Lc x Ll = Low risk.

Therefore no remedial works are required.

NOMINATED END USES

- Heritage area with limited and controlled access by the public.

REMEDIATION OPTIONS

(i) Fence Off

This would entail local fencing (7’ diamond mesh) for 5m radius around each shaft and suitable notices. The approximate cost for 4 shafts is €3,400.

(ii) Engineered Cap

An engineered cap would comprise a 200mm reinforced concrete slab placed on solid foundations. The latter could be the shaft collar if concreted or steel. This option is not considered necessary for any shaft, but a contingency of €12,880 should be provided.

(iii) Safety Grill

The whim shaft has a steel girder grill but the bars are sufficiently wide apart that a child or small animal can fall through. The grill must be replaced or augmented but kept open for possible visitor interest and bat access. The estimated cost for the grill is €3,300.

RECOMMENDED ACTIONS

It is recommended that options (i) and (iii) be adopted. The recommended key actions are:

- Survey each shaft position and assess condition of each;
- Identify fencing and grill needs;
- Prepare schedule of remediation works.

TOTAL ESTIMATED COST OF WORK

The total cost is €6,642.

I 5.3 UNDERGROUND MINE :SUBSIDENCE / COLLAPSE

INTRODUCTION:

There are significant underground mining works which are readily accessible by humans from the open pits. Although most are flooded, they represent a significant danger for uncontrolled access.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) Subsidence/Collapse: Danger to humans & livestock/wildlife.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Subsidence/Collapse

The *consequence* of the underground workings in terms of being a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the openings.

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as *medium* given evidence of public access and use of the area, the lack of restrictions on grazing and the absence of institutional controls.

The assessed risk is Hc x Ml = Medium risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the underground workings is as a heritage site.

End use compliance criteria are to be developed and would be based on geotechnical stability and verification of any areas proposed for human and livestock access.

Post-remediation monitoring of subsidence and shaft stability would be required over 3 years.

Contingency planning for will be required in the event of major subsidence and shaft collapse beyond predicted zones of affectation. Plans could include further institutional controls and acquisition of adversely affected property.

(i) Institutional Controls

The objective of opting for institutional controls would be to control public access to the whole or portions of the area of the underground workings.

Institutional controls typically focus on fencing and signage.

This would be incorporated in a fence around the open pits (see I 5.1).

(ii) Controlled Collapse

Engineering the collapse of a shaft known or considered likely to be unstable is routinely carried out to ensure the longer term safety of an underground working. It typically entails strategic blasting and/or excavation.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use(s);
- findings of geotechnical assessment;
- findings of heritage value assessment;
- associated cost estimates.

it is recommended that remediation options (i) be adopted and option (ii) be investigated further. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Topographic survey and design drainage;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORK

The total cost is integrated with I 5.1.

I 5.3 SAFETY (DROWNING AND FALLS)

It is relatively easy for humans to access the underground workings. These workings are partially flooded and there is possibility of roof collapse. If developed as a heritage site, access would be controlled and some stabilisation would be done.

HAZARD / ISSUE AND POTENTIAL IMPACT

(a) Human Injury and Death

The consequence of rock falls or drowning is high.

The likelihood is medium due to the limited access.

The assessed risk is Hc x Ml = Medium risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use is as a heritage site.

End use compliance criteria are to be developed and would be based on accessibility.

REMEDIAL OPTIONS CONSIDERED

(i) Restrict Public Access

This would comprise fencing and notices if the land is derelict, or fencing and institutional controls if it is developed as a heritage site. Fencing would be integrated with I 5.1.

(ii) Rock Support / Barring

If used as a heritage site, some making safe by barring down and rock anchors would probably be required. This option would need to be costed following a more detailed investigation and consideration of the final site end use.

RECOMMENDED ACTIONS

It is recommended that option (i) be adopted. Key actions are:-

- Survey length of fencing required together with number of notices required;
- Prepare a schedule of works integrated with other remedial options for the site;
- Nominate end use compliance criteria;
- Define a maintenance programme;
- Prepare subproject budget.

TOTAL ESTIMATED COST OF WORK

The total cost is integrated with I.5.1.

I 5.3 UNDERGROUND MINE : WATER CONTAMINATION

INTRODUCTION

The flooded underground workings may have water with elevated sulphate and metals in solution which can migrate through groundwater or surface water.

HAZARD / ISSUE AND POTENTIAL IMPACT

(i) Contamination of Surface Water and Groundwater

The consequence of seepage loss to the water environment is *low*.

The likelihood is *high* due mainly to the active discharge from the field shaft to the stream. The recent borehole investigation showed possibly elevated TDS and metals down hydraulic gradient of Shallee.

The assessed risk is Lc x Hl = Medium risk.

NOMINATED END USE

The nominated end use for the mine is as a heritage site.

REMEDIATION OPTIONS

(i) Intercept and treat seepage in a wetland

This will comprise collecting the existing discharge and passing through a constructed wetland.

The discharge flow rate and variation will require monitoring and evaluation to design the wetland requirements.

This would be integrated for a wetland for the site drainage at an estimated cost of €484,510 excluding land costs.

(ii) Divert Surface Water

There is considerable inflow of water from the hillsides which flows into the open pits and then underground. This should be diverted round the pits.

A detailed topographic and drainage survey is required.

Estimated costs are €1,810.

RECOMMENDED ACTIONS

The recommended action is options (i) and (ii).

The actions required are:

- Topo survey of site above the mine;
- Clean out and extend the existing diversion channel. Water should be diverted to the storage tank;
- Monitor flows and chemistry in the Field shaft discharge on a seasonal basis for an initial period of 1 year to assess wetland design requirements, followed by a further 2 years;
- Assess wetland size requirements;

- Integrate with other wetland requirements from Shallee;
- Identify land availability;
- Design and construct.

TOTAL ESTIMATED COST OF WORK

Total cost is estimated at €484,510 excluding land purchase for wetland.

Monitoring costs for the site will be €19,320 for a 3 year period.

Ongoing maintenance of the wetland will be required with allowance for clean out every 20 years.

Allowance for clean out at present day cost €8,050.

I 5.4 TAILINGS : DUST

INTRODUCTION:

As noted in the Phase I report sampling indicates that levels of Pb, Zn and Fe in the Shallee Tailings Management Facility (TMF) were elevated however they were significantly lower than those of the Garryard TMF and Gortmore TMF.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Dust with elevated metals: Elevated metals in local streams.
(b) Dust with elevated metals: Human toxicity and nuisance.
(c) Dust with elevated metals: Toxicity in herbage.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated Metals in Local Streams

The *consequence* of increased metals in local streams as a result of dust from the TMF was assessed as *medium.*

The *likelihood* of this occurring was also assessed as *low* given measured metals levels in the TMF.

The assessed risk is Mc x Ll = Low risk.

It has however been determined that remediation actions are required.

(b) Human Toxicity and Nuisance

The *consequence* of human toxicity as a consequence of dissolved metals in dust from the TMF was assessed as *medium* due to low levels of metals.

The *likelihood* of human toxicity occurring was assessed as *low* given the general lack of public access and use of the area.

The assessed risk is Mc x Ll = Low risk.

Nevertheless it has been determined that some remediation actions are required.

(c) Toxicity in Herbage

The *consequence* of livestock toxicity associated with high dissolved metals in dust from the TMF settling on pasture was assessed as *medium*.

The *likelihood* of such an event was assessed as *low* given the limited exposure on non-vegetated tailings and low metals.

The assessed risk is Mc x Ll = Low risk.

No specific remedial measures are required.

NOMINATED END USE

The nominated end use for the TMF is as a heritage site and/or derelict land.

End use compliance criteria are to be developed and would be based on air quality data for dust emissions from the TMF and any future public use of the area.

One-off post-remediation monitoring of TMF dust quality would be required within 12 months.

Contingency planning will be required in the event of non-compliant dust emissions. Plans could include alternative capping and/or revegetation methodologies.

REMEDIATION OPTIONS CONSIDERED

(i) Placement of Appropriate Cover

The objectives of applying a cover over the TMF would be to:

- reduce the potential for mobilisation of sediment laden with elevated levels of TDS and metals;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover.

To achieve these objectives approximately 500m^3 of suitably benign material would be required to provide a cover of 100mm across the TMF area where vegetation is weak. Some re-profiling would be required on the north tailings where some excavation has been done.

Likely costs will be around €13,000.

(ii) Revegetation

May be required to promote initial growth. Cost included in (i) above.

(iii) Maintain Fencing

There is existing farm fencing around the northern tailings which should be maintained. Controlled access for public to the southern tailings would be as part of overall site development for heritage.

(iv) Designated Monitoring Program & Contingency Planning

This option would involve the establishment of a sampling, analysis and assessment program to monitor the quality and quantity of dust emissions from the TMF. Plans would need to be in place in the event that monitoring indicated emissions that were not in compliance with pre-determined criteria.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the TMF sediment;
- availability of borrow material;
- associated cost estimates.

It is recommended that remediation options (i), (ii) and (iii) be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Topographic survey and schedule of quantities;
- Identify suitable borrow material source;
- Develop a revegetation plan;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

Total costs are €13,000.

I 5.4 TAILINGS : STABILITY

HAZARD/ISSUE AND POTENTIAL IMPACT

Slope failure and release (flow) of tailings

ASSESSED RISK

The likelihood of a tailings embankment failure is considered low, and because the tailings mass is consolidated and not covered by surface water the consequences of tailings release is also considered low because the tailings would not be expected to flow.

The risk is therefore Lc x Ll = Low risk.

NOMINATED END USE

No change is proposed other than revegetation.

ACTIONS

None proposed with respect to slope failure.

I 5.4 TAILINGS : LEACHING

INTRODUCTION

The surface water sampling programme indicated that the streams increased in metal content past the northern tailings but less so than past the southern tailings. The majority of elevated constituents are in suspended form. Some values are above the standards. There are some small erosion features which will require backfilling, re-profiling and vegetation.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Tailings leachate/erosion: Elevated TDS & metals in surface and ground water.
(b) Tailings leachate/erosion: Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated TDS and Metals in Water

The *consequence* of increased metals in local streams and groundwater via flows (& seepage) from the tailings lagoon was assessed as *low*.

The *likelihood* of this occurring was assessed as *medium* given measured metals levels in the TMF and the small catchment area of the TMF.

The assessed risk is Lc x Ml = Low risk.

It has however been determined that remediation actions are required.

(b) Livestock Toxicity

The *consequence* of livestock toxicity associated with high dissolved metals in the TMF was assessed as *medium*.

The *likelihood* of such an event was assessed as *low* given the stream water quality and the potential for livestock to access the TMF area.

The assessed risk is Mc x Ll = Low risk.

NOMINATED END USE

The nominated end use for the TMF is as a heritage site.

End use compliance criteria are to be developed and would be based on water balance data for the TMF, inflow and outflow water quality, statutory discharge water quality requirements and any future public use of the area.

Post-remediation monitoring of wetland discharge water and sediment quality would be required over 3 years to confirm variation and wetland design and performance.

Contingency planning will be required in the event of non-compliant discharge water and sediment quality. Plans could include institutional controls, and diversionary drainage works and adoption of a discharge treatment system.

REMEDIATION OPTIONS CONSIDERED

The key issue is reduction of erosion of suspended solids from some areas of the TMF

(i) Placement of Appropriate Cover

See as for Dust.

(ii) Drain to Constructed Wetland

The objective of directing TMF seepage via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended solids retention. The run-off from the tailings will be integrated with drainage from the Shallee Mine site.

The costs are integrated with I 5.3 for underground water discharge.

(iii) Revegetation

Some revegetation would reduce the risk of erosion and this is covered under ‘dust’.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of seepage
- availability of suitable borrow material;
- availability of wetland or water treatment plant sites; and
- associated cost estimates

It is recommended that remediation options (ii) and (iii) be adopted. Key actions for the implementation of this remediation measure are summarised below.

The costs are included under Tailings : Dust and Underground water contamination (I 5.3).

RECOMMENDED KEY ACTIONS

- Establish monitoring programme;
- Prepare TMF water balance and integrate with I 5.3;
- Identify suitable borrow material source;
- Where required undertake revegetation trials with selected cover material;
- Develop a revegetation plan;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Prepare an overall sub-project budget.

I 5.5 WASTE DUMPS

INTRODUCTION

The main waste dump on the north west side of the site comprise a mixture of mine rock waste, metal scrap, concentrate from Mogul, process chemicals and unknown mixed wastes. It is understood that process materials and chemical drums and other mine scrap was brought from the Mogul plant site. Some of the dump overlies a small non-perennial drainage.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Surface disposal of concentrate, process chemicals & unknown mixed wastes, metal & general scrap: Contamination of local streams.
(b) Surface disposal of concentrate, process chemicals & unknown mixed wastes, metal & general scrap: Human toxicity.
(c) Surface disposal of concentrate, process chemicals & unknown mixed wastes, metal & general scrap: Livestock toxicity.
(d) Surface disposal of concentrate, process chemicals & unknown mixed wastes, metal & general scrap: Negative aesthetic impact.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Contamination of Local Streams

The *consequence* of run-off from the area of the waste material at Shallee (South & West) resulting in contamination local streams, was assessed as *high*.

The *likelihood* of this occurring was also assessed as *high* based on available water and sediment quality data.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

(b) Human Toxicity

The *consequence* of run-off resulting in human toxicity was assessed as *high*.

The *likelihood* of such an event occurring was assessed as *low* given the current level of public access to the area.

The assessed risk is Hc x Ll = Medium risk.

It has been determined however, that some remediation actions are required.

(c) Livestock Toxicity

The *consequence* of the surface run-off being toxic to livestock/wildlife has been assessed as *high*.

The *likelihood* of this occurring was assessed as *high* based on the general lack of institutional controls limiting livestock access to the area and the credibility of the material and proximity to the drainage channel.

The risk is assessed as Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

(d) Aesthetics

The *consequence* of the waste material resulting in negative aesthetic impact was assessed as *high* given the visibility of the material from areas of habitation.

The *likelihood* of this occurring was also assessed as *high* for the same reason.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the underground workings is as a heritage site , or derelict land.

End use compliance criteria are to be developed and would be based on findings of the heritage assessment, geotechnical stability and verification of any areas proposed for human and livestock access.

Post-remediation monitoring of subsidence and shaft stability would be required over 12 months.

Contingency planning will be required in the event of major subsidence and shaft collapse beyond predicted zones of affectation. Plans could include further institutional controls and acquisition of adversely affected property.

REMEDIATION OPTIONS CONSIDERED

(i) Integrated Drainage Control

The objectives of improved drainage control would be to divert upstream 'clean' water and intercept 'dirty' water, to reduce the potential for contaminated surface runoff. Intercepted 'dirty' water would be directed to a wetland.

Upstream diversion would also be required and would be integrated with 5.3.

(ii) Drainage Works

The objective of remedial drainage works would be to control surface runoff and seepage from the area of the waste material. This could be achieved via the establishment of drainage channels and retention basins to provide residence time to settle sediment-laden runoff. The effluent water would require some treatment in a constructed wetland as a minimum.

This would be integrated with 5.3.

(iii) Remove Contaminated Material & Dispose of On-site/Off-site

The main objective of this option is to eliminate the potential for further contamination of downstream waterbodies. This would necessitate the excavation, removal and emplacement of approximately 4,000 m^3 of waste material, and importation of topsoil to create vegetated cover, over 5,000 m^2. Some site rehabilitation works would also be required to create a landscape in keeping with the visual theme of the surrounding area. The excavated material would be removed to the Gortmore waste disposal facility. Excavation works, haulage, disposal and rehabilitation costs would be around €118,420.

Other wastes (scrap metals, drums, piping, cables etc.) will require segregation and it is assumed that this material would be disposed of in a registered tip, such as that at Shannon. An allowance of €50,000 has been made for this.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use(s);
- findings of heritage value assessment;
- downstream water quality data;
- availability of disposal site(s);
- associated cost estimates

It is recommended that remediation option (iii) be adopted. Key actions for the implementation of this remedial measure are summarised below. Items (i) and (ii) would be part of other remedial works (I5.3).

RECOMMENDED KEY ACTIONS

- Survey quantity of materials to move;
- Identify disposal site for removed material, confirm haul distances & costs;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria & incorporate into post-remediation monitoring program;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall subproject budget.

TOTAL ESTIMATED COST OF WORKS

The total cost for the waste dump removal and rehabilitation is €168,420.

I 5.6 MINE BUILDINGS / PLANT SITE

INTRODUCTION

The Shallee area contains a number of remnant buildings of heritage value, and it is recommended that they be conserved where practical.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Remnant buildings: Danger to humans & livestock/wildlife.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Danger

The *consequence* of the remnant structures representing a danger to humans and livestock/wildlife was assessed as *medium* based on the physical dimensions of the structures and hence the minor nature of associated possible dangerous situations.

The *likelihood* of the structures being a danger to humans and livestock/wildlife was assessed as *low* given the condition of the structures and access.

The assessed risk is Mc x Ll = Low risk.

Nevertheless it has been determined that some specific remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the remnant structures is a heritage site.

End use compliance criteria are to be developed and would be based on the findings of detailed heritage assessment.

REMEDIATION OPTIONS CONSIDERED

Subject to the findings of the heritage value assessment some specific remediation is proposed to limit, to the extent possible, any residual safety and environmental issues.

A critique of the remedial options considered to address these issues is as follows.

(i) Removal of Buildings and Site Rehabilitation

The objective of this option would be to ensure to the extent possible that the area is left in a state that would not pose a serious or likely risk to human and/or animal health as a consequence of the presence of the plant and infrastructure. This is not a realistic option in view of the heritage value.

(ii) Conservation of Heritage Structure

Conservation works will be required on the stone structures. Limited work will be required on the concrete plant foundations to make safe. The major work would be to restore the Kings house. This would cost of the order of €161,000.

The engine house consolidation would require €16,100 and allowance of €128,800 should be made for all other structures, including core sheds, laboratory and offices.

The total cost of this option is estimated to be €305,900.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- findings of the heritage assessment;
- nominated post-closure conceptual end use(s); and
- associated cost estimates

It is recommended that option (ii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Prepare a schedule of remediation and conservation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring program;
- Assess potential for integration with remediation actins for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL COST

- €305,900.

I 5.7 WATER RESERVOIR

The reservoir is part of the drainage system and part of the mine heritage that is worth preserving. The key concern is the potential for drowning.

HAZARD/ ISSUE AND POTENTIAL IMPACT

(a) Injury and Death

The consequence of falling in the water is *medium*.

The likelihood is *low* due to the limited access.

The assessed risk is Mc x Ll = Medium risk.

Remedial actions are required, particularly if there is public access.

NOMINATED END USE

The nominated end use is as a heritage site.

End use compliance criteria are to be developed and would be based on accessibility.

REMEDIAL OPTIONS CONSIDERED

iii) Backfill or Re-profile

This would require emptying the reservoir and backfilling.

ii) Fence Off

This would require a 7’ diamond mesh fence all around the perimeters plus notices. This would entail some clearance of vegetation and a fence length of 200m at a cost of €4,200.

RECOMMENDED ACTIONS

It is recommended that option (ii) be adopted. Key actions are:

- Survey length of fencing required together with number of notices required;
- Prepare a schedule of works integrated with other remedial options for the site;
- Nominate end use compliance criteria;
- Define a maintenance programme;
- Prepare subproject budget.

TOTAL ESTIMATED COST OF WORK

The total cost is estimated at €4,200 with annual maintenance of €800.

I 5.8 SHALLEE WEST : OPEN PITS : SAFETY (PONDS AND ROCK FACES)

The nature of the various open pits and trenches is that most faces are dangerous in terms of animals or humans falling into them. Drowning could occur in the ponds although the ponds are very small.

HAZARD/ ISSUE AND POTENTIAL IMPACT

(a) Injury and Death

The consequence of falling over the edge or in the water is *high*.

The likelihood is *medium* to *low* due to the limited access.

The assessed risk is Hc x Ml = Medium risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use is as derelict mine land.

End use compliance criteria are to be developed and would be based on accessibility.

REMEDIAL OPTIONS CONSIDERED

(i) Backfill or Re-profile

This would cover the ponds and re-shape the rock faces and trenches to make safe. This would entail drilling and blasting all the edges as well as importing rock fill. This option is not considered necessary (see 5.9).

ii) Clear Vegetation

This would entail clearance of vegetation for 5m around the face edges to ensure visibility. This would also require ongoing bi-annual maintenance. This would be integrated with (i) and 5.9.

iii) Fence Off

This would require a 3 strand wire fence and signs all around the open pit areas. This would entail a length of 750m at a cost of €6,038, with annual maintenance of €400.

RECOMMENDED ACTIONS

It is recommended that option (iii) be adopted. Key actions are:

- Survey length of fencing required together with number of notices required;
- Prepare a schedule of works integrated with other remedial options for the site;
- Nominate end use compliance criteria;
- Define a maintenance programme;
- Prepare subproject budget.

TOTAL ESTIMATED COST OF WORK

The total cost is estimated at € 6,038 with annual maintenance of €400.

I 5.9 SHALLEE WASTE DUMPS

INTRODUCTION:

The waste dumps are small and limited to around the open pits. They comprise mined waste rock with similar chemistry to Shallee South/East.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Contact and ingestion from animals. Human contact is not considered an issue due to very limited access and area exposed.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Contamination of Local Streams

The *consequence* of run-off from the area of the waste material at Shallee (West) resulting in contamination local streams, was assessed as *low* due to limited downstream exposure.

The *likelihood* of this occurring was also assessed as *low* based on limited exposed sediment.

The assessed risk is Lc x Ll = Low risk.

Therefore it has been determined that remediation actions are required.

(b) Livestock Toxicity

The *consequence* of direct contact being toxic to livestock/wildlife has been assessed as *medium*.

The *likelihood* of this occurring was assessed as *medium* based on livestock access to the area.

The risk is assessed as Mc x Ml = Medium risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area is derelict land, although the area could be included as part of the Shallee South/East heritage site.

REMEDIATION OPTIONS CONSIDERED

The only option considered is to consolidate the waste into the adjacent open pit and to cover with soil substitute. Natural seeding will enable vegetation growth. The cost would be of the order of €3,220.

RECOMMENDED ACTIONS:

It is recommended that the remediation option above be adopted. Key actions for the implementation of this remedial measure are summarised below.

RECOMMENDED KEY ACTIONS

- Survey quantity of materials to move;
- Identify suitable source of soil substitute;
- Prepare a schedule of remediation works;
- Confirm end use compliance criteria;
- Integrate with remediation actions for Shallee South/East;
- Prepare an overall subproject budget.

TOTAL ESTIMATED COST OF WORK

The cost for limited backfilling would be €3,220.

I 6 GORTMORE TMF

There are a number of key issues associated with the TMF. The following assessments are based on the engineering and chemical information and our interpretation of environmental issues and observations.

Unless a full cover is specified, the possible end use is as derelict land with limited, controlled grazing as part of vegetation management. However, part of the TMF should also be considered as an option for disposal of various mining wastes and stream sediments identified in assessments of other areas of the study. Remediation option discussed here considers ecological issues which are presented in Appendix I.

The preparation and management of the site for other waste disposal must be considered as a separate cost to remediation costs.

A key issue is the maintenance of the TMF in perpetuity and closure of the responsibility of Mogul. This is considered in the Phase III report.

I 6.1 METALS IN DUST

INTRODUCTION

Dust blow has been a key issue for the TMF and the following assessment is based on the present situation. If conditions are changed on the surface of the TMF by a change of land use resulting in lack of mitigation, then the risk assessments could change from low to high. The present vegetation cover is fair but approximately 20% of the area is poor or has no cover.

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 4.7):

(a) Dust with elevated metals: Elevated metals in soil and herbage.
(b) Dust with elevated metals: Pollution of water courses.
(c) Dust with elevated metals: Human and animal toxicity.
(d) Dust: nuisance.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated metals in soil and herbage

The *consequence* of human toxicity as a consequence of high dissolved metals in dust from the TMF was assessed as *medium*.

The *likelihood* of human toxicity was assessed as *low* given the vegetation cover and the nature of the present surface of the TMF provided it is not disturbed by animals or other means.

The assessed risk is Mc x Ll = Low.

Nevertheless some remediation is considered appropriate and necessary to improve and ensure the future integrity of the vegetation cover.

(b) Pollution of water courses

The *consequence* of increased metals in local streams as a result of dust from the TMF was assessed as *low* due to the limited amount of blow and the high dispersion.

The *likelihood* of this occurring was also assessed as *low* given the vegetation cover and the nature of the present surface of the TMF provided it is not disturbed by animals or other means.

The assessed risk is Lc x Ll = Low.

Nevertheless some remediation is considered appropriate and necessary to improve and ensure the future integrity of the vegetation cover.

(c) Human and animal toxicity and dust nuisance

The *consequence* of human and livestock toxicity associated with high dissolved metals in dust from the TMF was assessed as *medium*.

The *likelihood* of such an event was assessed as *low*

The *likelihood* of this occurring was also assessed as *low* given the vegetation cover and the nature of the present surface of the TMF provided it is not disturbed by animals or other means.

The assessed risk is Lc x Ll = Low.

Nevertheless some remediation is considered appropriate and necessary to improve and ensure the future integrity of the vegetation cover.

NOMINATED END USE

The nominated end use for the TMF is for derelict land with part for mine waste disposal.

End use compliance criteria are to be developed and would be based on air quality data for dust emissions from the TMF and any future public use of the area.

Existing dust monitoring should continue for three years after completion of any remedial works.

Contingency planning will be required in the event of non-compliant dust emissions. Plans could include alternative capping and/or revegetation methodologies.

REMEDIATION OPTIONS CONSIDERED

Remedial options considered appropriate are as follows.

(i) Restrict access

Access by animals or machinery that could significantly disturb the balance of the existing cover must be avoided by exclusion. There are existing physical barriers such as fences and ditches but additional constraints such as notices and policing will be required.

(ii) Improve vegetation cover

The objective would be to provide a growth medium over areas presently not covered or poorly covered by grasses. The cover should have some organic content and be approximately 300mm thick. Various sources of material could be used. The volume of material required would be 37,500m^3 and the costs to provide material from a formal source of borrow would be € 582,000.

Reseeding of the TMF (approx. 12 ha) would cost approximately €40,000. Some maintenance and supplementary works may also be required.

The revegetation would incorporate vegetation wind breaks to provide additional wind protection and improve the visual landscape. Detail of revegetation issues are presented in Section 3 of Appendix G. The above is a summary of a likely option but final details will depend on detailed survey and use for other waste disposal

Revegetation must take cognisance of existing vegetation and drainage as discussed in Section 2.8 of the report and Appendix G.

The total cost of this option would be approximately €622,000.

(iii) Engineered cover

The objectives of applying an engineered cover over the TMF would be to:

- reduce the potential for mobilisation of seepage water laden with elevated levels of TDS and metals;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover which could sustain grazing.

The cover would require a capillary break of limestone gravel, an impermeable layer of about 500mm thickness and a growth medium.

Approximate cost of materials, delivery and construction are €6,393,500.

(iv) Establish monitoring programme & Contingency planning

This would comprise ongoing dust monitoring and development of a vegetation monitoring programme. This should continue for a period of 5 years until fully established. It is understood that the EPA maintain the present dust monitoring programme.

Contingency plans would need to be in place in the event that monitoring indicated emissions that were not in compliance with pre-determined criteria. An allowance of €20,000 should be made for monitoring for a 5 year period.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the TMF sediment;
- availability of borrow material;
- associated cost estimates.

It is recommended that remediation options (i), (ii) and (iv) be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Restrict access to the site;
- Identify suitable growth medium sources;
- Where required undertake re-vegetation trials with selected cover material;
- Develop a revegetation plan;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare vegetation and dust monitoring programme;

- Prepare an overall sub-project budget.

TOTAL ESTIMATED OF COST OF WORK

The cost is estimated at €622,000 with an allowance of €20,000 for monitoring for 5 years.

I 6.2 VISUAL

INTRODUCTION

Key concern of local residents is the appearance of the outer slopes of the TMF. This appearance is aggravated by variable sulphide oxidation and associated iron staining.

HAZARD/ISSUE AND POTENTIAL IMPACT

(a) Visual Appearance

The consequence of the visual effect must be assessed as medium.

The likelihood must be assessed as medium as it is an existing visual effect primarily on the eastern side. The western side is already well screened.

The assessed risk is Mc x Ml = Medium risk.

REMEDIATION OPTIONS CONSIDERED

(i) Revegetate Crests of Slope

The crest comprises about 1 to 2m of tailings around part of the perimeter where a step back wall was constructed from tailings. This is often pyritic and poorly vegetated and requires reprofiling to a flatter shape covering with soil and planting with gorse or suitable shrub vegetation as a wind break.

Approximate cost is €8,300.

(ii) Tree Screen

It is not feasible to vegetate the rock slopes but tree planning will provide an effective screen. It is estimated that the cost will be of the order of €81,000.

RECOMMENDED ACTIONS

It is recommended that options (i) and (ii) are implemented.

RECOMMENDED KEY ACTIONS

- Survey the TMF for quantities of works required and areas to be remediated;
- Identify suitable mix of tree species;
- Identify source of trees;
- Integrate with other remedial works on the TMF;
- Develop programme and cost of works.

TOTAL ESTIMATED COST OF WORK

The total cost is approximately €89,300.

I 6.3 LEACHING OF METAL

INTRODUCTION:

Leaching occurs through the embankment walls as shown by ferruginous staining at the toe. It is assumed there is vertical leakage to the groundwater. Around the toe are various collection paddocks, drain and wetlands (east side). These perform a valuable wetland function.

The TMF does not appear to have a large effect on the quality of the Kilmastulla River but there are elevated metals identified in groundwater (Section 7.7).

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 14.7)

(a) Tailings leachate: Elevated TDS & metals in surface and ground water.
(b) Tailings leachate: Human and Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated TDS and metals in water

The *consequence* of increased metals in local streams and groundwater via flows (& seepage) from the tailings lagoon was assessed as *medium* given the measured quality of leachate and proximity of streams.

The *likelihood* of this occurring was also assessed as *medium* given measured metals levels in the TMF and lack of lining to prevent access to groundwater.

The assessed risk is Mc x Ml = medium.

Remedial actions are required although the indicated groundwater and surface water qualities in the area do not show high levels of TDS or metals apart from some mercury. This requires further evaluation.

(b) Human and livestock toxicity

The *consequence* of human and livestock toxicity associated with high dissolved metals in the TMF was assessed as *medium*.

The *likelihood* of such an event was assessed as *low* given the stream water quality and the potential for livestock to access the TMF area and for humans to drink the water.

The assessed risk is Mc x Ll = low.

NOMINATED END USE

The nominated end use for the TMF is for derelict land and for mine waste disposal.

End use compliance criteria are to be developed and would be based on air quality data for dust emissions from the TMF and any future public use of the area.

Existing dust monitoring should continue for three years after completion of any remedial works.

Contingency planning will be required in the event of non-compliant dust emissions. Plans could include alternative capping and/or revegetation methodologies.

REMEDIATION OPTIONS CONSIDERED

The leaching will be influenced by infiltration from surface and the vegetation.

Routine sampling of groundwater from the piezometers and surface water from the discharges and the streams, on a quarterly basis for four years will provide the baseline to reassess the profile of leaching. Investigation of the occurrence of mercury in groundwater, identified in the recent groundwater investigation has shown levels to be very low and the risks of impact on any receptor is very low.

Remedial options considered appropriate are as follows.

(i) Restrict access

Access by animals or machinery that could significantly disturb the balance of the existing cover must be avoided by exclusion. This will maintain the integrity of the surface layer and minimise infiltration. There are existing physical barriers such as fences and ditches but additional constraints such as notices and policing will be required.

(ii) Treatment plant

A treatment plant could be established but the level of metals or TDS is not generally outside acceptable limits. It would be very difficult to extract the ground water to treat and it is considered to be not warranted.

(iii) Wetlands at Toe

The existing paddocks, drains and wetlands to be improved to ensure all seepage is collected and has sufficient residence time in wetlands. This would be integrated with I6.2 and I6.4.

(iv) Information Signs

The indicated level of impact of the tailings on water is small and remedial action is likely to be limited to information signs in the immediate area of the TMF. A nominal cost of €1,600 is assumed.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the TMF sediment;
- availability of borrow material;
- associated cost estimates.

It is recommended that remediation options (i), (iii) and (iv) be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Restrict access to the site;
- Establish a monitoring schedule;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;

- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Integrate with monitoring actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORK

The total costs are €17,000.

Ongoing monitoring for a 4 year period is essential and costs would be €16,000.

I 6.4: EROSION BY RUN-OFF

INTRODUCTION

Refer to the comments above for the TMF.

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 14.7)

(a) Contamination of agricultural land.
(b) Metal sediments in river.
(c) Human toxicity.
(d) Livestock toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Contamination of agricultural land

The *consequence* of erosion products getting onto agricultural land was assessed as *medium* given the known effects of excess sediment albeit over a probable limited area.

The *likelihood* of this occurring was assessed as *low* given low present runoff and existing catch facilities including vegetation around the toe and catch drains.

The assessed risk is Mc x Ll = low.

Improvement of the toe catchments should be carried out together with other remedial works (Item I 6.3).

(b) Metal sediments in rivers

The *consequence* of erosion products getting in the rivers was assessed as *medium* given the known effects of excess sediment albeit over a probable limited area.

The *likelihood* of this occurring was assessed as *low* given the existing catch facilities including vegetation around the toe and catch drains.

The assessed risk is Mc x Ll = low.

Improvement of the toe catchments should be carried out together with other remedial works (Item I 6.3).

(c) Human and livestock toxicity

The *consequence* of human and livestock toxicity associated with high dissolved metals in the transported sediment was assessed as *medium* principally in terms of animals ingesting sediment. There is negligible risk to humans.

The *likelihood* of such an event was assessed as *low* given the stream water quality and the potential for livestock to access the TMF area.

The assessed risk is Mc x Ll = low.

Remedial action is not required.

(i) Restrict access to prevent surface disturbance

Access by animals or machinery that could significantly disturb the balance of the existing cover must be avoided by exclusion. There are existing physical barriers such as fences and ditches but additional constraints such as notices and policing will be required.

(ii) Improve vegetation cover

The objective would be to provide a growth medium over areas presently not covered or poorly covered by grasses. This would be integrated with I6.1.

(iii) Improve sediment traps around toe

There are existing traps but they need to be re-engineered in the light of observed weak points and future requirements for sediment control during construction of any other remedial works.

Once the surface of the TMF is vegetated ongoing maintenance should not be necessary.

A program of this nature would cost approximately €9,390

(iv) Establish monitoring programme & Contingency planning

This would comprise development of a vegetation monitoring programme. This should continue for a period of 5 years until fully established.

Plans would need to be in place in the event that monitoring indicated emissions that were not in compliance with pre-determined criteria. This monitoring would be integrated with I 6.1

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the TMF sediment;
- availability of borrow material;
- associated cost estimates.

It is recommended that all the above remediation options be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Restrict access to the site;
- Integrate revegetation plans with I 6.1;
- Survey the toe to compile earthworks requirements for toe paddocks;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare vegetation and erosion monitoring programme;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORK

The total cost would be approximately €9,390.

I 6.5 DEEP SEATED INSTABILITY

INTRODUCTION

The TMF is well constructed and stability analyses during operations showed factors of safety against failure of 1.2. Since closure, consolidation and reduction in moisture will have improved the stability.

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 14.7)

(a) Contamination of agricultural land.
(b) Metal sediments in river.
(c) Human toxicity.
(d) Livestock and herbage toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Contamination of agricultural land

The *consequence* of erosion products getting onto agricultural land was assessed as *low* because the extent of influence of a failure is likely to be local.

The *likelihood* of this occurring was assessed as *low* because of the low probability of failure combined with the low probability of the material reaching the fields.

The assessed risk is Lc x Ll = low.

Remedial actions are not required.

(b) Metal sediments in rivers

The *consequence* of erosion products getting in the rivers was assessed as *low* given the limited probable extent of a possible failure.

The *likelihood* of this occurring was assessed as *low* because of the low probability of failure combined with the low probability of the material reaching the fields.

The assessed risk is Lc x Ll = low.

Remedial actions are not required

(c) Human and livestock toxicity

The *consequence* of erosion products getting onto agricultural land was assessed as *low* because the extent of influence of a failure is likely to be local.

The *likelihood* of this occurring was assessed as *low* because of the low probability of failure combined with the low probability of the material reaching the fields.

The assessed risk is Lc x Ll = low.

Remedial actions are not required

NOMINATED END USE

The nominated end use for the TMF is derelict land.

REMEDIATION OPTIONS CONSIDERED:

Although the assessed risks are low, certain remediation options should be considered as part of ensuring sustainability and integrated with other items.

Remedial options considered appropriate are as follows.

(i) Push Down outer slopes

The objective would be to flatten the outer slopes but there is no justification for this provided the rock berm is not disturbed and the phreatic surface is maintained in a low level within the dam by maintaining the drainage of the surface of the TMF.

(ii) Maintain surface water drainage

The existing pond on the TMF can be developed into a wetland feature but it should not be allowed to develop larger than at present. Drainage to the settlement pond should be maintained.

(iii) Establish monitoring programme & Contingency planning

This would comprise development of a monitoring programme for the slopes and for the pond. This would be an ongoing requirement.

Plans would need to be in place in the event that monitoring indicated conditions that were not in compliance with pre-determined criteria.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the TMF sediment;
- availability of borrow material;
- associated cost estimates.

It is recommended that remediation options (ii) and (iii) be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Prepare monitoring programme;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORK

Final costs integrated with 6.1 and 6.6.

I 6.6: TAILINGS POOL

INTRODUCTION:

The tailings pool is important to maintain some source of water to maintain vegetation growth and local ecosystem with abundant birdlife which has developed. The negative aspect is that it maintains a vertical driving force for leachate to groundwater. However the quality of the water is known to be ranging from (pH3) to (pH6). Ongoing sampling is required to properly characterise the chemistry.

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 14.7)

(a) Elevated TDS & metals in surface and ground water.
(b):Human and Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated TDS and metals in groundwater and surface water

The *consequence* of increased metals in local streams and groundwater via flows (& seepage) from the tailings pool was assessed as *medium* given the measured quality of leachate and proximity of streams and the vertical recharge to groundwater.

The *likelihood* of this occurring was also assessed as *medium* given measured metals levels in the pool, and lack of lining to prevent access to groundwater. However, it is assessed as *low* for surface water due to drainage to the retention ponds.

The assessed risk is Mc x Ml = medium for groundwater (low for surface water)

Remedial actions are required although the indicated groundwater and surface water qualities in the area do not show high levels of TDS or metals apart from some mercury. This requires further evaluation.

(b) Human toxicity

The *consequence* of toxicity to Humans associated with high dissolved metals in the pool was assessed as low.

The *likelihood* of such an event was assessed as *low* given the access.

The assessed risk is Lcx Ll = low.

(c) Livestock, wildlife and herbage toxicity

The *consequence* of toxicity associated with high dissolved metals in the pool was assessed as *medium* due to the poor quality.

The *likelihood* of such an event was assessed as *medium* given the access particularly for birds and wildlife.

The assessed risk is Mc x Ml = medium.

Some remedial work is required.

NOMINATED END USE

The nominated end use for the TMF is derelict land.

End use compliance criteria are to be developed and would be based on air quality data for dust emissions from the TMF and any future public use of the area.

REMEDIATION OPTIONS CONSIDERED

Remedial options considered appropriate are as follows.

(i) Treat the decant water

This would be an ongoing treatment requirement and would not solve the problem of recharge to ground water or the remove the surface pond. This would be an expensive and ongoing option and will not be costed.

(ii) Drain pool, backfill and revegetate

This would require backfilling to a profile to promote drainage off the surface of the TMF. This would either require re-profiling of the tailings surface with a benign cover or to import material to fill. The former would require smaller quantities of imported fill but would require disturbance of sulphide bearing tailings. It is not practical to re-profile the whole TMF due to disturbance of tailings and mobilisation of leachate and sediment. It would be preferable (if drainage is required) to lower the decant and discharge system. This would be similar to option (iii) but with more excavation work. The estimated cost would be €66,000.

(iii) Upgrade the pond decant

This will enable a smaller pond to be maintained. This will require some earthworks, pipework and concrete works to decant water to the retention ponds.

The estimated costs are €31,500.

(iv) Prevent access for livestock

Prevention of access is required to maintain the surface integrity for dust blow.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the TMF sediment;
- availability of borrow material;
- associated cost estimates.

It is recommended that remediation option (iii) be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Restrict access to the site;
- Survey the site;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Integrate with remediation actions for items 6.1 and 6.5;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORK

The total costs are estimated as €31,500.

I 6.7 RETENTION PONDS

INTRODUCTION

The retention ponds are well established and appear to provide an improvement in the discharge water from the tailings pool. They also provide a good wildlife habitat.

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 14.7)

(a) Elevated TDS & metals in surface and ground water.
(b) Human and Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated TDS and metals in groundwater and surface water

The *consequence* of increased metals in local streams and groundwater via flows (& seepage) from the tailings pool was assessed as *medium* given the measured quality of leachate and proximity of streams and the vertical recharge to groundwater.

The *likelihood* of this occurring was also assessed as *medium* given measured metals levels in the source water and lack of control over groundwater seepage. However, it is assessed as *low* for surface water due to the measured effects of the retention ponds.

The assessed risk is Mc x Ml = medium for groundwater (low for surface water).

Remedial measures are required to improve the effectiveness of the system.

(b) Human toxicity

The *consequence* of toxicity to Humans was assessed as low due to limited access.

The *likelihood* of such an event was assessed as *low* given the access.

The assessed risk is Lc x Ll = low.

(c) Livestock, wildlife and herbage toxicity

The *consequence* of toxicity associated with high dissolved and presumably precipitated metals in the ponds was assessed as *medium*.

The *likelihood* of such an event was assessed as *medium* given the access particularly for birds and wildlife.

The assessed risk is Mc x Ml = medium.

Some remedial work is required.

NOMINATED END USE

The nominated end use is to maintain for water retention and wetland treatment of TMF water.

End use compliance criteria are to be developed and would be based on water quality data for the inlet and outlets.

REMEDIATION OPTIONS CONSIDERED

Remedial options considered appropriate are as follows.

(i) Treat the pond water before discharge

This would be an ongoing treatment requirement. This would be an expensive and ongoing option and will not be costed.

(ii) Drain pool, backfill and revegetate

This would require backfilling to a profile to suit local conditions. The area is permanently wet being within the flood plain of the Kilmastulla River.

This option is not practical as the ponds should be retained to receive all water from the TMF.

(iii) Upgrade the ponds as a wetland

This will require some earthworks, pipework and concrete works to decant water from the tailings outlet to the retention ponds. Some armouring of the embankment crests should be considered for protection. Most of this is costed in 6.6.

The estimated additional costs for works to the ponds is €,220.

(iv) Institutional controls

Prevention of access is required to maintain the integrity of the ponds as a natural treatment system. Access is generally difficult. Some notice boards will be required.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- associated cost estimates

it is recommended that remediation options (iii) and (iv) be adopted. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Survey the site;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORK

The total costs are integrated with item I 6.6, apart from some work to the ponds at €3,220.

I 6.8: DELIVERY PIPE LINE

INTRODUCTION:

The tailings delivery pipeline took tailings from the plant site at Garryard to the TMF. Following mine closure the pipeline was removed and poses no further risk. It is not unusual for tailings spillage to occur from pipelines due to breaks and there could be some risk from residual deposits although no records have been seen.

HAZARD/ISSUE & POTENTIAL IMPACT (REFER TABLE 14.7):

(a) Livestock/Wildlife toxicity from residual tailings

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Elevated TDS and metals in soils and herbage

The *consequence* of increased metals was assessed as low given the likely limited quantities of spillage and the time that has passed since closure.

The *likelihood* of contamination occurring was also assessed as *low* given that although spillage may have occurred the probability of that occurrence times the probability of not being cleaned or the magnitude of spillage, is low.

The assessed risk is Lc x Ll = low

Remedial actions are not required

NOMINATED END USE:

The nominated end use for the pipeline route is pasture.

REMEDIATION OPTIONS CONSIDERED:

None

RECOMMENDED ACTIONS:

None

APPENDIX J

INFORMATION RELATING TO MOGUL CLAUSE K RESPONSIBILITY

I 4 : GARRYARD (MOGUL): INCLUDING SUBSIDENCE ZONE (REFER TABLE 14.4)

I 4.1 SETTLEMENT POND

INTRODUCTION

The discharge from the ponds shows slightly elevated sulphate but metals are within acceptable limits. The inflow shows slightly elevated Pb and Mn which presumably settle out in the ponds and sulphate (369 mg/l) (see Section 7.4.1). Pond B is to be left as it is. The following description refers to Pond A. (See Figure 3.3).

In 1999 sediment with elevated metal concentrations was found throughout the area and was particularly pronounced in a small stream draining the Garryard settlement pond.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) High dissolved metals in sediment & water: Elevated TDS & metals in local streams.
(b) High dissolved metals in sediment & water: Human toxicity.
(c) High dissolved metals in sediment & water: Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Elevated TDS and Metals in Local Streams

The *consequence* of increased TDS & metals in local streams via flows from the settlement pond was assessed as *medium* based on water quality data available for areas upstream and downstream of the pond.

The *likelihood* of this occurring was assessed as *medium* given the area of the catchment and dimensions of the pond, combined with local rainfall patterns and visual confirmation, which indicate the likely frequent outflow from the pond.

The assessed risk is Mc x Ml = Medium risk.

Remediation actions are required.

(b) Human Toxicity

The *consequence* of human toxicity as a consequence of high dissolved metals in the settlement pond was assessed as *Medium*.

The *likelihood* of human toxicity occurring was assessed as *low* given the general lack of public access and use of the pond area.

The assessed risk is Mc x Ll = Medium risk.

Some remediation actions are required.

(c) Livestock/Wildlife Toxicity

The *consequence* of livestock toxicity associated with high dissolved metals in the settlement pond was assessed as *medium*.

The *likelihood* of such an event was assessed as *high* given the quality of the sediment and the water and the potential for livestock to access the pond and areas immediately downstream.

The assessed risk is Mc x Hl = High risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use for the Garryard settlement pond is wetland for water treatment.

End use compliance criteria are to be developed and would be based on water balance data for the pond, inflow and outflow water quality, statutory discharge water quality requirements and any future public use of the area.

Post-remediation monitoring of wetland discharge water and sediment quality would be required over 4 years.

Contingency planning will be required in the event non-compliant discharge water and sediment quality. Plans could include institutional controls, diversionary drainage works and adoption of an alternate treatment system.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

Given the high consequence and likelihood of human and livestock toxicity (respectively) some remedial actions are deemed necessary to achieve compliance with the nominated end land uses. A critique of the remedial options considered is as follows.

(i) Remove Contaminated Material From the Settlement Pond

The main objective of this option is to eliminate the potential for further contamination of downstream waterbodies sediments. This would necessitate the excavation, removal and emplacement of approximately 10,000 m^3 of material from the pond.

The excavated material could be disposed of in Gortmore TMF, Magcobar open pit or any other on-site area deemed appropriate, subject to disposal permission.

Excavation works, haulage and disposal costs could be around €100,000.

(ii) Placement of Appropriate Cover

The objectives of applying a cover over the pond would be to:

- reduce the potential for mobilisation of sediment laden with elevated levels of TDS and metals;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

To achieve these objectives approximately 5,000 m^3 of suitably benign material would be required to provide a cover of no less than 0.5m across the pond area.

The cost would be approximately €80,000.

(iii) Drain Pond to a Water Treatment Plant

The objective of directing pond discharge via a water treatment plant would be to treat influent to an extent that effluent complies with regulatory or other prescribed standards for water quality.

Considering the ongoing requirement for treatment, this is not a practical option.

(iv) Encourage Wetland Growth

Converting the settlement pond to a wetland provides a means of 'treating' inflow and thence, lowering the system effluent TDS and metals loads.

There is some wetland development in the second pond (Figure 3.3) but some earthworks would be required to establish suitable aquatic macrophyte growth zones and together with plantings, this could cost around €4,830 to create, together with some minor fence repairs at €1,000.

(v) Drain Pond to Constructed Wetland

The objective of directing pond discharge via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended soilds retention. The discharge quality is presently acceptable and an alternative method to redeveloping the existing ponds is not a practical option.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & pond sediment
- availability of suitable disposal sites;
- availability of wetland or water treatment plant sites; and
- associated cost estimates

It is recommended that remediation option (iv) be adopted. Key actions for the implementation of this remedial measure are summarised below.

RECOMMENDED KEY ACTIONS

- Prepare preliminary pond water balance;
- Monitor inflows and quality (3 years);
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for the tailings lagoon;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €5,830.

I 4.2 TAILINGS LAGOON

INTRODUCTION:

The water in the lagoon contains elevated Cd, Fe, Mn, Pb, SO_4, As and Al, particularly as particulates greater than 0.45μm.

Refer to comments above for the Garryard Settlement Pond.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) High dissolved metals in sediment & water: Elevated TDS & metals in local streams.
(b) High dissolved metals in sediment & water: Human toxicity.
(c) High dissolved metals in sediment & water: Livestock/Wildlife toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD):

(a) Elevated TDS and Metals in Local Streams

The *consequence* of increased TDS & metals in local streams via flows (& seepage) from the tailings lagoon was assessed as *high*.

The *likelihood* of this occurring was also assessed as *high* given the area of the catchment and dimensions of the pond, combined with local rainfall patterns and visual confirmation, which indicate the likely frequent outflow from the lagoon.

The assessed risk is Hc x Hl = High risk.

Remediation actions are required.

(b) Human Toxicity

The *consequence* of human toxicity as a consequence of high dissolved metals in the lagoon was assessed as *high*.

The *likelihood* of human toxicity occurring was assessed as *low* given the general lack of public access and use of the area.

The assessed risk is Hc x Ll = Medium risk.

Some remediation actions are required.

(c) Livestock / Wildlife Toxicity

The *consequence* of livestock toxicity associated with high dissolved metals in the settlement pond was assessed as *high*.

The *likelihood* of such an event was assessed as *high* given the quality of the sediment and the water and the potential for livestock to access the lagoon and areas immediately downstream.

The assessed risk is Hc x Hl = High risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use for the Garryard tailings lagoon is a wetland for water treatment.

End use compliance criteria are to be developed and would be based on water balance data for the lagoon, inflow and outflow water quality, statutory discharge water quality requirements and any future public use of the area.

Post-remediation monitoring of wetland discharge water and sediment quality would be required over 4 years.

Contingency planning will be required in the event of non-compliant discharge water and sediment quality. Plans could include institutional controls, diversionary drainage works and adoption of an alternate treatment system.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

A critique of the remedial options considered is as follows.

A water treatment plant is an option but was not considered further as it is impractical as an ongoing solution.

(i) Placement of Appropriate Cover

The objectives of applying a cover over the lagoon would be to:

- reduce the potential for mobilisation of sediment laden with elevated levels of TDS and metals;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff and increased seepage.

To achieve these objectives approximately 11,000m^3 of suitably benign material would be required to provide a cover of no less than 0.5m across the pond area, together with a 200mm limestone drainage layer and geotextile. This would then be topsoiled and seeded.

It is estimated that this option would cost in the vicinity of €410,000 but would not provide any ongoing water treatment.

(ii) Remove Contaminated Material From the Tailings Lagoon

The main objective of this option is to eliminate the potential for further contamination of downstream waterbodies. This would necessitate the excavation, removal and emplacement of approximately 22,000 m^3 of material from the pond.

The excavated material could be disposed of in Gortmore TMF, Magcobar open pit or any other on-site area deemed appropriate.

Excavation works, haulage and disposal costs could be around €215,000. However, if a hazardous formal waste facility is used then a contingency cost of €160,000 should be allowed.

(iii) Reprocess Tailings as Ore

There is potential for processing the tailings to extract any residual ore. This option would necessitate haulage of the material to a suitable plant such as at Lisheen or Galmoy. It is suggested that likely returns from reprocessing this material would not be sufficient to warrant further investigation of feasibility.

(iv) Drain Lagoon to Constructed Wetland

The objective of directing lagoon discharge via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended soilds retention. This option would still leave the existing sediment and ongoing generation of contaminated water to pass through the wetland.

It is considered not to be a sustainable long term option.

(v) Integrated Drainage Control

The objectives of an integrated drainage system for the lagoon would be to segregate 'clean' and 'dirty' water and direct the 'dirty' water to a treatment facility (e.g. wetland, treatment plant, via sedimentation basins, etc.). This would have the effect of reducing the potential for contaminated seepage and surface runoff from discharging from the lagoon to downstream waterbodies.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such works would cost an estimated €8,000. The ‘dirty’ water would then pass through a developed wetland (Item vi).

(vi) Develop Wetland on the site after removal of contaminated material

This would require design of earthworks and sizing to treat discharge from the plant site. The estimated total cost of wetland development after removal of the sediment (Item ii) is approximately €453,000. There will be opportunities to simplify design requirements and reduce costs after detailed design.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & pond sediment
- availability of suitable disposal sites;
- availability of wetland or water treatment plant sites; and
- associated cost estimates

it is recommended that remediation option (ii), (v) and (vi) be developed. Key actions for the implementation of this remediation measure are summarised below.

RECOMMENDED KEY ACTIONS

- Survey volume of materials to excavate and identify suitable disposal site;
- Prepare preliminary lagoon water balance and diversion requirements;
- Determine the required size and type of wetland to treat the predicted inflows/outflows;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;

- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site.
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €676,000, plus a contingency of €161,000 for hazardous waste disposal elsewhere.

Periodic cleaning of sediment and precipitated ore will be required. This interval will be a minimum of 20 years at a present day estimate of €20,000.

I 4.3 MAIN GARRYARD SHAFT

INTRODUCTION

The main shaft at the plant site has a concrete cap but also has a discharge pipe for water which flows into a drain under the buildings and ultimately into the tailings lagoon.

The discharge occurs particularly after heavy rain but the continuity of flow is unknown. Based on field measurements, the discharge contains elevated TDS. It is important to maintain this discharge to prevent uncontrolled overflows elsewhere.

The details of the shaft cap construction are unknown but it is assumed that there is no risk of failure of the cap foundations as the shaft was the main hoist shaft and foundations will be well designed. Shaft collapse or cap failure is not considered an issue but the site should be clearly identified.

Detailed water quality data is not available because there was no discharge at the time of sampling. Field measurements showed elevated TDS.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Shaft cap damage: Human safety.
(b) Shaft discharge: Contamination of local streams.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Human Safety

The *consequence* of human injury occurring as a result of shaft cap damage was assessed as *medium*.

The *likelihood* of damage occurring was assessed as *low* based on the relative inaccessibility of the area and knowledge of the existence of the shaft.

The assessed risk is Mc x Ll = Low risk.

Nevertheless it has been determined that remediation actions is required.

(b) Contamination of Streams

The *consequence* of shaft discharge resulting in contamination of local streams was assessed as *medium*. The discharge will enter the tailings lagoon, where it will be remediated as part of the lagoon works.

The *likelihood* of shaft discharge resulting in contamination of local streams was assessed as *high* based on the quality of the shaft discharge and downstream water quality data.

The assessed risk is Mc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the Garryard shaft is continued light industrial use.

End use compliance criteria are to be developed and would be based on shaft discharge rates, receiving stream water and sediment quality and public/livestock access restrictions.

Post-remediation monitoring of stream water and sediment quality would be required over 12 months.

Contingency planning will be required in the event of continued non-compliant water quality and sediment quality. Plans could include institutional controls and diversionary drainage works.

REMEDIATION OPTIONS CONSIDERED:

In terms of the shaft cap, practical remediation is limited to ensuring that the cap and shaft are clearly identified and should be protected from damage.

For the discharge, discussions with the Irish EPA indicate that there are currently no Irish groundwater standards, however the EPA are currently working on producing a set of standards for groundwater. In the interim in areas prior to any anthropogenic influences, the EPA advise that reference is made to drinking water standards i.e. SI No. 81 of 1988, which will be revoked by SI No 439 of 2000 but not until 1st January 2004. For example standards in drinking water for Pb are 0.05 mg/l, Zn 1 mg/l, Cd 0.005 mg/l and Fe 0.2 mg/l. However the implications of the background levels of metals (*in situ* mineralogy) and the effects of mining need to be considered.

The remedial options considered are as follows.

(i) Install clear warning sign on the shaft cap

(ii) Drain Shaft Discharge to Constructed Wetland

The objective of directing shaft discharge via a constructed wetland would be to provide residence time and 'polish' the influent via aquatic ecosystem uptake of metals and suspended solids retention.

Discharge rates are variable but the available wetland area will be sufficient to achieve suitable levels of residence and metals uptake, based on discontinuous inflows.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end uses;
- chemical constituents of the discharge water & sediment;
- availability of wetland or water treatment plant site;
- associated cost estimates.

It is recommended that remediation options (i) and (ii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Install warning sign;
- Determine shaft discharge flow rates;
- Determine the required size of the constructed wetland and costs;
- Identify constructed wetland site;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (wetland influent and effluent water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;

- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

Drainage works to be maintained by occupier. Signage as part of other cost items.

I 4.4 UNDERGROUND MINES

INTRODUCTION

The early mined areas of Garryard have suffered significant collapse in the area of steeply dipping orebody in the outcrop area, which is clearly visible on the hillside.

Later workings were backfilled with cemented, pyrite-rich tailings, which limited the potential for collapse. There is a collapse feature adjacent to the road at the entrance to the Magcobar site, but this may not be attributed directly to mining subsidence. It is more likely to have been a palaeo sinkhole which has developed due to erosion of underlying fill material during the period of dewatering of Magcobar or Mogul mines

The source of pyrite, oxidation products and presence of groundwater, could result in the migration of groundwater with elevated TDS and metals in solution.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) Mine workings: Subsidence/Collapse (loss of productive land use);
(b) Mine workings: subsidence (property damage);
(c) Mine workings: Danger to humans & livestock/wildlife;
(d) Mine workings: seepage of contaminated groundwater.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Loss of Productive Land Use

The *consequence* of subsidence resulting in the potential loss of productive land resources, has been assessed as *medium* based on the historic and current land capability of the area.

The *likelihood* of subsidence occurring has been assessed as *high* over a limited area where subsidence has been observed and where further subsidence is possible.

Therefore it has been determined that remediation actions are required.

(b) Surface Dwelling

The consequence of subsidence resulting in damage to dwellings has been assessed as low based on relationship of workings to dwellings and likely damage.

The likelihood of damage is also low based on relationship of dwellings to undermined areas.

The assessed risk is Lc x Ll = Low risk.

No remediation is required.

(c) Danger to Humans and Livestock

The *consequence* of the underground workings being a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the openings.

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as *medium* given evidence of public access and use of the area.

The assessed risk is Hc x Ml = High risk.

Therefore it has been determined that remediation actions are required.

(d) Contaminated Ground Water

The consequence of contaminated ground water seepage is considered low as flows will be low due to low hydraulic gradient and relatively low hydraulic conductivity.

The likelihood is medium based on the fact that the source of contaminants exists but the process should be slow in a largely anaerobic environment.

The assessed risk is Lc x Ml = Low risk.

No specific remedial measures are proposed apart from surface water diversion.

NOMINATED END USE:

The nominated end use for the area of the underground workings is as farmland or derelict land.

End use compliance criteria are to be developed and would be based on geotechnical stability and verification of any areas proposed for human and livestock access.

Post-remediation monitoring of subsidence and shaft stability would be required over 12 months.

Contingency planning will be required in the event of major subsidence and shaft collapse beyond predicted zones of affectation. Plans could include further institutional controls and acquisition of adversely affected property.

REMEDIATION OPTIONS CONSIDERED:

(i) Fencing

Upgrading and augmenting the existing fencing would enable greater control on public and livestock access to the whole or portions of the area of the underground workings, thus significantly limiting the potential for an accident.

Institutional controls typically focus on fencing and signage. The Mogul shafts appear to have been capped but the construction is unknown.

There is an existing fence which is in poor condition in some areas and would require extending. An increase in warning signs would be appropriate.

Total cost would be of the order of €9,400 plus ongoing inspection and maintenance of €500 / year.

(ii) Backfilling

Backfilling of subsidence areas may be considered to stabilise them, however this is not a realistic option in terms of the volume of backfill and the uncertainty of future integrity of the surface.

The mine and process waste material in the Gorteenadiha area may be potentially suitable as backfill material.

Due to the large area concerned and potential land use, this is not considered to be a viable option.

(iii) Integrated Drainage Control

The objectives of improved drainage control would be to divert 'clean' water around the subsidence areas to reduce the potential for contaminated seepage and discharge.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such works would cost an estimated €6,800.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use(s);
- findings of geotechnical assessment;
- findings of heritage value assessment;
- discharge water flow & quality data;
- associated cost estimates

It is recommended that remediation options (i) and (iii) be adopted. Key actions for the implementation of this remedial measure are summarised below.

RECOMMENDED KEY ACTIONS

- Survey positions of all shafts and adits;
- Detailed topographic survey to plan surface drainage;
- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Assess Requirement for specialist geotechnical assessment of shaft/adit stability;
- Incorporating the findings of the geotechnical assessment (where required), prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Design and install surface drainage measures;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €16,300 plus annual maintenance and inspection of €1,000.

I 4.5 OLD STOCK PILE

INTRODUCTION

The old stockpile contains a mixture of sulphide ore and plant process residues as well as other unknown plant wastes.

As part of the Phase II assessment, *in situ* paste pH and EC analyses were undertaken to help characterise the material. The results indicate that the material is reactive and contains leachable constituents.

Analysis of stream water and sediment quality downstream of the old stock pile indicated elevated levels of Fe, Mn, Zn, Pb, Cd, and Ba (EPA 2001 data).

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Sulphides/Oxidation products; Mill concentrate spillage & unknown materials: Elevated TDS & metals in local streams.
(b) Sulphides/Oxidation products; Mill concentrate spillage & unknown materials: Human toxicity.
(c) Sulphides/Oxidation products; Mill concentrate spillage & unknown materials: Livestock toxicity.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Elevated TDS, Solids and Metals

The *consequence* of elevated TDS & metals in local streams as a result of sulphide oxidation from the Old Stockpile was assessed as *high*, given the reactive nature of the waste material and the results of downstream water quality analysis.

The *likelihood* of receiving water and sediment quality being adversely affected by poor quality drainage from the dumps was also assessed as *high*.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that specific remediation actions are required.

(b) Human Toxicity

The *consequence* for human toxicity as a result of poor quality drainage from Old Stockpile was assessed as *high*.

However the *likelihood* of a toxicity event occurring was assessed as *low* given the level of current public access/usage of the area.

The assessed risk is Hc x Ll = Medium risk.

Therefore it has been determined that specific remediation actions are required.

(c) Livestock Toxicity

The *consequence* of livestock toxicity as a consequence of oxidation products from waste material was assessed as *high*.

The *likelihood* of a livestock toxicity event occurring was assessed as *high* also based on potential for livestock access to the area and to streams downslope of the dump.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the old stockpile is pasture.

End use compliance criteria are to be developed and would be based on performance of any contaminant disposal site(s), cover material geochemistry, as well as receiving stream water and sediment quality.

Post-remediation monitoring of stream water and sediment quality would be required over 4 years.

Contingency planning will be required in the event of non-performance of contaminant disposal site(s), loss of cover material, inability to establish vegetative covers, continued non-compliant water quality and sediment quality. Plans could include institutional controls, diversionary drainage works, placement of additional/ alternative cover material, application of soil ameliorants, growth additives, etc. to encourage revegetation.

REMEDIATION OPTIONS CONSIDERED

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline.

Stream sediment immediately downstream of the site contains levels of Fe, Mn, Pb, Cd and Ba above target values and intervention values.

Remediation work will consider ecological and environmental management. The ecological considerations are discussed in Appendix G.

A critique of the remedial options considered is as follows.

(i) Intercept and Treat Surface Runoff and Seepage

The objectives of an integrated drainage system would be to segregate 'clean' and 'dirty' water and direct the 'dirty' water to s treatment facility (e.g. wetland, treatment plant, via sedimentation basins, etc.). This would have the effect of reducing the potential for contaminated seepage and surface runoff from discharging to downstream waterbodies.

The ‘dirty’ water could be culverted under the road to the settlement pond. The total cost of drainage would be €8,000, due mainly to the requirement for road culverts. This option is not acceptable on its own as it would still leave exposed stockpile.

(ii) Placement of Appropriate Cover

The objectives of applying a cover over the dumps are to:

- reduce the potential oxidation of pyritic material and the generation of ARD;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

It is estimated that this option would cost in the vicinity of €180,000, but this would not remove the risk of long term erosion and contaminated seepage.

(iii) Remove Potentially Acid Forming Material

The main objective of this option is to eliminate to potential for further generation of acid drainage from the waste dump.

This would necessitate the excavation, removal and emplacement of approximately 14,000m^3 of contaminated material. The proposed disposal site would be the TMF. There is uncertainty as to the content of the stockpile and care will be required to identify and segregate any non ore or process material for alternative disposal as necessary.

Some restoration would be desirable in the form of a cover for a growth medium over a layer of limestone aggregate (0.2m).

Estimated costs associated with excavation, haulage and emplacement with topsoil replacement would be €205,000. This option is preferred because it removes the same material which would otherwise remain as a potential risk. A contingency of €193,000 should be allowed for hazardous waste disposal elsewhere.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- availability of suitable disposal sites and borrow material;
- associated cost estimates

it is recommended that remediation options (i) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Survey quantity of material to remove and confirm disposal site;
- Identify cover material source(s) and growing medium;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (cover material geochemistry, receiving stream water and sediment quality) and incorporate into post-remediation monitoring programme (3 years);
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget and schedule.

TOTAL ESTIMATED COST OF WORKS

- €213,000.

Allow contingency of €193,000 for hazardous waste disposal at licensed site.

I 4.6 MINE BUILDINGS AT PLANT SITE

INTRODUCTION

The Mogul plant site at Garryard contains a number of large buildings and concrete structures but all of the plant has been removed. The site is currently used by a haulage contractor who is using the buildings and the open yard space. Some aspects of the site have some value as part of an integrated heritage site.

It must be expected that the subsoil below the site is contaminated in some areas. The majority of the site is paved and while this is not disturbed, potential leaching of contaminants off site will be minimised. Effluent from the site will currently arrive in the tailings lagoon or settlement pond. Any exposed areas of fill should either be covered or removed to a licensed site.

The overall site must be cleaned and landscaped to acceptable visual appearance.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Remnant buildings: Danger to humans & livestock/wildlife.
(b) Contaminated land.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Remnant Buildings

The *consequence* of the remnant structures representing a danger to humans and livestock/wildlife was assessed as *medium* based on the physical dimensions of the structures and hence the minor nature of associated possible dangerous situations.

The *likelihood* of the structures being a danger to humans and livestock/wildlife was assessed as *low* given the condition of the structures, and general public access.

The risk was assessed as Mc x Ll = Low risk.

Nevertheless it has been determined that some specific remediation actions are required.

(b) Contaminated Land

The consequence of exposure to potentially contaminated land to humans and livestock as well as leaching or erosion to surface water must be considered as *medium*. This is based on the likely high ground contamination of parts of the site.

The likelihood of exposure is considered as *medium* based on the fact that some ground works are being conducted at present by the occupants of the site. There are also some areas of exposed waste materials adjacent to the settlement pond.

The assessed risk is Mc x Ml = Medium risk.

Remedial action is required.

NOMINATED END USE

The nominated end use for the area of the remnant structures is alternative commercial use (e.g. workshops, visitor centre, etc.).

End use compliance criteria are to be developed and would be based on the findings of the heritage value assessment.

REMEDIATION OPTIONS CONSIDERED

Subject to possible conservation of some structures as heritage value, some specific remediation is proposed to limit, to the extent possible, any residual safety and environmental issues.

A critique of the remedial options considered to address these issues is as follows.

(i) Removal of Infrastructure and Site Rehabilitation

The objective of this option would be to ensure to the extent possible that the area is left in a state that would not pose a serious or likely risk to human and/or animal health as a consequence of the presence of the plant and infrastructure.

Site rehabilitation could cost in the order of €330,000

(ii) Retention of Plant & Infrastructure for an Alternative Use & Site Rehabilitation

Some of the infrastructure in place at the site may be retained for an alternative post-closure use. Some site rehabilitation works should be carried out to clean up and landscape peripheral areas. Depending on the after use, an investigation should be carried out to characterise the level of risk from contaminated ground. Investigation costs would be of the order of €33,000.

(iii) Site Drainage and Contaminated Areas

Existing site drainage must be maintained and any additional sources of potential contamination controlled. Exposed contaminated areas should be covered or removed and drained to engineered specification. No earthworks should be carried out without prior investigation of underlying materials and potential contaminants.

Estimated costs are €30,000.

(iv) Removal of Hostel Building

Estimated cost of €23,000.

RECOMMENDED ACTIONS:

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- findings of the heritage assessment;
- nominated post-closure conceptual end use(s); and
- associated cost estimates

it is recommended that options (iii) and (iv) be adopted in the first instance, with consideration of the final end use. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Itemise existing infrastructure and evaluate potential for re-use;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Prepare detailed plan of site drainage and develop modification and maintenance plan;
- Prepare detailed site plan to show areas for upgrade of cover, new cover and drainage works;
- Confirm end use compliance criteria and incorporate into post-remediation monitoring programme;
- Define site investigation programme to characterise contamination and risks;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF THE WORK

Costs estimated to be €53,000 for remedial works and €33,000 site investigation.

The site investigation may reveal a need for more remedial works if specific hazards are identified. A contingency of €164,000 should be allowed.

I 4.7 GORTEENADIHA MINING HERITAGE

Below the open cast workings there are a series of stone dressing structures from the early phase of working the open pit (Plate 4.5.2). These occur within the waste piles and are of archaeological interest. They should be protected until they can be surveyed.

HAZARD/ISSUE AND POTENTIAL IMPACT

(a) Destruction of Structures

There is no impact apart from the high risk of losing the structures if the area is accessed for other remedial works or any other purpose.

They should be protected as heritage and archaeological interest.

REMEDIAL OPTIONS CONSIDERED

The area should be fenced and conserved for heritage.

ACTIONS

The area should be fenced and surveyed, excavated and recorded as soon as possible.

The survey could be allocated to a University group and a cost of €8,000 should be allowed.

The cost of fencing the area is €2,415.

I 4.8 GORTEENADIHA: WASTE DUMPS

INTRODUCTION:

The site comprises the area of waste disposal and former ore processing around and north of the open cast mine.

It must be expected that the dumps contain sources of material which can result in elevated metals and salts due to sediment erosion and dissolved solids. The site is also of archaeological and heritage value.

HAZARD/ISSUE & POTENTIAL IMPACT:

(a) Surface waste & process dumps: Human toxicity.
(b) Surface waste & process dumps: Livestock toxicity.
(c) Surface waste & process dumps: Contamination of surface water.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Human Toxicity

The *consequence* for human toxicity as a result of poor quality drainage from this area was assessed as *high*.

The *likelihood* of a toxicity event occurring was assessed as *low* based on the potential for contact with the material to an extent to be toxic.

The assessed risk is Hc x Ll = Medium risk.

Remediation actions are required.

(b) Livestock Toxicity

The *consequence* of livestock toxicity as a consequence of oxidation products from waste material was assessed as *high*.

The *likelihood* of a livestock toxicity event occurring was assessed as *medium* given the general lack of a vegetative cover across the area and hence the absence of grazing, but there is access for animals.

The assessed risk is Hc x Ml = Medium risk.

Therefore it has been determined that remediation actions are required.

(c) Contamination of Surface Water

The *consequence* of erosion of contaminated sediment to surface water is *medium* due to cattle grazing downstream.

The *likelihood* of erosion is *high* due to existing gully erosion and lack of vegetation.

The assessed risk is Mc x Hl – Medium risk.

Remedial actions are required.

NOMINATED END USE

The nominated end use for the Gorteenadiha surface waste and process dumps is a heritage site.

End use compliance criteria are to be developed and would be based on the findings of relevant heritage value assessments.

REMEDIATION OPTIONS CONSIDERED:

There are no specific European statutory standards or guidelines for the elevated heavy metals identified in relation to concentrations in soils/sediment (DAFRD 2000). However, the Dutch Ministry of Housing, Spatial Panning & Environment Circular on Target Values for Soil Remediation (MHSPE Circular 2000), provides a comparative guideline. As noted above, no data are available on the geochemistry of the Gorteenadiha waste material.

A critique of the remedial options considered is as follows.

(i) Placement of Appropriate Cover

The objectives of applying a cover over the waste material are to:

- reduce the potential oxidation of pyritic material and the generation of poor quality drainage;
- provide a growth medium for the establishment of a stable (perennial) vegetative cover;
- decrease uncontrolled surface runoff.

To achieve these objectives approximately 2000 m^3 of suitably benign material would be required to provide a cover of no less than 0.2 m across the area.

It is estimated that this option would cost in the vicinity of €33,000.

(ii) Institutional Controls

The objective of opting for institutional controls would be to control public access to the whole or portions of the area and to establish warning signs.

Institutional controls typically focus on fencing and signage. It is considered that only signage is required at a nominal cost of €800.

(iii) Drainage Works

The objective of remedial drainage works would be to control surface runoff from the area of the waste material. This could be achieved via the establishment of drainage channels and retention basins to provide residence time for sediment-laden runoff to settle. This would include cleaning of the drain along the roadside, and fencing with a drain along Cromwell’s road.

The estimated costs associated with this option are in the vicinity of €26,000.

(iv) Integrated Drainage Control

The objectives of an integrated drainage system would be to segregate 'clean' and 'dirty' water and direct the 'dirty' water to the Garryard wetland. This would have the effect of reducing the potential for contaminated seepage and surface runoff from discharging to downstream waterbodies.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such works are included under I 4.9 (iii). Cost estimates for conveying the dirty water through a culvert under the road to the wetland would cost in the order of €15,000, if required, and a contingency for this should be allowed.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- water balance data;
- heritage value assessment;
- availability of suitable disposal sites and borrow material; and
- associated cost estimates

It is recommended that remediation options (ii), (iii) and (iv) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Fence, excavate and record archaeology as soon as possible;
- Identify cover material source(s), confirm haul distances and costs;
- Draft up a conceptual integrated erosion and sediment control plan;
- Confirm extent of drainage works required and costs;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Confirm end use compliance criteria (cover material geochemistry, receiving stream water and sediment quality) and incorporate into post-remediation monitoring programme;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL COST

- €26,800 plus a contingency of €15,000 to take drainage to the Garryard wetland if required.

I 4.9 UNDERGROUND AND SURFACE WORKINGS

INTRODUCTION

In the Gorteenadiha area there are some open pit workings and shallow, underground workings that are believed to date back to the early 19th century. The area is known to be dangerous due to small, open shafts in thick undergrowth and uncertain stability of the shallow open pit workings.

HAZARD/ISSUE & POTENTIAL IMPACT

(a) Open pit & underground workings: Subsidence/Collapse (loss of productive land use).
(b) Open pit & shafts: Danger to humans & livestock/wildlife.

ASSESSED RISK (CONSEQUENCE x LIKELIHOOD)

(a) Subsidence or Collapse

The *consequence* of subsidence resulting in the potential loss of productive land resources, has been assessed as *medium* based on the historic and current land capability of the area.

The *likelihood* of subsidence occurring has been assessed as *high* given the current extent of subsidence observed across much of the area of the underground workings.

The assessed risk is Mc x Hl = Medium risk.

Therefore it has been determined that remediation actions are required.

(b) Danger to Humans and Livestock

The *consequence* of the underground workings in terms of being a danger to humans and livestock/wildlife has been assessed as *high* based largely on the lack of definitive information on the number, location and condition of all the openings.

The *likelihood* of the shafts posing a danger to humans and livestock/wildlife was assessed as *high* given evidence of public access and use of the area, the lack of restrictions on grazing and the absence of institutional controls.

The assessed risk is Hc x Hl = High risk.

Therefore it has been determined that remediation actions are required.

NOMINATED END USE

The nominated end use for the area of the underground workings is derelict land.

End use compliance criteria are to be developed and would be based on geotechnical stability and verification of any areas proposed for human and livestock access.

Post-remediation monitoring of subsidence and shaft stability would be required over 3 years.

Contingency planning will be required in the event of major subsidence and shaft collapse beyond predicted zones of affectation. Plans could include further institutional controls and acquisition of adversely affected property.

REMEDIATION OPTIONS CONSIDERED

Remedial options considered to address these requirements are as follows:

(i) Institutional Controls

The objective of opting for institutional controls would be to control public and livestock access to the whole or portions of the area of the underground workings.

Institutional controls typically focus on fencing and signage.

Costs associated with fencing and signage would be included with item I4.8.

(ii) Backfilling

Backfilling of a shaft is typically undertaken to permanently increase the safety of underground mine workings by stabilising shafts and adits.

Settlement of backfilled material can occur and implications on future land use need to be considered. Each shaft should be fenced.

Detailed survey is required to accurately locate and evaluate shaft remediation requirements. An allowance of €3,500 should be made for backfilling or local fencing as required.

The mine and process waste material in the Gorteenadiha area may be potentially suitable as backfill material, which would reduce costs.

(iii) Drainage Control

The objectives of improved drainage control would be to divert ‘clean’ water around the open void/underground workings.

Works required to achieve these objectives would entail the establishment of upstream diversionary drainage and such would be included in item I4.8.

RECOMMENDED ACTIONS

In consideration of the information presented above, specifically the:

- assessed risk;
- applicable statutory requirements;
- nominated post-closure conceptual end use;
- water balance data;
- heritage value assessment;
- availability of suitable disposal sites and borrow material;
- associated cost estimates

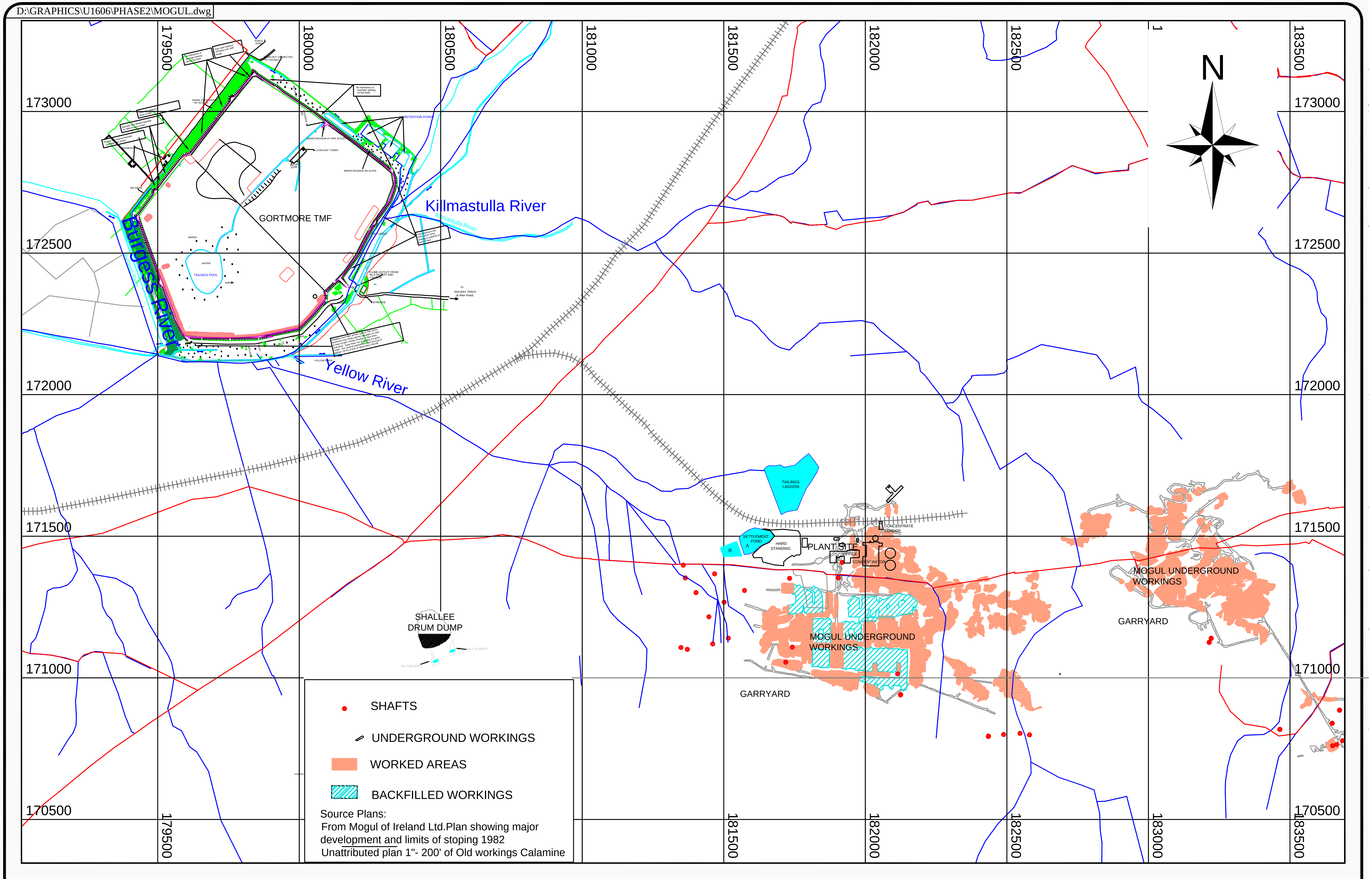
It is recommended that remediation options (i), (ii) and (iii) be adopted. Key actions for the implementation of these remedial measures are summarised below.

RECOMMENDED KEY ACTIONS

- Survey all shafts and adits;
- Identify extent of fencing (metres) and signage (number) to be installed and costs;
- Investigate feasibility of backfilling shafts and selected surface workings with surface waste material;
- Prepare a schedule of remediation works including identification of milestones, costs and responsible parties;
- Assess potential for integration with remediation actions for other areas of the Silvermines site;
- Prepare an overall sub-project budget.

TOTAL ESTIMATED COST OF WORKS

- €3,500 (plus items considered as part of I4.8).



Source Plans:
From Mogul of Ireland Ltd.Plan showing major development and limits of stoping 1982
Unattributed plan 1"- 200' of Old workings Calamine

FEB 2002	PROJ. No: U1606	SIVERMINES	Scale 1:12500

SRK Consulting
Engineers and Scientists

AREAS OF MOGUL RESPONSIBILITY

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216.	Silvermines Lead and Zinc Co - Shallee Mine Longitudinal Section, 00/00, 1/500	1953	Silvermines Lead and Zinc Co. Ltd
217.	Silvermines Lead and Zinc Co - Plan 4, 1/480	1954	Silvermines Lead and Zinc Co. Ltd.
218.	Assay Plan of Shallee Coughlan, 1/480	1955	Silvermines Lead and Zinc Co. Ltd.
219.	Silvermines project - Gortshanaroe & Garryard West, 1/1200(includes subsidence)	1958	Cyrus Mines Corporation
220.	Gortnadyne 1/1200	1958	Cyrus Mines Corporation
221.	Shallee Mine, 1/480	1958	Silvermines Lead and Zinc Co. Ltd.
222.	3000 TPD Concentrator plant, Tailings disposal, tailings area, plan and typical sections, Dwg. 140-2 Rev 1 (TMF and pipeline)	1966	Mogul of Ireland Ltd.
223.	3000 TPD Concentrator plant, Tailings disposal, 8” diameter tailings line, plant to tailings area plan and profile, Dwg. 140-1 Rev 1	1966	Mogul of Ireland Ltd.
224.	County Tipperary, Sheet Tipperary XXVI-II, Geological Plan, 1/2500	1975	Mogul of Ireland Ltd.
225.	Soil Testing Program with Pionjar Drill (Gortmore tailings)	1976	None given
226.	General Mine Plan, 1/1200	1976	Mogul of Ireland Ltd.
227.	“G” Zone - 1 Level Haulage, Plan showing holing of stope into Haulage East, 1/1200	1976	Golder Associates
228.	K-Zone Dewatering, Inter Office Memorandum, 2p + 4 maps	1978	Joshi, R.V. Mogul of Ireland Ltd
229.	Section 45300E South, 1/480	1979	Mogul of Ireland Ltd.
230.	Early workings, 1/480	1979	Nichols A.B.
231.	Knight shaft, ore and waste passes, 1/480	1980	
232.	Mogul of Ireland, Ltd. - Surface Plan of "B" Zone Ventilation Raises Area, 1/240	1980	Mogul of Ireland Ltd.
233.	Overburden sampling compilation. 1:10560	1981	Irish Base Metals Ltd
234.	Cross-sections of the Silvermines area. 3p.	1981	Mogul of Ireland
235.	General Mine Plan (three sheets)	1982	Mogul of Ireland Ltd.
236.	Plan showing major development and stopes, 1/2400	1982	Mogul of Ireland Ltd.

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237.	Irish Base Metals Exploration Department, Silvermines, Overburden sampling compilation (lead), 1/10560	1982	Irish Base Metals
238.	Irish Base Metals Exploration Department, Silvermines, Overburden sampling compilation (zinc), 1/10560	1984	Irish Base Metals
239.	Irish Base Metals Exploration Department, Silvermines, Overburden sampling compilation (copper), 1/10560	1984	Irish Base Metals
240.	Irish Base Metals Exploration Department, Silvermines, Compilation of geochemical data (moil), 1/10560	1984	
241.	Silvermines CP, Surface Topography, K - Zone - Calamine Zone Compilation, 1/480	1984	Irish Base Metals Ltd., Exploration Department
242.	Silvermines CP, Compilation, 1/2400	1984	Irish Base Metals Ltd., Exploration Department
243.	Silvermines CP, Overburden Thickness	1984	Irish Base Metals Ltd.
244.	Silvermines CP, B & G Zones Ore Reserves, 1/2400	1984	Irish Base Metals Ltd.
245.	Silvermines Feasibility Study, Outline mine planning of main development, Map 1	1984	Irish Base Metals Ltd
246.	Compilation map of overburden geochemical and geophysical surveys with bedrock geology for the Silvermines licence area. 1:2500	1984	Irish Base Metals Ltd
247.	1W6 - S Stope, Surface subsidence	1984	Mogul of Ireland Ltd
248.	1W1 - S Stope/Old Shaft connection, 1/240	Undated	Mogul of Ireland Ltd
249.	Silvermines CP, Drillhole Location Plan, Gorteenadiha Zone – Surface Elevation Contours, 1/480	1985	Westland Exploration Ltd.
250.	Integrated Soil Geochemistry-Geophysics map.	1985	Westland Exploration Ltd.
251.	Mine Plan, 1/12,000	1986	Magcobar (Ireland) Ltd
252.	Silvermines CP Compilation, Gorteenadiha Zone, 34000E-42000E, 1/2400	1986	Westland Exploration Ltd.
253.	Silvermines Drillhole Compilation, 1/10560	1987	Westland Exploration Ltd.
254.	Silvermines Mineral Ownership, 1/10560	1988	Mogul of Ireland Ltd.
255.	Silvermines Mineral Ownership	1988	Mogul of Ireland Ltd.
256.	Characterisation Study of the Silvermines Area, 1/5000	2000	Natural Resource Consultant
257.	Magcobar Underground mine, Plan and Sections	2000?	Nigel Barnes & Associates
258.	Hand annotations on 1904 1/10,000 topo plan showing archaeological sites identified by the Tipperary Heritage Officer, Duchas	2001	Dr. S. Gerraghty, Duchas