

Department of Communications,
Climate Action and Environment



**Environmental
Monitoring Services at the
Former Mining Areas of
Silvermines (Co. Tipperary)
and Avoca (Co. Wicklow)**

**Silvermines Monitoring
Report - Round 2 (2016)**

Final



**CDM
Smith**



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Section 1

Introduction

1.1 Objectives and Scope

The Department of Communications, Climate Action and Environment (the Department) appointed CDM Smith Ireland Ltd (CDM Smith) to undertake a programme of environmental monitoring at the closed mine sites of Silvermines and Avoca, commencing in 2013.

The scope of the field investigation activities for the first three years was defined in the *Environmental Monitoring of Former Mining Areas of Silvermines and Avoca Monitoring Plan*, (Document Ref: 95735/40/DG/01, dated 26 February 2013) and sampling activities were performed in accordance with the programme and procedures set out therein.

Based on the findings of the monitoring program for the first three years, adjustments were made to the monitoring programme in 2016 which are detailed in the *Environmental Monitoring of Former Mining Areas of Silvermines and Avoca Summary Report*, (Document Ref: 95735/40/DG/25, dated 20 January 2016).

The Monitoring Report for the Silvermines Mining Area presents an evaluation of the results of the field investigations carried out in August 2016. This report should be read alongside the Silvermines Data Report (Document Ref: 95735/40/DG/28, dated October 2016) which contains all field observations and laboratory analytical results collected during the monitoring programme.

1.2 Background of Silvermines Mining Area

The Silvermines mining area is located in the northern foothills of the Silvermine Mountains in Co. Tipperary. The area has been mined intermittently for over one thousand years for a range of commodities including lead, zinc, copper, silver, barite and sulphur. The mining sites include Ballygown (BG), Garryard (GA), Gorteenadiha, Magcobar (MA) and Shallee South (ShS) /East (ShE), and cover an area of approximately 2,300 ha as shown on Map 1 in [Appendix A](#). The last working mine, a barite operation at Magcobar, closed in 1993. Just over a decade previously, the final base metal mine shut down, following the cessation of underground operations by Mogul Mines Ltd. (Mogul) at Garryard. The latter operation resulted in the generation of significant volumes of fine to coarse grained sand particles referred to as tailings. Approximately 8 Mt of such tailings were deposited in a specially constructed, 60 ha tailings management facility (TMF) at Gortmore (GM). Rehabilitation works have been completed at various localities including Gortmore TMF, with the site work administered by North Tipperary County Council on behalf of the Department. To date this rehabilitation work has included:

- Capping poorly and non-vegetated areas of the TMF surface, covering approximately 24 ha, with a range of materials (Geogrid/geotextile, crushed calcareous rock and blinding layers and a seeded, growth medium);
- Establishing a vigorous grass sward on the capped areas of the TMF to minimise the risk of future dust blow events;

- Various engineering works on the TMF (e.g. improvements to the surface water drainage system, construction of rockfill buttresses to lessen the slopes of the TMF sidewalls, etc.);
- Remedial works to the TMF's retention ponds and wetlands, so as to improve the quality of waters discharging into adjoining watercourses;
- Fencing and/or capping of old mine shafts and adits at Ballygown, Garryard and Shallee;
- Drainage improvement works at Ballygown, Gorteenadiha and Shallee; and
- Filling an open pit at Ballygown and re-vegetating the pit area.

1.3 Catchment Description

The area is located in the northern foothills of the Silvermine Mountain, Co. Tipperary as shown on Map 1 in [Appendix A](#). The Kilmastulla River is the main river which rises in the Silvermine Mountain just south of Silvermines Village (called the Silvermines Stream) and flows north through the Ballygown mining area. The river then flows west towards the Gortmore TMF which is located to the north of the river. The river is located northwest of the other main areas of previous mining activity including Shallee, Garryard and Magcobar. Streams from Shallee and Garryard drain into the Yellow Bridge River which discharges to the Kilmastulla River at the south-eastern corner of Gortmore TMF.

Ballygown has been extensively worked both on the surface and underground. Most of the many shafts sunk in the area are collapsed or backfilled but a drainage adit that links them continues to discharge mine water into the Silvermines Stream north of the village of Silvermines.

Magcobar mine was the last active mine in the district. Open-pit mining was followed by limited underground mining developed from the base of the pit. Streams draining Silvermines Mountain have been diverted around the open pit using drainage channels which are still operational. SW6-MAG is the sampling point on Foilborrig Stream which has been diverted around the pit.

Garryard is located on both sides of the main road R499. To the south of the road is the old ore stockpile area, whilst north of the road, the site is split by a railway. Knight Shaft was the main mine access and is now covered by a concrete cap. An overflow pipe in the cap discharges mine water, typically after heavy rainfall, which flows north under the railway to the tailings lagoon. The tailings lagoon also receives run-off from the yard. Both the water and the tailings in this lagoon contain high concentrations of mine-related metals such as lead, zinc, arsenic and cadmium. The two settlement ponds south of the railway receive surface runoff from the Garryard plant area, which can also have high metal concentrations. Ponds and the tailings lagoon ultimately drain into the Yellow Bridge River, 1km downstream of the site. Surface water run-off from the stockpile area south of the main road enters a drain that runs westwards, parallel to the road, before crossing under the road to enter farmland.

Shallee has been extensively worked both on the surface and underground. A cut-off drain is located upslope of the surface working and drum dump which collects and diverts runoff from Silvermine Mountain; however, the mine does act as a drain for rain water and the open pit and underground workings are partially flooded. Near the southernmost tailings dump, a spring is present in an old streambed that is thought to be fed by water from the underground workings.

This then passes under the main R499 road via a culvert and flows along the western boundary of the north tailings impoundment to join the Yellow Bridge River.

Gortmore TMF is some 60ha in area with surface elevations ranging from approximately 54.0m to 56.5m. The tailings were pumped as a slurry through a pipe from Garryard and deposited in lagoons on the surface of the impoundment. When production at the Garryard plant ceased, the tailings impoundment was closed and the pipeline removed. Various works have been carried out to rehabilitate the impoundment, and most of the surface is now vegetated with grass and moss. Some areas have exposed tailings, with some ponded water. Typical existing ground elevations outside the perimeter of the dam range from approximately 48 to 50m. Excess water drains via a decant system to ponds which overflow into the Kilmastulla River. A number of constructed wetlands are also present at various locations near the toe of the dam.

1.4 Geology and Hydrogeology

1.4.1 Geology

The geology of the Silvermines district comprises Silurian and Devonian sedimentary rocks (greywackes, pebble conglomerates, sandstones and siltstones) which are overlain by Lower Carboniferous transgressive siliciclastics and carbonates. The local geology of the area is dominated by a complex structure known collectively as the Silvermines Fault. The fault zone trends broadly east-northeast but includes west-northwest-striking components. The fault has downthrown the younger Carboniferous strata against the older Silurian and Devonian clastic sequences. Mineralization occurs in fracture zones and as stratabound zones within brecciated and dolomitized Waulsortian reef limestone.

1.4.2 Hydrogeology

The bedrock is overlain by subsoils derived from Devonian Sandstone Till (DSTs). Subsoils are thin (<2 metres) or absent on hilltops and thicker (>2 metres) along valley floors. The Gortmore area is underlain by alluvial sediments along the Kilmastulla River valley. Similarly, the groundwater vulnerability ranges from Extreme in the upland areas to Moderate in low-lying areas.

In terms of groundwater yield, the Geological Survey of Ireland (GSI) classifies the bedrock in the Silvermines area as poorly productive: LI (Locally Important Bedrock Aquifer, Moderately Productive only in Local Zones) and Lm (Locally Important Bedrock Aquifer, Generally Moderately Productive). A locally important (Lg) gravel aquifer overlies the bedrock aquifers in the valley north of the Silvermine Mountain where gravels have accumulated.

LI is the predominant aquifer type: a relatively poorly connected network of fractures, fissures and joints exists, giving a low fissure permeability which tends to decrease further with depth. A shallow zone of higher permeability is likely to exist within the top few metres of more fractured/weathered rock, and higher permeability may also occur along fault zones. In general, the lack of connection between the limited fissures results in relatively poor aquifer storage and flow paths that may only extend a few hundred metres. Artesian and upward vertical flows are present in the Garryard area and the Gortmore TMF area as indicated by recorded groundwater levels.

Section 2

Methodology

2.1 Field Sampling Methods

2.1.1 Groundwater Sampling

Two groundwater monitoring wells were sampled on 22 August 2016, as listed in Table 1 and shown on Map 2 in [Appendix A](#). Water levels were measured at an additional seven monitoring wells located within the TMF near the perimeter of the tailings surface, using a portable electronic water level recorder. Four of the monitoring wells which were in addition to the nine wells have been removed from the monitoring programme because in the first round of sampling (2013) they were either found buried, or believed to be destroyed.

Groundwater level data are contained in Appendix C of the Data Report and discussed in Section 6.

Table 1 Location of Groundwater Monitoring Points

Borehole Identifier	Easting	Northing	Water Level	Field Parameters & Chemical Analysis	Depth (m bgl)	Screen Interval (m bgl)
TMF1(D)/SRK/01 (TMF1)	179826	173165	Yes	Yes	23	22-23
TMF2(D)/SRK/01 (TMF2)	179445	172307	Yes	Yes	18	none
BH1A-GORT-06	180181	172490	Yes	No	8.8	5.5 - 8.8
BH2A-GORT-06	180216	172855	Yes	No	10	7 - 10
BH3A-GORT-06	179835	173126	Yes	No	10	7 - 10
BH4A-GORT-06	179570	172826	Yes	No	10	7 - 10
BH5A-GORT-06	179537	172312	Yes	No	10	7 - 10
BH6A-GORT-06	179868	172212	Yes	No	10	7 - 10
BH6B-GORT-06	179867	172225	Yes	No	5	3 - 5

TMF1 (D)/SRK/01 (TMF1) is upgradient of the TMF and TMF2 (D)/SRK/01 (TMF2) is downgradient (Golder Technical Memo 4 April 2007). TMF1 and TMF2 have a double well installation: the deep installation is sealed in the bedrock and the shallow well is sealed within the overlying soil overburden. Samples were obtained from the deep well installations outside the perimeter of the TMF.

Groundwater samples are collected using the procedure consistent with the Low Flow Groundwater Sampling Procedure (SOP 1-12) detailed in the Monitoring Plan. Groundwater is collected using a portable submersible low-flow pump (Grundfos MP1 pump). The static water level is measured prior to pumping and is also measured throughout the purging process to monitor drawdown.

Water quality indicator parameters are monitored in the field during low-flow purging using a flow-through cell to minimise oxidation by the atmosphere. Water quality indicator parameters include temperature, pH, ORP, conductivity and dissolved oxygen (DO). Purging continues until the field parameters have stabilised. The results are recorded approximately every five minutes

during the purging process on the Groundwater Purging and Sampling Form. Field sheets are contained in Appendix H and physico-chemical field data are summarised in Appendix A of the Data Report.

After water is purged and the parameters have stabilised, the flow is reduced for low-flow sample collection. Samples for trace metal analyses were filtered in the field using a 0.45 micron membrane syringe filter before preservation. New bottles supplied by the laboratories were used for sample collection.

In August 2016, TMF1 borehole was an exception to the low flow sampling procedure. The borehole was damaged approximately 1m from the surface. A major obstruction exists and the pump could not be lowered into the well. The borehole was sampled by hand pumping the well using designated tubing with a foot valve. The sample was collected after three volumes of the well (calculated as $\pi r^2 h$; r is the inner casing radius and h is the height of the water column) had been purged and the field parameters had stabilised.

2.1.2 Surface Water Sampling

Thirty surface water locations were sampled between 22 and 26 August 2016, as listed in Table 2 and shown on Maps 2 to 5 in [Appendix A](#). Two samples (SW13-SHAL and SW14-SHAL) were added to the monitoring programme to provide greater detail on the calculated loadings of dissolved metals in the main rivers and streams. Two samples could not be obtained because the stream bed was dry at SW14-SHAL and SW1-GAR.

Surface water sampling was conducted in accordance with the Surface Water Sampling Procedure (SOP 1-1) as detailed in the Monitoring Plan. The predetermined surface water sampling locations were located in the field using a GPS. Photographs were taken of the surface water sampling location (Appendix D of the Data Report). Samples were grab samples collected from a well-mixed portion of the water stream where possible. The sample location was approached from downstream so that the underlying sediments were not disturbed.

Table 2 Location of Surface Water Monitoring Points

Site Name	Area	Easting	Northing	Sample Site Notes	Sample collected	Flow
SW10-GORT-US	GM	180206	172396	Immediately upstream of the outfall on the Kilmastulla River	Yes	NR
SW10-GORT-Discharge	GM	180205	172393	Wetland discharge prior to outfall	Yes	Bucket and Stopwatch
SW10-GORT-DS	GM	180189	172365	20m downstream of the outfall, on the Kilmastulla River	Yes	NR
SW12-GORT-Discharge	GM	179562	172165	Sample of wetland discharge prior to outfall	Yes	Bucket and Stopwatch
SW12-GORT-DS	GM	179532	172137	20m downstream of the outfall, on the Kilmastulla River	Yes	NR
SW14-GORT	GM	179336	172164	Site located on Kilmastulla River, downstream of TMF	Yes	NR
SW17-GORT	GM	180538	173038	Site located on Kilmastulla River, upstream of TMF	Yes	NR
SW18-GORT	GM	179772	172666	Site of discharge from the main pond on the TMF	Yes	NR
SW19-GORT	GM	180097	172982	Discharge at the bottom of the decant	Yes	Flume
DS-GORT	GM	178501	171870	Site located on Kilmastulla River, downstream of TMF	Yes	Float Method
SW1-SM	BG	184083	170732	Site on Silvermines Stream (upstream of Ballygown mine workings)	Yes	Flow Meter
SW2-SM-South	BG	184244	171584	Discharge from 'Southern' adit.	Yes	Bucket and Stopwatch
SW3-SM	BG	184258	171412	Site on Silvermines Stream (downstream of main Ballygown workings, but upstream of North adit)	Yes	Flow Meter
SW5-SM	BG	184303	171691	Site on Silvermines Stream (downstream of main Ballygown workings and of North adit)	Yes	Flow Meter
SW4-SM-GA	BG	183961	172483	Site on Silvermines Stream (downstream of all mine workings)	Yes	Flow Meter
SW6-MAG	MG	182776	171399	Foilborrig Stream diverted around Magcobar Pit. Sampling site is just south of R499 road.	Yes	NR
SW1-GAR	GA	182116	171322	Stream sampled south of R499 road (south of old Mogul Yard)	No	NR
SW3-GAR	GA	181300	171648	Stream site containing drainage flows from both the tailings lagoon and western part of Mogul Yard.	Yes	Flow Meter
SW5-GAR	GA	181950	171418	Discharge from Knight Shaft	Yes	No Overflow

Site Name	Area	Easting	Northing	Sample Site Notes	Sample collected	Flow
SW7-GAR	GA	181523	171493	Discharge from smaller settlement pond	Yes	Bucket and Stopwatch
SW10-GAR	GA	181640	171730	Discharge from Garryard tailings lagoon	Yes	Flume
SW12-GAR	GA	181791	171569	Combined run-off from Knight Shaft and eastern part of Mogul Yard sampled north of railway and up-gradient of tailings lagoon.	Yes	Flume
US-SHAL	ShS	180749	171783	Yellow River upstream of ShS	Yes	Flow Meter
SW1-SHAL	ShS	180703	171776	Water-course that runs parallel to R500. Sampling site occurs close to northern-most corner of Shallee tailings impoundment.	Yes	Flow Meter
SW4-SHAL	ShS	180324	171089	Water-course occurring west of 'Drum Dump' and Shallee South workings.	Yes	Bucket and Stopwatch
SW5-SHAL	ShS	180574	171301	Water course west of fenced off area enclosing King's House and core sheds. Further west, this same feature runs along the toe of the drum dump.	Yes	Flume
SW6-SHAL	ShS	180591	171331	Stream emanating from flooded Field Shaft	Yes	Bucket and Stopwatch
SW9-SHAL	ShS	180571	171470	Stream occurring immediately east of the southernmost Shallee tailings impoundment. Sample site is south of R499 road.	Yes	Flow Meter
SW12-SHAL	ShS	180670	171165	Stone lined drainage channel SSW of reservoir	Yes	Bucket and Stopwatch
DS-SHAL	ShS	180609	171845	Yellow River downstream of ShS and BG	Yes	Flow Meter
SW13-Shal*	ShS	180709	171775	Stream draining the eastern section of the tailings impoundment (adjacent to SW1-Shal in northern most corner)	Yes	Flow Meter
SW14-Shal*	ShS	TBC	TBC	Stream downgradient of the drum dump in the Shallee mining area prior to re-entering the main channel	No	NR

Notes:

Abbreviations: GM- Gortmore; BG- Ballygown; MG- Magcobar; GA- Garryard; ShS- Shallee South, NR-Not Required

*New sampling location

Samples were placed into new laboratory provided bottles with the correct preservatives. The sample bottles that required no filtering (and contained no preservatives) were filled directly in

the stream. A container was filled at the same time and transported to the shore for filtering using a 0.45 micron membrane syringe filter before preservation for the trace metal analysis.

Water quality indicator parameters were monitored during sampling by collecting them directly from the stream or discharge when possible using a multi-parameter meter. The final stabilised results were recorded in the field notebook (Appendix H of the Data Report) and are summarised in Appendix A of the Data Report.

Flow Measurements

Flow was measured at twenty two locations using various methods depending upon the quantity of flow to be measured and any safety concerns as detailed in the standard operating procedures in the Monitoring Plan (see Table 2). Twenty three locations are required to have flow measured, however at the time of sampling flow couldn't be measured at the discharge from one shaft (SW5-GAR) due to the grating covering it (refer to Table 2).

Surface water flow results are discussed in Section 5.1 and the data and measurement methodologies are contained in Appendix B of the Data Report. A portable flume was used for small discharges and streams while for very small discrete discharges, a stop watch and calibrated volume container was used. At some locations with greater flow, a Marsh McBirney meter was used to measure flow velocities and depths at regular intervals across the stream by wading.

The Float Method was used when the location of the river was unsafe to wade. It is the least accurate method but provides a reasonable estimate. This method requires the measurement and calculation of the cross-sectional area of the channel as well as the time it takes an object to "float" a designated distance. The water depth was measured (approximately 8 locations) and the float was released into the channel upstream from the beginning of the section and measured the amount of time it takes the "float" to travel the marked section. This was repeated at least three times and the average time calculated.

2.1.3 Vegetation and Soil Sampling

No vegetation or soil sampling was undertaken in August 2016.

2.1.4 Field QA/QC Samples

In accordance with the QA/QC Protocols set out in the Monitoring Plan, the following field QA/QC samples were collected:

Groundwater and Surface water

- Groundwater:
 - One duplicate groundwater sample was collected; and
 - One decontamination blank was collected by pumping deionised (DI) water through the groundwater pump after decontamination.
- Surface Water:
 - Three duplicate surface water samples; and
 - One decontamination blank was collected by pouring DI water over the surface water sampling equipment after decontamination.

- Two certified standard reference material samples containing known concentrations of the 18 metals were shipped blind to ALcontrol laboratory (the SRM certificate is contained in Appendix G of the Data Report).
- One water blank was collected of the DI water during the sampling event. An additional filtration blank was collected in order to try to quantify any contamination caused by the filtration procedure.

Sample IDs for the field QA/QC samples are listed in Table 3. The duplicate samples are an independent check on sampling and laboratory precision. The standard reference materials are an independent check on laboratory accuracy. The decontamination blanks are a check on the decontamination procedures used in the field. These checks are very important and are independent from the QA/QC samples performed by the laboratories (see discussion in Section 3).

Table 3 Field QA/ QC Sample IDs and Descriptions

Sample ID	QA/QC Sample Type	Description
<i>Groundwater and Surface water</i>		
SMGD01.8	GW Duplicate	Duplicate of TMF1
SMDB01.8	GW Decontamination blank	DI water (Lennox Lab Supplies: Batch No. 602-5965) pumped through groundwater pump after final decon at site TMF2.
SMSD01.8	SW Duplicate	Duplicate of DS-GORT
SMSD02.8	SW Duplicate	Duplicate of SW12-SHAL
SMSD03.8	SW Duplicate	Duplicate of SW1-SM
SMDB02.8	SW Decontamination blank	DI water (Lennox Lab Supplies. Batch No: 602-5965) poured over SW sampling beaker after final decon at site SW1-SM.
SMSR01.8	Standard Reference Material	Water ERA Lot #P252-740A
SMSR02.8	Standard Reference Material	Water ERA Lot #P252-740A
WB01.8	Filtration blank	Deionised water (Lennox Lab Suppliers. Batch No: 602-5965)
WB02.8	Water blank	Deionised water (Lennox Lab Suppliers. Batch No: 602-5965)

2.2 Sample Handling

One waterproof label for each sample container collected was completed with an indelible, waterproof, marking pen. The label contained the location, Sample ID code and date and time of sample collection. Samples were stored appropriately so they remained representative of the time of sampling. Sufficient ice packs and ice was added to cool the samples.

A Chain-of-Custody (COC) form was filled out for each sample type at each sampling location. The field staff double-checked that the information recorded on the sample label was consistent with the information recorded on the COC record. The COC record was placed in a re-sealable plastic bag and placed inside of all shipping and transport containers. All samples were hand delivered or shipped by courier to the laboratory specified. Samples were packed so that no breakage would occur. Signed COCs are provided in Appendix E of the Data Report.

2.3 Sample Analysis

2.3.1 ALcontrol

Analysis of water samples was undertaken by ALcontrol. Water (both surface water and groundwater) samples were dispatched from its distribution centre in Dublin and analysed at its facility in North Wales. ALcontrol is accredited by the United Kingdom Accreditation Service (UKAS) in accordance with ISO/IEC 17025:2005 and has also obtained a Certification of Approval by Lloyd's Register Quality Assurance for Environmental Management System Standard ISO 14001:2004.

For groundwater and surface water, analyses were performed for the following parameters: pH, ammoniacal nitrogen as N, sulphate and dissolved metals including Al, Sb, As, Ba, Cd, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, V and Zn.

The Monitoring Plan provides details on the analytical methods, holding times and reporting limits. Most metals were analysed by ICP-MS to achieve the lowest possible detection limits. As noted in the Monitoring Plan, ALcontrol is certified for most of the analyses and the few analyses for which certifications are not available are not critical for comparison to regulatory standards.

All the laboratory reports and analytical data are contained in Appendix F of the Data Report and discussed in Section 4 of this report.

Section 3

Data Quality and Usability Evaluation

3.1 Introduction

Laboratory data quality and usability were assessed using data quality indicators (DQIs). Data “usability” means that the data are considered acceptable to use for their intended purpose and associated evaluations. The DQIs for assessing data are expressed in terms of precision and accuracy. These DQIs provide a mechanism to evaluate and measure laboratory data quality throughout the project. The definitions and methods of measurement of precision and accuracy are discussed below. In addition, use of blank samples as a DQI is also discussed.

3.1.1 Accuracy

Accuracy is defined as the degree of agreement of a measurement with an accepted reference or true value. The accepted reference is typically a standard reference material (SRM) provided by an established institute or company. The “true” value has been determined by performing multiple analyses by various methods and laboratories. Accuracy is a measure of the bias in a system (i.e. the laboratory procedures). Each measurement performed on a sample is subject to random and systematic error. Accuracy is related to the systematic error. Attempts to assess systematic error are always complicated by the inherent random error of the measurement. Accuracy is quantitative and usually expressed as percent recovery (%R) of a sample result compared to the SRM.

%R is calculated as follows:

$$\% R = \frac{A}{T} \times 100$$

where: %R	=	Percent recovery
A	=	Measured value of analyte (metal) as reported by the laboratory
T	=	True value of the analyte in the SRM as reported by the certified institute

Acceptable QC limits are typically between 80 to 120 %R for inorganic methods (i.e. metals in this report). The SRMs used for this project are discussed below.

3.1.2 Precision

Precision is the measurement of the ability to obtain the same value on re-analysis of a sample (i.e. the reproducibility of the data). The closer the results of the measurements are together, the greater is the precision. Precision is not related to accuracy or the true values in the sample. Instead precision is focused upon the random errors inherent in the analysis that result from the measurement process and are compounded by the sample vagaries. Precision is measured by analysing two portions of the sample (sample and duplicate) and then comparing the results. This comparison can be expressed in terms of relative percent difference (RPD). RPD is calculated as the difference between the two measurements divided by the average of the two measurements.

RPD is calculated as follows:

$$RPD = \frac{D_1 - D_2}{(D_1 + D_2) \times 0.5} \times 100$$

where: RPD = Relative percent difference
 D_1 = First sample value
 D_2 = Second sample value (duplicate)

Acceptable RPD values for duplicates generated in the laboratory are usually 65 % to 135 %. Acceptable RPD values for field duplicates are usually 50 % to 150 %. The higher values for field duplicates reflects the difficulty in generating homogeneous duplicates in the field. Both field and laboratory duplicates were generated for this project and are discussed below.

3.1.3 Blanks

Several different types of “blank” samples may be generated to assist in evaluating general data usability. Periodic analysis of laboratory method blanks ensures there is no carryover of contaminants between samples because of residual contamination on the instrument or from contaminants introduced in the laboratory. Laboratory method blanks are typically laboratory pure water, acids or sand that have been processed through all of the procedures, materials, reagents and labware used for sample preparation and analysis. In addition to the laboratory blanks, DI water blanks and DI filtration blanks were generated in the field. Decontamination blanks were also generated to evaluate the sampling equipment decontamination process. Each of these types of blanks is discussed below.

3.1.4 Field QA/QC Samples

Field QA/QC samples were submitted to the laboratories and analysed to enable the following evaluations:

- Duplicate Samples: Duplicate surface water samples were created in the field and submitted blind to the laboratory (see Table 3 for sample IDs). The results are used to evaluate the combined reproducibility of both the laboratory analyses and field sampling.
- Decontamination Blanks: After the sampling equipment was cleaned, DI water was poured over or pumped through the sampling equipment and collected for laboratory analysis (see Table 3 for sample IDs). Analyses of these samples were used to evaluate the adequacy of the sampling equipment cleaning or decontamination procedure;
- Two certified water SRMs were sent blind to ALcontrol (Sample IDs SMSR01.8 and SMSR02.8) to evaluate laboratory accuracy. The certified SRM was supplied by ERA Certified Reference Materials and was Lot #P252-740A (Metals). The Certificate of Analysis is provided in Appendix G of the Data Report. The use of a blind or unknown SRM is the only method to independently verify the laboratory accuracy.
- One water blank was collected of the DI water during the sampling event. An additional filtration blank using DI water was collected in order to try to quantify any contamination caused by the filtration procedure.

3.2 Results of Field QA/QC Samples

3.2.1 Duplicates

Surface water and Groundwater Duplicates

Four duplicate samples (one groundwater and three surface waters) were generated in the field and sent to ALcontrol for analysis. Table 4 provides the results of the 15 dissolved metals for the four duplicate samples and the calculated RPD between each pair of samples. Note if both the original and duplicate results were less than the limit of detection (LOD) then the RPD was zero. In addition, if one of the values was less than the LOD, the LOD value is used to calculate the RPD.

The majority of RPD values shown in Table 5 are below 50 %. The RPDs for the following parameters are good: Arsenic (0 to 16.1%), barium (0 to 0.7%), cadmium (0 to 13.7%), chromium (0%), cobalt (0 to 9%), copper (0 to 10.8%), Iron (1.2 to 44.9%), lead (0 to 2.7%), manganese (1.1 to 6.6%), nickel (0 to 17.1%), vanadium (0%) and zinc (0 to 48.5%).

The RPDs that were above 50% included aluminium at 106.1 % RPD (TMF1 and SMGD01.8), antimony at 175.6 % RPD (SW1-SM and SMSD03.8) and molybdenum at 63.7 % RPD (SW1-SM and SMSD03.8). These results were checked and confirmed with ALcontrol. The highest reported value of the duplicate pair is selected for interpretive use in Section 4 therefore providing a conservative evaluation.

Table 4 Water Duplicate Pairs Reported Values (µg/l) and Calculated % RPD

Dissolved Metal	LOD (µg/l)	TMF 1	SMGD01. 8	% RPD	DS-GORT	SMSD01. 8	% RPD	SW12- SHAL	SMSD02. 8	% RPD	SW1-SM	SMSD03. 8	% RPD
Aluminium	<2.9	6.52	<2	106.1	37.8	37.5	0.8	114	117	-2.6	<2	<2	0
Antimony	<0.16	0.873	1.1	-23.0	0.279	0.248	11.8	0.276	0.417	-40.7	<0.16	2.46	-175.6
Arsenic	<0.12	2.26	2.42	-6.8	0.795	0.878	-9.9	0.599	<0.51	16.1	<0.51	<0.51	0
Barium	<0.03	174	174	0.0	138	139	-0.7	215	216	-0.5	68.4	68.8	-0.6
Cadmium	<0.1	<0.08	<0.08	0	0.226	0.197	13.7	<0.08	<0.08	0	<0.08	<0.08	0
Chromium	<0.22	<1.2	<1.2	0	<1.2	<1.2	0	<1.2	<1.2	0	<1.2	<1.2	0
Cobalt	<0.06	0.868	0.95	-9.0	0.222	0.204	8.5	0.303	0.316	-4.2	<0.15	<0.15	0
Copper	<0.85	<0.85	<0.85	0	4.25	4.53	-6.4	1.49	1.66	-10.8	<0.85	<0.85	0
Iron	<19	<0.019	0.03	-44.9	0.163	0.161	1.2	0.296	0.285	3.8	0.0346	0.0305	12.6
Lead	<0.02	<0.1	<0.1	0	14.2	14.2	0.0	54.8	56.3	-2.7	<0.1	<0.1	0
Manganese	<0.04	61.9	62.6	-1.1	49.6	50.6	-2.0	63	64	-1.6	7.86	8.4	-6.6
Molybdenum	<0.24	0.995	1.54	-43.0	<0.62	<0.62	0	<0.62	<0.62	0	<0.62	1.2	-63.7
Nickel	<0.15	1.63	1.7	-4.2	2.1	2.38	-12.5	1.28	1.52	-17.1	<0.44	<0.44	0
Vanadium	<0.24	<1.3	<1.3	0	<1.3	<1.3	0	<1.3	<1.3	0	<1.3	<1.3	0
Zinc	<0.41	<1.3	<1.3	0	80.2	81.1	-1.1	16.4	17.6	-7.1	3.78	6.2	-48.5

Notes:

Bold indicates an exceedance in the Duplicate RPD acceptance criteria

3.2.2 Decontamination Blanks

Surface Water and Groundwater

Two decontamination blanks were created by pouring DI water over (surface water) and pumping DI water through (groundwater) the sampling equipment after decontamination and sent to ALcontrol for analysis. Table 5 provides the results of the 15 metals for the two decontamination blank samples, the DI water blank and filtration blank samples and the associated laboratory method blank samples. The majority of reported concentrations were below the limits of detection. Most metals were analysed by ICP-MS to achieve the lowest possible detection limits. The limits of detection ranged from 0.02 to 2.9 µg/l except for iron with a detection limit of 19 µg/l.

Detections were observed for seven dissolved metals (excluding detections recorded in the DI filtration blank) ranging from 0.117 to 6.36 µg/l. Zinc was also detected in the DI water filtration blank (34.4 µg/l) but at levels which were up to 25 times greater than recorded values at SMDB01.8 and SMDB02.8. Aluminium (95.5 µg/l), copper (12.3 µg/l) and manganese (5.94 µg/l) were also detected in the DI water filtration blank but not in the decontamination blanks. The concentrations recorded in the DI filtration blank sample were checked and confirmed by ALcontrol. The laboratory advised that such cases may be caused by hotspots in the sample.

Such relatively high concentrations of dissolved metals have not been observed in the DI filtration blank samples in previous monitoring rounds which indicates that the concentrations recorded in August 2016 were not a result of the equipment used in the filtration process or the associated methodology. Additionally, significantly lower values for the relevant dissolved metals, particularly copper and zinc were recorded at multiple sampling locations throughout the mining area. Therefore, the concentrations found in the DI filtration blank sample are not considered to affect the interpretation of results; however, this note should be taken into consideration with any use of the dissolved metal results.

In total there were nine detections of dissolved metals in the decontamination blanks. Five of the recorded values in SMDB01.8 were greater than ten times the detection limit; antimony (6.36 µg/l), barium (0.34 µg/l), chromium (2.54 µg/l), molybdenum (2.89 µg/l) and nickel (2.3 µg/l). All of the detections with the exception of antimony were significantly less than the assessment criteria outlined in Section 4; therefore, these low concentrations in the blanks do not affect interpretation of results. Overall, the decontamination procedures employed in the field were adequate.

The results from the laboratory instrumentation blank were obtained from ALcontrol to determine if any contamination occurred within the laboratory (Table 5). It was noted dissolved molybdenum was detected in the method blank (1.55 µg/l) for Sample Batch 160825-107 and was similar to the concentration in the decontamination blank sample (2.89 µg/l).

To assess the level of cross-contamination between samples in the field, the concentrations in the decontamination blanks were compared with the concentration in the preceding water samples. The reported values of zinc in SMDB01.8 (1.36 µg/l) and SMDB02.8 (2.86 µg/l) were greater than 75% and 32% of the preceding sample respectively. However, these values were significantly less than the concentrations recorded in the DI water blank.

In SMDB01.8, molybdenum (2.89 µg/l) and nickel (2.3 µg/l) were detected at a higher concentration than the preceding sample. Note that molybdenum was also detected in the lab method blank. As discussed, dissolved nickel at 2.3 µg/l was significantly less than the assessment criteria for ecological health (20 µg/l) and human health (20 µg/l). Antimony and chromium were below the detection limit in the preceding sample but had reported values of 6.36 µg/l and 2.54 µg/l respectively in the decontamination blank. These concentrations may indicate cross contamination within the laboratory. However, only one groundwater well was sampled using the low flow method in August 2016 and concentrations of dissolved antimony and chromium were below the detection limit at this location. Therefore, the interpretation of results is not affected.

In SMDB02.8, antimony and lead had reported values of 0.385 µg/l and 0.117 µg/l respectively but were below the detection limit in the preceding sample. Both concentrations are significantly below the assessment criteria outlined in Section 4; therefore, these low concentrations in the blanks do not affect the interpretation of results.

Overall, the decontamination blank samples indicate that the results are considered acceptable for their intended use.

Table 5 Water Blank and Decontamination Blank Reported Values and Laboratory Method Blanks (µg/l)

Sample Description Dissolved Metal	LOD (µg/l)	Filtration Blank WB01.8 (µg/l)	Water Blank WB02.8 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank SMDB01.8 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank SMDB02.8 (µg/l)	Laboratory Method Blank (µg/l)
<i>Sample batch:</i>		<i>160902-24</i>			<i>160825-107</i>		<i>160829-19</i>	
Aluminium	<2.9	95.5	<2	<2	<2	<2	<2	<2
Antimony	<0.16	<0.16	<0.16	<0.16	6.36	<0.16	0.385	<0.16
Arsenic	<0.12	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51
Barium	<0.03	<0.2	<0.2	<0.2	0.34	<0.2	<0.2	<0.2
Cadmium	<0.1	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Chromium	<0.22	<1.2	<1.2	<1.2	2.54	<1.2	<1.2	<1.2
Cobalt	<0.06	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15
Copper	<0.85	12.3	<0.85	<0.85	<0.85	<0.85	<0.85	<0.85
Iron	<19	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019	<0.019
Lead	<0.02	<0.1	<0.1	<0.1	<0.1	<0.1	0.117	<0.1
Manganese	<0.04	5.94	<0.76	<0.76	<0.76	<0.76	<0.76	<0.76
Molybdenum	<0.24	<0.62	<0.62	1.2	2.89	1.55	<0.62	1.26
Nickel	<0.15	<0.44	<0.44	<0.44	2.3	<0.44	<0.44	<0.44
Vanadium	<0.24	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Zinc	<0.41	34.4	<1.3	<1.3	1.36	<1.3	2.86	<1.3

Notes:

Bold indicates a detection. **Bold and italics** indicates a detection of a parameter also detected in the laboratory method blank.*Italics* indicates a detection of in the lab method blank that was also detected in a field water or decontamination blank in the same batch

3.2.3 Standard Reference Materials

SRM Water

As previously discussed two certified water SRMs were sent blind to the laboratory (Sample IDs SMSR01.8 and SMSR02.8) to evaluate laboratory accuracy. The ALcontrol laboratory reports are provided in Appendix F of the Data Report. Table 6 summarises the SRM results and provides the calculated %R values for the 15 requested metals.

Reported values for dissolved aluminium, antimony, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, vanadium and zinc are in good agreement with the certified value (%R ranged from 87 to 110%).

One of the reported values for dissolved arsenic (85 %) and lead (115%) were outside the acceptable range, however the corresponding reported values for the second SRM were within acceptable ranges and therefore the interpretation of the results is not affected. Both of the reported values for dissolved barium (85 % and 88 %) and cadmium (86 % and 88 %) were low and outside of the acceptable range. This indicates that values for barium and cadmium may be biased low and any use of these values should be noted with this observation.

Table 6 Water SRM Reported Values (µg/l) and Calculated % R

Dissolved Metal	Certified Value (µg/l)	Acceptance Limits		SMSR01.8 (µg/l)	% R	SMSR02.8 (µg/l)	% R
		Lower (%)	Upper (%)				
Aluminium	1370	88	114	1420	104	1370	100
Antimony	665	87	111	731	110	620	93
Arsenic	647	87	111	549	85	561	87
Barium	1150	91	109	975	85	1010	88
Cadmium	221	89	106	191	86	194	88
Chromium	783	91	109	791	101	792	101
Cobalt	919	93	111	960	104	948	103
Copper	390	91	109	410	105	400	103
Iron	1900	90	111	1960	103	2000	105
Lead	1380	90	110	1590	115	1370	99
Manganese	499	92	109	509	102	493	99
Molybdenum	467	90	109	466	100	465	100
Nickel	625	91	109	632	101	631	101
Vanadium	597	91	107	608	102	605	101
Zinc	637	91	110	644	101	654	103

Notes:

Bold indicates an exceedance in acceptance limits

3.3 Laboratory QA/QC Samples

3.3.1 ALcontrol

ALcontrol conducts a range of activities associated with both quality control and assessment to assure the quality of test results. Specifically, ALcontrol conduct the following analyses on water samples

- Analytical Quality Control Samples (AQC) including, Certified Reference Material (CRM), Internal Reference Material (IRM) and Matrix spiked material. For batch sizes of 20 samples or less, a minimum of one AQC and for batches of greater than 20 samples, one AQC every additional twenty samples or part thereof. They are introduced into the sample batch on a random basis where possible. They are prepared at the same time as the rest of the batch and by the same person who prepares the batch;
- Process Blanks: A process blank was included with each batch of samples. The blanks are matrix matched where possible and were taken through the entire analytical system;
- Instrument Blanks: An instrument blank was run to check for any contamination within the instrument;
- Independent Check Standard: An independent check standard was included with every instrumental run of samples. This standard is prepared from a different standard than the calibration standards and is used as a check on the validity of the calibration standards. The acceptance criteria for this standard was method specific; and
- Replicate samples (samples tested more than once using the same method) were included at the same frequency as the AQCs.

All of the ALcontrol laboratory reports were reviewed to ensure that reported values were ISO17025 certified (where relevant) and for any sample deviations. None of the sample holding times were exceeded. ALcontrol provided the associated analytical quality control samples (AQC) data. The percentage recovery results for the AQC samples that were performed with the regular environmental samples were checked against the individual lower control and upper control limits. Several of the AQC samples exceeded either the upper or lower control limits as detailed in Appendix F of the corresponding data report. ALcontrol advised that the AQC samples have two limits, a warning limit and a failure limit. Tests which exceed the failure limit are immediately re-run but tests that exceed the warning limit can still be reported. The test only fails automatically if there are multiple warning limit exceedances. Laboratory analysts check the individual cases where the warning limit is exceeded and report the results if they are satisfied with all other factors involved.

The results of method blanks were also assessed as described in Section 3.2.2 above.

3.4 Summary of Data Checks

3.4.1 Field physico-chemical Versus Laboratory Data

Table 7 summarises the field and laboratory results for pH and provides the calculated %RPD values between the two results. Note that pH measurements in the laboratory were taken from the unpreserved sample and therefore the results do not affect the results of samples from preserved bottles (e.g. metals).

The RPDs between laboratory and field pH were good at less than 25%. 80% of samples had calculated %RPD values of less than 10% which is very good. Field pH is more representative of actual conditions and is used for interpretive purposes. Recordings of pH in the field are typically lower than the laboratory due to some carbon dioxide degassing during transport or within the

laboratory itself. Overall, the %RPDs between the field and laboratory data are considered satisfactory.

Table 7 Field physico-chemical data and Laboratory Reported Values and Calculated % RPD

Sample Description	pH	pH	% RPD
	Lab	Field	
(pH Units)			
SW10-GAR	8.02	7.65	-4.7
SW12-GAR	7.91	7.19	-9.5
SW3-GAR	8.13	7.63	-6.3
SW5-GAR	7.3	6.88	-5.9
SW7-GAR	8.33	6.84	-19.6
SW1-SM	7.86	7.19	-8.9
SW2-SM South	7.99	6.26	-24.3
SW5-SM	7.91	7.2	-9.4
SW3-SM	7.88	7.45	-5.6
SW4-SM-GA	7.99	6.89	-14.8
SW6-MAG	7.56	7.39	-2.3
SW12-GORT-Disc	7.51	6.88	-8.8
SW10-GORT-Disc	7.74	6.95	-10.8
SW10-GORT-DS	7.8	7.19	-8.1
SW10-GORT-US	7.81	6.86	-13.0
SW12-GORT-DS	7.77	7.1	-9.0
SW14-GORT	7.76	7.21	-7.3
SW17-GORT	7.76	7.33	-5.7
SW18-GORT	7.6	7.63	0.4
SW19-GORT	7.66	7.6	-0.8
DS-GORT	7.68	7.1	-7.8
DS SHAL	7.57	7.14	-5.8
US-SHAL	6.74	7.03	4.2
SW12-SHAL	6.07	4.84	-22.5
SW4-SHAL	7.17	6.99	-2.5
SW5-SHAL	6.86	6.78	-1.2
SW6-SHAL	6.9	6.64	-3.8
SW9-SHAL	7.45	6.9	-7.7
SW1-SHAL	7.53	7.07	-6.3
SW13-SHAL	7.59	7.1	-6.7

Notes:

Bold indicates an exceedance in acceptance limits

Section 4

Results and Evaluations

This section provides a statistical summary of the analytical results for groundwater and surface water and a comparison of the analytical results against selected assessment criteria. An analysis of loading and time trends is provided in Section 5 and groundwater levels are discussed in Section 6.

All the laboratory reports and analytical data are contained in Appendix F of the Data Report.

4.1 Statistical Summary of Analytical Results

4.1.1 Groundwater Sample Results

Table 8 provides a summary of the reported results of the two groundwater samples. Included in the table are the minimum, maximum and mean dissolved metals concentrations. Where the reported values were below the detection limit, the values were substituted with a value of half the limit of detection. The highest reported value of the field duplicate pair was used where applicable.

Table 8 Summary of Dissolved Metal Concentrations in Groundwater

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)
Aluminium	<2	2	1	1	6.52	-
Antimony	<0.16	2	1	0.08	1.1	-
Arsenic	<0.51	2	2	2.42	4.55	3.49
Barium	<0.2	2	2	174	618	396
Cadmium	<0.08	2	0	0.04	0.04	-
Chromium	<1.2	2	0	0.6	0.6	-
Cobalt	<0.15	2	2	0.648	0.95	0.8
Copper	<0.85	2	0	0.425	0.425	-
Iron	<19	2	2	30	220	125
Lead	<0.1	2	1	0.05	0.58	-
Manganese	<0.76	2	2	62.6	1,080	571
Molybdenum	<0.62	2	2	1.12	1.54	1.33
Nickel	<0.44	2	2	1.33	1.7	1.52
Vanadium	<1.3	2	0	0.65	0.65	-
Zinc	<1.3	2	1	0.65	4.14	-

Notes:

If less than LOD minimum value taken to be half LOD.

The highest concentrations of dissolved barium (618 µg/l), iron (220 µg/l) and manganese (1,080 µg/l) were recorded at TMF2 (downgradient of the TMF), and were significantly higher than the concentrations at TMF1 (upgradient of the TMF). Dissolved arsenic was detected in both wells with the highest concentration recorded at TMF2 (4.55 µg/l). Detections of dissolved lead and zinc were slightly more elevated in TMF2 compared to TMF1.

4.1.2 Surface Water Sample Results

Surface water samples were collected for two major categories: the first includes mine adit discharges and discharges from wetlands as well as some drainage ditches and the second includes the rivers and streams. Table 9 provides a summary of the reported results of the 12 discharge/drainage samples and Table 10 provides a summary of the reported results of the 18 river and stream samples. Included in the tables are the minimum, maximum, mean and standard deviation (SDEV) for dissolved metals concentrations. Where the reported values were below the detection limit, the values were substituted with a value of half the limit of detection. The highest reported value of the field duplicate pair was used where applicable.

Discharges and Drainage

Table 9 Summary of Dissolved Metal Concentrations in Discharges and Drainage

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2	12	2	1	117	71.7	-
Antimony	<0.16	12	10	0.08	5.04	1.2	1
Arsenic	<0.51	12	10	0.255	2.08	0.79	0.49
Barium	<0.2	12	12	18.5	216	94.8	69.3
Cadmium	<0.08	12	10	0.04	40.7	6.57	11.8
Chromium	<1.2	12	0	0.6	0.6	-	-
Cobalt	<0.15	12	6	0.075	9.36	1.43	2.65
Copper	<0.85	12	7	0.425	12.8	2.59	3.62
Iron	<19	12	8	9.5	1,470	199	419
Lead	<0.1	12	9	0.05	352	36.8	100
Manganese	<0.76	12	11	0.38	2,500	491	752
Molybdenum	<0.62	12	5	0.31	4.45	1.28	1.38
Nickel	<0.44	12	12	1.42	135	19.9	37.8
Vanadium	<1.3	12	0	0.65	0.65	-	-
Zinc	<1.3	12	12	17.6	17,000	3,140	5,540

Notes:

If less than LOD minimum value taken to be half LOD.

SW5-GAR (Knights Shaft) had the highest concentrations of dissolved nickel (135 µg/l) and zinc (17,000 µg/l). The highest dissolved lead was recorded at SW6-Shal (Field Shaft) with a value of 352 µg/l. SW12-Gort-Discharge had the highest concentration of dissolved manganese (2,500 µg/l) and SW12-GAR had the highest concentration of dissolved cadmium (40.7 µg/l).

Rivers and Streams

Table 10 Summary of Dissolved Metal Concentrations in Rivers and Streams

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2	18	12	1	103	37.7	24.7
Antimony	<0.16	18	15	0.08	2.46	0.66	1.03
Arsenic	<0.51	18	11	0.255	1.29	0.56	0.4
Barium	<0.2	18	18	49.8	379	164	93.8
Cadmium	<0.08	18	14	0.04	14.6	1.76	8.16
Chromium	<1.2	18	0	0.6	0.6	-	-

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Cobalt	<0.15	18	11	0.075	3.76	0.58	1.83
Copper	<0.85	18	14	0.425	16.8	5.42	4.8
Iron	<19	18	18	34.6	183	96	266
Lead	<0.1	18	17	0.05	249	38.1	82.1
Manganese	<0.76	18	18	2.17	528	75.9	517
Molybdenum	<0.62	18	4	0.31	4.33	0.66	1.17
Nickel	<0.44	18	17	0.22	32.7	5.37	25.1
Vanadium	<1.3	18	0	0.65	0.65	-	-
Zinc	<1.3	18	18	1.58	4,750	515	3,760

Notes:

If less than LOD minimum value taken to be half LOD.

SW1-SM and SW17-Gort are located upstream of the mining areas of Silvermines and Gortmore respectively and had significantly lower concentrations of zinc than the rest of the rivers and streams sampled in the Silvermines area (6.2 and 1.58 µg/l, respectively). SW1-SM and SW17-Gort had background concentrations of barium at 68.8 µg/l and 217 µg/l respectively

SW5-Shal (downstream of the drum dump) had the highest concentrations of cadmium (14.16 µg/l), manganese (528 µg/l), nickel (32.7 µg/l) and zinc (4,750 µg/l). Note that very low flow at SW5-Shal was observed at the time of sampling. SW9-Shal (downstream of field shaft) had the highest concentrations of lead (249 µg/l).

4.2 Assessment Criteria

4.2.1 Groundwater and Surface Water Assessment Criteria

To assess the analytical results of the groundwater and surface water samples, assessment criteria have been selected to screen reported values against both ecological and human health. To assess ecological criteria, the environmental quality standards (EQS) from the European Communities Environmental Objectives (Surface Water) Regulations, 2009 (S.I. 272 of 2009) and amendments were utilised, as shown in Table 11. These include standards for physico-chemical conditions supporting the biological elements, general conditions and standards for specific pollutants. In the case of metals, the EQS refers to the dissolved concentration. Compliance with the standards in the surface water regulations is either based on an annual average (AA), a maximum allowable concentration (MAC) or a 95 percentile standard. The MAC or 95 percentile (95%-ile) was selected where possible as the assessment criteria because it is the most appropriate for the assessment of one value; however, the AA was used in the absence of the MAC or 95%-ile. To supplement the Irish legislation, screening criteria were selected from Oak Ridge National Laboratory (Suter and Tsao, 1996) for certain metals including aluminium, barium, cobalt, manganese and uranium (Table 11).

For hardness-dependent metals (copper, zinc and cadmium), the hardness is taken into account when selecting the appropriate EQS value. The average hardness in the rivers and streams in the Silvermines mining area was determined to be 165 mg/l CaCO₃ (CDM Smith, 2013) and therefore the EQSs for hardness greater than 100 mg/l were selected as shown in Table 11. The appropriate ecological assessment criteria are highlighted in bold in Table 11.

To assess the potential human health risks, the Drinking Water Regulations, 2007 (S.I. No. 106 of 2007) and amendments were utilised and are listed in Table 12. These values are the maximum permissible values for a drinking water source. In the case of metals, the standards are for total metals, however they apply post treatment (including filtration) and therefore the dissolved portion is used in the assessment in Section 4.

The current Drinking Water Regulations set limit values for iron and manganese but they are categorised as Indicator Parameters. Indicator Parameters are not considered to be important health criteria but rather exceedances can affect the aesthetic quality of drinking water supplies. Iron and manganese are commonly found above the drinking water limit in groundwaters in Ireland and are intermittently above the standard in some surface waters.

The two main receptors of groundwater at Gortmore TMF are surface water bodies and the groundwater resource as a drinking water supply. Therefore, to assess the potential impact of the groundwater quality on relevant groundwater receptors, the same standards and guidelines as mentioned for surface water were utilised for screening purposes (Table 11 and Table 12).

Table 11 Surface Water and Groundwater Assessment Criteria for Biological Elements

Parameter	Unit	AA	MAC (or 95%-ile)	Source	Description
Ammonia as N	mg/l	0.065	0.14	S.I. No. 272 of 2009	Good status
pH	pH units		> 4.5 and < 9.0	S.I. No. 272 of 2009	Within range
Dissolved Oxygen	% Sat		80 to 120	S.I. No. 272 of 2009	Within range
Arsenic	µg/l	25	-	S.I. No. 272 of 2009	
Cadmium	µg/l	≤0.08 (Class 1) 0.08 (Class 2) 0.09 (Class 3) 0.15 (Class 4) 0.25 (Class 5)	≤0.45 (Class 1) 0.45 (Class 2) 0.6 (Class 3) 0.9 (Class 4) 1.5 (Class 5)	S.I. No. 327 of 2012	Hardness measured in mg/l CaCO ₃ (Class 1: <40 mg CaCO ₃ /l, Class 2: 40 to <50 mg CaCO ₃ /l, Class 3: 50 to <100 mg CaCO ₃ /l, Class 4: 100 to <200 mg CaCO ₃ /l and Class5: ≥200 mg CaCO ₃ /l)
Chromium	µg/l	3.4		S.I. No. 272 of 2009	
Copper	µg/l	5 or 30	-	S.I. No. 272 of 2009	5 µg/l applies where the water hardness measured in mg/l CaCO ₃ is ≤ 100; 30 µg/l applies where the water hardness > 100 mg/l CaCO ₃ .
Lead	µg/l	7.2	-	S.I. No. 327 of 2012	
Nickel	µg/l	20	-	S.I. No. 327 of 2012	
Zinc	µg/l	8 or 50 or 100	-	S.I. No. 272 of 2009	8 µg/l for water hardness with annual average values ≤ 10 mg/l CaCO ₃ ; 50 µg/l for water hardness >10 mg/l CaCO ₃ and ≤ 100 mg/l CaCO ₃ ; and 100 µg/l elsewhere.
Supplementary standards:					
Aluminium	µg/l	-	1900	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids
Barium	µg/l	-	4	Oak Ridge National Laboratory	Invertebrates and Salmon fish

Parameter	Unit	AA	MAC (or 95%-ile)	Source	Description
Cobalt	µg/l	-	5.1	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids
Manganese	µg/l	-	1,100	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids

Notes:

Bold indicates the selected assessment criteria for ecological health

Table 12 Surface Water and Groundwater Assessment Criteria for Drinking Water

Parameter	Unit	Parametric value
pH	pH units	>6.5 to <9.5
Conductivity	mS/cm	2.5
Ammonium	mg/l	0.3
Sulphate	mg/l	250
Aluminium	µg/l	200
Antimony	µg/l	5
Arsenic	µg/l	10
Cadmium	µg/l	5
Chromium	µg/l	50
Copper	µg/l	2,000
Iron	µg/l	200
Lead	µg/l	10
Manganese	µg/l	50
Nickel	µg/l	20

4.2.2 Livestock Drinking Water Assessment Criteria

There are currently no Irish or European guidelines for the quality of drinking water for livestock. Recommendations for levels of toxic substances in drinking water for livestock are available from the US National Academy of Sciences (1972). Table 13 summarises the recommended levels for metals where limits have been established, and for total dissolved solids and sulphate.

Table 13 Assessment Criteria for Livestock Drinking Water Quality

Parameter	Unit	Parametric Value	Source	Comment
Aluminium	µg/l	5,000	NAS 1972	
Arsenic	µg/l	200	NAS 1972	
Cadmium	µg/l	50	NAS 1972	
Chromium	µg/l	1,000	NAS 1972	
Cobalt	µg/l	1,000	NAS 1972	
Copper	µg/l	500	NAS 1972	
Lead	µg/l	100	NAS 1972	Lead is accumulative and problems may begin at threshold value of 0.05 mg/l. (Soltanpour and Raley, 2007)
Vanadium	µg/l	100	NAS 1972	
Zinc	µg/l	24,000	NAS 1972	
Sulphate	mg/l	500	Higgins <i>et. al.</i> 2008	<500 mg/l for calves <1,000 mg/l for adults

4.3 Comparison to Assessment Criteria

A comparison of the groundwater and surface water analytical results was performed against the relevant assessment criteria for ecological and human health as described in Section 4.2. The results and exceedances are discussed in this section.

Table B-2 in [Appendix B](#) highlights the exceedances of the assessment criteria. Where there was an exceedance of the ecological assessment criteria, the result is highlighted in purple; for an exceedance of the human health criteria the result is highlighted in blue. In some cases, the reported values exceed both the ecological and human health criteria and these results are highlighted in pink.

A comparison of the surface water analytical results was made against the relevant assessment criteria for livestock drinking water as described in Section 4.2. Table B-3 in [Appendix B](#) highlights the exceedances of the assessment criteria. Where there was an exceedance of the livestock assessment criteria, the result is highlighted in green.

4.3.1 Groundwater Assessment

In groundwater, the pH was found to be within the acceptable ranges for ecological (4.5 to 9 pH units) and human health (6.5 to 9.5 pH units) criteria with an average of pH 6.9. The specific conductance ranged from 0.481 to 0.498 mS/cm which was well within the criteria for human health of 2.5 mS/cm.

Sulphate was within normal ranges with values ranging from <2 to 34.3 mg/l, which was well below the criteria for human health of 250 mg/l. Ammonia was less than the limit of detection for both monitoring wells.

For dissolved metal concentrations, barium and manganese exceeded the assessment criteria in both groundwater samples, with higher concentrations in the downgradient monitoring well. Barium exceeded the ecological health criteria of 4 µg/l in both monitoring wells; TMF1 (upgradient) had a result of 174 µg/l and TMF2 (downgradient) had a result of 618 µg/l. Manganese exceeded the human health criteria of 50 µg/l in both wells that were sampled; TMF1 had a result of 62.6 µg/l and TMF2 had a result of 1,080 µg/l. As well, iron exceeded the human health criteria (200 µg/l) at TMF2 with a concentration of 220 µg/l. Note that manganese and iron are not important criteria for human health (see Section 4.2.1).

4.3.2 Surface Water Assessment

The pH in surface waters in the Silvermines mining area ranged from 4.84 to 7.65 with an average of 7.03. There were two exceedances of the assessment criteria for pH at SW12-Shal (4.84 pH) and SW2-SM-South (6.26 pH) which were below the acceptable range for human health of 6.5 to 9.5 pH. The conductivity ranged from 0.03 to 2.1 mS/cm with an average of 0.6 mS/cm, with no exceedances of the human health criteria (2.5 mS/cm).

The ecological assessment criteria for ammonia (0.14 mg/l) was exceeded at SW12-Gort-Discharge which had a concentration of 0.298 mg/l. Both the ecological assessment criteria and the human health criteria (0.3 mg/l) were exceeded at SW14-Gort (0.329 mg/l).

Sulphate exceeded the criteria for human health (250 mg/l) at both pond discharge locations at Gortmore TMF and both wetland discharges in the Gortmore area. As well, three of the discharge

and drainage locations in the Garryard area exceeded the criteria for human health. The sulphate results that exceeded the criteria ranged from 329 to 1130 mg/l, with an average of 853 mg/l. The highest sulphate result was from SW10-Gort-Disc.

Dissolved Metals Assessment

Concentrations of dissolved barium, cadmium, iron, lead, manganese, nickel and zinc were elevated and exceeded the assessment criteria in many locations as discussed below, see the Table B-2 in [Appendix B](#) for the full listing. Table 14 provides a summary of the reported values for rivers and streams at the upstream and downstream locations at the different mining areas that exceeded the relevant ecological and human health assessment criteria for dissolved metals. For the locations refer to the maps in [Appendix A](#).

The ecological assessment criterion for barium of 4 µg/l was exceeded at all locations with high results even at upstream locations SW1-SM (68.8 µg/l) and SW17-Gort (217 µg/l). Note that these concentrations of barium are similar to the values recorded at the upstream locations in previous monitoring rounds. Exceedances of dissolved barium are not discussed further. Dissolved arsenic was detected at the majority of surface water locations but was significantly below both the ecological (25 µg/l) and human health (10 µg/l) assessment criteria, with the highest concentration of 2.08 µg/l at SW5-Gar.

In the Ballygown area (Map 5 of [Appendix A](#)) where the Silvermines stream is located, in addition to dissolved barium, dissolved cadmium and zinc exceeded the assessment criteria at certain locations. Upstream at SW1-SM there were no exceedances of the ecological or human health criteria (except barium). At the southern Adit (SW2-SM-South), concentrations of dissolved cadmium (4.9 µg/l) and dissolved zinc (1,720 µg/l) exceeded the ecological assessment criteria of 0.9 and 100 µg/l respectively. Downstream on the Silvermines stream at SW5-SM, dissolved zinc was also above the ecological assessment criteria with a concentration of 101 µg/l. Further downstream at SW4-SM-GA the concentration of zinc (94.7 µg/l) was below the assessment criteria.

SW6-Mag downstream of the Magcobar area also had dissolved zinc (370 µg/l) above the ecological assessment criteria.

Table 14 Summary of Reported Values for Rivers and Streams and the Surface Water Assessment Criteria

				Date Sampled	Ammoniacal Nitrogen as N	pH (field)	Cadmium (diss.filt)	Lead (diss.filt)	Manganese (diss.filt)	Nickel (diss.filt)	Zinc (diss.filt)
Sample Description		Sample Location	Units	mg/l			µg/l	µg/l	µg/l	µg/l	µg/l
Ecological Criteria				0.14	4.5 to 9		0.9	7.2	1100	20	100
Human Health Criteria				0.3	6.5 to 9.5		5	10	50	20	-
Ballygown	SW1-SM	Upstream	25/08/2016	<0.2	7.19		<0.08	<0.1	8.4	<0.44	6.2
	SW3-SM	DS (underground workings)	26/08/2016	<0.2	7.45		<0.08	0.674	2.17	0.631	22.8
	SW5-SM	DS (underground workings & Adits)	26/08/2016	<0.2	7.2		0.311	0.671	3.12	0.695	101
	SW4-SM-GA	Downstream (all)	26/08/2016	<0.2	6.89		0.24	1.04	5.03	0.78	94.7
Magcobar	SW6-Mag	Downstream	23/08/2016	<0.2	7.39		0.874	1.03	9.66	5.06	370
Garryard	SW1-GAR	Upstream	No Flow	-	-		-	-	-	-	-
	SW3-GAR	Downstream (all)	25/08/2016	<0.2	7.63		7.7	1.43	290	8.47	1820
Shallee	SW4-SHAL	Upstream	24/08/2016	<0.2	6.99		0.437	16.8	69.1	4.16	47.9
	SW5-SHAL	DS (drum dump)	24/08/2016	<0.2	6.78		14.6	34.6	528	32.7	4750
	SW9-SHAL	Downstream	24/08/2016	<0.2	6.9		2.71	249	71.1	14	674
	SW1-SHAL	Downstream (all)	24/08/2016	<0.2	7.07		2.16	191	59.6	11	532
Garryard/ Shallee	US SHAL	Downstream of SW3-GAR	24/08/2016	<0.2	7.03		0.424	49.4	16	2.22	65.2
	DS SHAL	Downstream of SW3-GAR and SW1-SHAL	24/08/2016	<0.2	7.14		1.22	84.2	40.6	5.24	403
Gortmore	SW17-GORT	Upstream	23/08/2016	<0.2	7.33		<0.08	0.5	29.8	1.56	1.58
	SW12-GORT-DS	Downstream (TMF)	23/08/2016	<0.2	7.1		0.29	21.3	77.3	2.37	113
	SW14-GORT	Downstream (TMF and Yellow River)	23/08/2016	0.329	7.21		0.238	16.2	47.6	2.05	82.9
	DS-Gort	Downstream (TMF and Yellow River)	23/08/2016	<0.2	7.1		0.226	14.2	50.6	2.38	81.1

Notes:

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

Metals are dissolved

At Gortmore TMF (Map 2 of [Appendix A](#)), dissolved zinc and cadmium exceeded the ecological assessment criteria (100 and 0.9 µg/l, respectively) and dissolved iron exceeded the human health assessment criteria (200 µg/l). Dissolved lead and manganese exceeded both the ecological (7.2 and 1,100 µg/l, respectively) and human health assessment criteria (10 and 50 µg/l, respectively) at several locations. Concentrations of dissolved nickel were detected at all sampling locations but were significantly lower than the assessment criteria. Dissolved manganese exceeded the human health assessment criterion of 50 µg/l at three locations; SW18-Gort (106 µg/l), SW12-Gort-DS (77.3 µg/l) and SW10-Gort-Disc. (808 µg/l) and exceeded both the human health and ecological health assessment criteria (1,100 µg/l) at SW12-Gort-Disc. (2,500 µg/l).

Dissolved zinc exceeded the ecological assessment criteria of 100 µg/l at five locations at Gortmore TMF. The highest concentrations were recorded at SW18-Gort (789 µg/l) and SW19-Gort (1,000 µg/l) which are the pond discharges on the TMF. The two wetland discharges at Gortmore TMF had exceedances ranging from 189 µg/l at SW12-Gort-Disc. to 590 µg/l at SW10-Gort-Disc. The concentration of zinc increased on the Kilmastulla River from 1.58 µg/l at the upstream location SW17-Gort to 113 µg/l at the downstream location SW12-Gort-DS, which exceeded the ecological assessment criteria. This location is downstream of the wetland discharges and the Yellow Bridge Tributary which drains Garryard and Shallee. The loading from these areas are discussed in Section 5.

At Shallee (Map 3 of [Appendix A](#)), dissolved lead exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria at all locations (with the exception of drainage channel SW13-Shal) with concentrations ranging from 16.8 to 352 µg/l. The highest concentration (352 µg/l) was from the Field Shaft discharge (SW6-Shal). At SW4-Shal which is upstream of the mining area, the dissolved lead concentration was 16.8 µg/l (above both assessment criterion). With the exception of SW12-Shal (stone lined drainage channel), SW13-Shal, SW4-Shal and US-Shal which is located upstream of the Shallee mining area on the Yellow Bridge River, dissolved zinc exceeded the ecological assessment criteria of 100 µg/l with values ranging from 253 to 4,750 µg/l. Manganese was above the criteria for human health (50 µg/l) but below the ecological assessment criteria (1,100 µg/l) at six Shallee locations with values ranging from 59.6 µg/l (SW1-Shal) to 528 µg/l (SW5-Shal). SW5-Shal exceeded the ecological and human health criteria for dissolved nickel of 20 µg/l (32.7 µg/l). Dissolved cadmium exceeded the ecological criteria (0.9 µg/l) at four locations. SW5-Shal (14.6 µg/l) exceeded both the ecological and human health criteria (5 µg/l).

DS-Shal is located on the Yellow River downstream of all the discharges from the Shallee and Garryard mining areas and located upstream of the confluence with the Kilmastulla River in the Gortmore area. The dissolved lead exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria with a concentration of 84.2 µg/l. The dissolved zinc exceeded the ecological assessment criteria (100 µg/l) with a concentration of 403 µg/l. DS-Shal also exceeded the ecological criteria (0.9 µg/l) for dissolved cadmium with a value of 1.22 µg/l.

In the Garryard area (Map 4 of [Appendix A](#)), some of the highest concentrations of dissolved metals were observed. Each location in Garryard exceeded the dissolved zinc ecological assessment criteria of 100 µg/l, ranging from 1,820 to 17,000 µg/l. However, SW7-Gar (discharge from wetlands) had a dissolved zinc concentration of 34.2 µg/l. All locations exceeded both the ecological (0.9 µg/l) and human health (5 µg/l) assessment criteria for cadmium (ranging from 7.7 to 40.7 µg/l) with the exception of SW7-Gar which was below the assessment criterion. At SW5-Gar (Knights Shaft), dissolved lead (9.22 µg/l) exceeded the ecological (7.2 µg/l) and human health

(10 µg/l) assessment criteria and dissolved nickel exceeded both the ecological and human health assessment criteria of 20 µg/l with a value of 135 µg/l. Dissolved manganese was above the criteria for human health (50 µg/l) but below the ecological assessment criteria (1,100 µg/l) at all locations with the exception of SW5-Gar (1,370 µg/l) which also exceeded the ecological assessment criteria.

4.3.3 Livestock Water Quality Assessment

Recommendations for levels of toxic substances in drinking water for livestock are provided in Table 13. A limit of 100 µg/l is recommended for lead in drinking water for livestock by the National Academy of Sciences (1972). However, lead is accumulative and problems may begin at threshold value of 50 µg/l. The Field Shaft (SW6-Shal) had a concentration of dissolved lead of 352 µg/l and the sampling location on the stream SW9-Shal which is just downstream of the Field Shaft had concentration of 249 µg/l. Further downstream at SW1-Shal which is located down gradient of the Shallee tailings impoundment the concentration of dissolved lead was 191 µg/l. Therefore, livestock should be prevented from drinking water in the stream in the Shallee mining area.

The water quality results for all of the ponds and streams sampled at Gortmore TMF were also assessed against the recommendations for levels of toxic substances in drinking water for livestock from the National Academy of Sciences (1972).

- No exceedances of the livestock threshold values for any metals were found;
- The maximum recommended sulphate levels for calves is 500 mg/l and for adults is 1,000 mg/l. Sulphate values exceeded the recommended values at the following sampling locations; SW18-Gort (1,080 µg/l), SW19-Gort (936 µg/l), SW10-Gort-Disc (1,130 µg/l), SW12-Gort-Disc (662 µg/l). The guidelines for sulphates in water are not well defined but high concentrations cause diarrhoea; however, at the levels found in the waterbodies at Gortmore TMF it is likely that livestock are accustomed to them also. Therefore, it is considered that the streams and ponds on top of the Gortmore TMF are safe for livestock but they should be continued to be monitored.

Section 5

Flows, Loads and Trend Analysis

5.1 Surface Water Flows

No river flow gauging stations are present within the Silvermines mining area. The nearest gauge on the Kilmastulla River is Coole (EPA station 25044) which is approximately 10 km downstream of the Silvermines mining area. The flow record from 1 March to 29 August 2016 from Station 25044 is reproduced in Figure 1. The figure shows the measured flows ranging from $>12 \text{ m}^3/\text{s}$ following rainfall events to less than $1 \text{ m}^3/\text{s}$ during low-flow, with a median flow of approximately $0.7 \text{ m}^3/\text{s}$. The recorded flow at the Coole gauging station showed that for a number of days in March and April high flows existed and were at or above the calculated 5%-ile (high flow) of $3.6 \text{ m}^3/\text{s}$ on several occasions after rainfall. The flow during this period shows a flashy response to rainfall. The highest recorded flow in the monitoring period was on 1 March 2016 with a mean daily flow of $12.5 \text{ m}^3/\text{s}$. From May to August the flows were low with a baseline of $0.29 \text{ m}^3/\text{s}$ which is below the 95%-ile (low flow) of $0.34 \text{ m}^3/\text{s}$. Overall flows were relatively high in March and April and low during the remainder of the monitoring period.

The flows in the Kilmastulla River in the Silvermines mining area are expected to be lower than that recorded at the EPA Station 10 km downstream, as many small tributaries drain from the surrounding mountains between the mining area and the gauging station. The EPA tool for ungauged catchments was utilised to estimate the 95%-ile flow (low flow) of the Kilmastulla River at the location just downstream of the Gortmore TMF which was $0.16 \text{ m}^3/\text{s}$. It is estimated that the flows would have been close to the 95%-ile low flow in the Silvermines mining area in June, July and August. The EPA tool for ungauged catchments was used to calculate the 5%-ile flow (high flow) which was $4.36 \text{ m}^3/\text{s}$ as the flows were likely greater than this on several occasions in March.

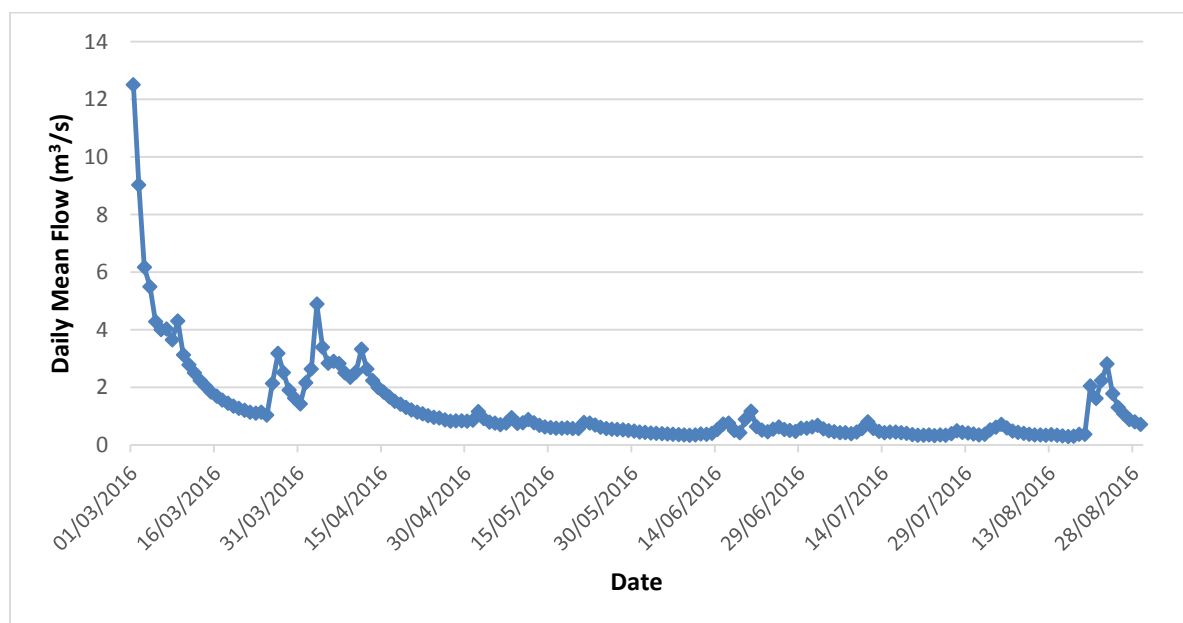


Figure 1 Mean Daily Flow (m^3/s) at Coole, Kilmastulla (Station 25044) from 1 Mar to 29 Aug 2016

Flow was measured directly in the field using different methodologies depending upon the quantity of flow to be measured and any safety concerns, as described in Section 2.1.2. Table 15 presents a summary of the results from the flow measured in August 2016 at the time of sampling. Appendix B of the Data Report contains details of methodologies used per site and associated calculations.

Table 15 Surface Water Flow Value Measured in August 2016

Site Name	Flow l/s	Date
DS-GORT	1,695	23/08/2016
SW10-GORT-DISCHARGE	4.50	23/08/2016
SW12-GORT-DISCHARGE	7.50	23/08/2016
SW19-GORT	0.29	22/08/2016
DS-Shal	90.8	24/08/2016
SW12-Shal	5.93	24/08/2016
SW13-Shal	4.81	24/08/2016
SW1-Shal	23.2	24/08/2016
SW4-Shal	0.17	24/08/2016
SW5-Shal	1.33	24/08/2016
SW6-Shal	6.22	24/08/2016
SW9-Shal	18.4	24/08/2016
US-Shal	44.9	24/08/2016
SW10-GAR	2.59	25/08/2016
SW12-GAR	0.09	25/08/2016
SW3-GAR	3.29	25/08/2016
SW5-GAR	Immeasurable Flow (grating)	25/08/2016
SW7-GAR	0.20	25/08/2016
SW1-SM	29.2	25/08/2016
SW2-SM-SOUTH	0.60	26/08/2016
SW3-SM	50.6	26/08/2016
SW4-SM-GA	60.1	26/08/2016
SW5-SM	43.5	26/08/2016

5.2 Loading Analysis

5.2.1 Loading Analysis Methodology

Mass loads (g/day) were calculated for the locations with measured flows using the measured flow and concentration data, as follows:

$$\text{Load (g/day)} = [C (\mu\text{g/L}) * F (\text{L/day})] / 1,000,000 \mu\text{g/g}$$

where: C = the concentration of the parameter in the water

F = the flow rate of the input

5.2.2 Loading Results and Discussion

The calculated mass loads in Table 16 aid with the interpretation of the loading of sulphate and dissolved cadmium, lead, manganese, nickel and zinc to rivers.

Table 16 Summary of Measured Flows and Concentrations and Calculated Loads of Sulphate and Dissolved Metals in g/day

Site Description	Date Sampled	Flow l/s	pH Units	Sulphate		Cadmium		Lead		Manganese		Nickel		Zinc	
				µg/l	g/day	µg/l	g/day	µg/l	g/day	µg/l	g/day	µg/l	g/day	µg/l	g/day
DS-GORT	23/08/2016	1695	7.1	42000	6150000	0.226	33.1	14.2	2080	50.6	7410	2.38	349	81.1	11900
SW10-GORT-DISC.	23/08/2016	4.5	7.0	1130000	439000	0.04	0.02	0.05	0.02	808	314	8.17	3.18	590	229
SW12-GORT-DISC.	23/08/2016	7.5	6.9	662000	429000	0.111	0.07	0.05	0.03	2500	1620	4.2	2.72	189	122
SW19-GORT	22/08/2016	0.3	7.6	936000	23800	2.58	0.07	1.46	0.04	12.4	0.31	6.43	0.16	1000	25.4
DS-SHAL	24/08/2016	90.8	7.1	44800	351000	1.22	9.57	84.2	661	40.6	319	5.24	41.1	403	3160
SW12-SHAL	24/08/2016	5.9	4.8	1000	513	0.04	0.02	56.3	28.9	64	32.8	1.52	0.78	17.6	9.02
SW13-SHAL	24/08/2016	4.8	7.1	28000	11600	0.25	0.1	5.43	2.26	14.9	6.2	1.42	0.59	21.3	8.86
SW1-SHAL	24/08/2016	23.2	7.1	23200	46400	2.16	4.32	191	382	59.6	119	11	22	532	1060
SW4-SHAL	24/08/2016	0.2	7.0	1000	14.7	0.437	0.01	16.8	0.25	69.1	1.01	4.16	0.06	47.9	0.7
SW5-SHAL	24/08/2016	1.3	6.8	65200	7490	14.6	1.68	34.6	3.98	528	60.7	32.7	3.76	4750	546
SW6-SHAL	24/08/2016	6.2	6.6	20100	10800	1.33	0.71	352	189	99	53.2	13.5	7.26	253	136
SW9-SHAL	24/08/2016	18.4	6.9	25000	39700	2.71	4.3	249	396	71.1	113	14	22.2	674	1070
US-SHAL	24/08/2016	44.9	7.0	20800	80600	0.424	1.64	49.4	191	16	62	2.22	8.6	65.2	253
SW10-GAR	25/08/2016	2.6	7.7	329000	73500	16.5	3.69	2.4	0.54	260	58.1	13.5	3.02	3940	880
SW12-GAR	25/08/2016	0.1	7.2	844000	6560	40.7	0.32	3.05	0.02	442	3.44	41	0.32	12100	94.1
SW3-GAR	25/08/2016	3.3	7.6	210000	59700	7.7	2.19	1.43	0.41	290	82.4	8.47	2.41	1820	517
SW7-GAR	25/08/2016	0.2	6.8	145000	2510	0.102	0	0.05	0	215	3.72	1.73	0.03	34.2	0.59
SW1-SM	25/08/2016	29.2	7.2	20300	51200	0.04	0.1	0.05	0.13	8.4	21.2	0.22	0.56	6.2	15.7
SW2-SM-SOUTH	26/08/2016	0.6	6.3	35200	1820	4.9	0.25	0.974	0.05	0.38	0.02	5.73	0.3	1720	89.2
SW3-SM	26/08/2016	50.6	7.5	1000	4370	0.04	0.17	0.674	2.95	2.17	9.49	0.631	2.76	22.8	99.7
SW4-SM-GA	26/08/2016	60.1	6.9	1000	5190	0.24	1.25	1.04	5.4	5.03	26.1	0.78	4.05	94.7	492
SW5-SM	26/08/2016	43.5	7.2	2600	9770	0.311	1.17	0.671	2.52	3.12	11.7	0.695	2.61	101	380

Notes:

Sites with no flow on the day of sampling are omitted from the table.

The dissolved metal with the highest mass loading was zinc ranging from 0.59 to 11,900 g/day with an average of 959 g/day overall. The largest mass load of zinc (11,900 g/day) was found at DS-Gort which is located on the Kilmastulla River, downstream of Gortmore TMF. The DS-Gort sampling location captures the total dissolved metal load from all of the primary mining areas (Gortmore, Shallee, Garryard, Magcobar and Ballygown). Of the two wetland discharges at Gortmore TMF, SW10-Gort-Discharge had the highest loading of dissolved zinc at 229 g/day. SW12-Gort-Discharge had 122 g/day of zinc.

SW10-Gar (the discharge from the tailings lagoon) had a zinc load of 880 g/day. Further downstream at SW3-Gar which is located in a stream containing the SW10-Gar discharge and the western part of the Mogul yard, there was a decrease in zinc loading to 517 g/day. Weather conditions were dry in the 24 hours prior to sampling and no significant flow was observed in the channels draining the western section of the Mogul yard. The stream discharges to the Yellow Bridge River which flows to the Kilmastulla River.

The dissolved zinc load upstream of Ballygown (SW1-SM) was calculated to be 15.7 g/day, which increases to 99.7 g/day downstream of the mine workings (SW3-SM). The dissolved zinc load at SW5-SM which is located downstream of the southern (89.2 g/day zinc) and northern adit (not sampled) would be expected to be 189 g/day. However, the calculated zinc load at SW5-SM was 380 g/day which indicates that there may be another source of dissolved zinc contributing to this stretch such as groundwater seeps in proximity to the adit discharges. Further downstream the calculated mass load at SW4-SM-GA was 492 g/day which is an increase of 112 g/day. The increase in dissolved zinc load along this stretch was also identified in R7 (February 2016) and indicates an additional source of dissolved zinc load. The Silvermines stream contributes this load to the Kilmastulla River.

The highest load of dissolved lead was found at DS-Gort (2,080 g/day). The mass load at DS-Shal which is located downstream of both the Shallee and Garryard mining areas was 661 g/day. The dissolved lead load increased from 382 g/day at SW1-Shal to 661 g/day at DS-Shal. This increase can be primarily attributed to the lead load at US-Shal (191 g/day) located on the stream draining the Garryard mining area. The calculated lead load at SW3-Gar located directly downstream of the Garryard area was 0.4 g/day which indicates an increase in dissolved lead load of approximately 190 g/day between SW3-Gar and US-Shal. This apparent increase indicates that a diffuse contribution of dissolved lead is likely along this stretch of river.

The dissolved zinc load at DS-Shal is 3,160 g/day which is a significant increase compared to the Shallee area (SW1-Shal – 1,060 g/day). The stream emerging from the Garryard area contributed 253 g/day (US-Shal) which indicates that there may be additional sources of zinc contributing to the loading result at DS-Shal. A sample (SW13-Shal) was collected from the stream draining the eastern section of the tailings impoundment which joins the Shallee stream downstream of SW1-Shal and a minor load of dissolved zinc was found (8.86 g/day). All results were checked and confirmed by ALcontrol.

Upstream of SW1-Shal the dissolved lead load was 396 g/day at SW9-Shal which is located immediately east of the southernmost Shallee tailings impoundment and downstream of the Field Shaft. The dissolved lead loading from Field Shaft (SW6-Shal) was 189 g/day. This indicates that the discharge from the Field Shaft is not the only contributor of lead load to the stream. The majority of the stream has been surveyed between the main road and Field Shaft (where

accessible) and no other inputs of surface water were observed. However, in February 2016, the stream at SW5-Shal (downstream of the drum dump) was discharging onto the road and subsequently flowing into the ditch east of the field shaft. This flow was likely joining the main stream downstream of the field shaft. Further investigation is required during high flow sampling to confirm this and it is recommended that this temporary stream is sampled directly before entering the main stream to assess the dissolved metal load contribution.

Discharges from the Garryard and Shallee area (DS-Shal – 3,160 g/day) provided the greatest mass loads of dissolved zinc to the Kilmastulla River.

5.3 Trend Analysis

5.3.1 Historical Trends

This section discusses concentration time trends for select locations including the main discharges (SW2-SM South, SW6-SHAL, SW10-GAR, SW10-Gort-Disc. and SW12-Gort-Disc.) and SW14-Gort which is located on the Kilmastulla River, downstream of the primary mining areas (Gortmore, Shallee, Garryard, Magcobar and Ballygown). The Mann-Kendall test was performed on the surface water data. The Mann-Kendall test is a non-parametric test that is well suited to use in water quality data analysis. The Mann-Kendall test was performed for dissolved cadmium, lead, manganese, nickel and zinc.

The Mann-Kendall test results in the identification of a trend (if one exists) and the probability of that trend being real. Table 17 shows the possible outcomes of the Mann-Kendall trend analysis as applied to the water quality data.

Table 17 Reporting the Mann-Kendall Results

Trend	P value	Trend
Decreasing	$0 \leq p < 0.05$	Decreasing
	$0.05 \leq p < 0.1$	Likely Decreasing
	$p \geq 0.1$	No Trend
Increasing	$0 \leq p < 0.05$	Increasing
	$0.05 \leq p < 0.1$	Likely Increasing
	$p \geq 0.1$	No Trend
No Trend	$p = 1$	No Trend
Not Calculated	n/a	Not Calculated

Notes:

Null Hypothesis: The null hypothesis is that there is no trend.

The p-value is the probability that the null hypothesis is true.

The confidence coefficient is 0.95

The Mann-Kendall test requires the following information for a trend to be calculated: A sample size of at least three value and a maximum of 50% of the sample set is reported as non-detect.

Trend analysis was conducted for all the available data since November 2006. The Mann-Kendall test results are presented in Table 18 and facilitate general observations about trends in the water quality of the main discharges and the downstream location on the Kilmastulla River.

Table 18 Mann-Kendall Trend Analysis of data from November 2006 to August 2016

Sample Location	Parameter	Reported values (n)	p value	s value	Trend
SW10-Gar	Diss. cadmium	13	0.2705	-11	No Trend
	Diss. lead	12	0.2033	-13	No Trend
	Diss. manganese	13	0.0252	-33	Decreasing
	Diss. nickel	13	0.2908	-10	No Trend
	Diss. zinc	13	0.2908	10	No Trend
SW10-Gort-discharge	Diss. cadmium	9	0.1473	-11	No Trend
	Diss. lead	7	0.1838	7	No Trend
	Diss. manganese	10	0.1416	13	No Trend
	Diss. nickel	10	0.0245	-23	Decreasing
	Diss. zinc	10	0.0537	-19	Likely Decreasing
SW12-Gort-Discharge	Diss. cadmium	8	0.1328	10	No Trend
	Diss. lead	7	0.3819	3	No Trend
	Diss. manganese	9	0.2328	8	No Trend
	Diss. nickel	9	0.1257	-12	No Trend
	Diss. zinc	9	0.3011	6	No Trend
SW6-Shal	Diss. cadmium	11	0.2667	9	No Trend
	Diss. lead	11	0.3777	5	No Trend
	Diss. manganese	11	0.3202	-7	No Trend
	Diss. nickel	11	0.5	-1	No Trend
	Diss. zinc	11	0.4381	-3	No Trend
SW14-Gort (Kilmastulla River)	Diss. cadmium	9	n/a	n/a	Not Calculated
	Diss. lead	10	0.1416	13	No Trend
	Diss. manganese	10	0.2958	-7	No Trend
	Diss. nickel	10	0.2958	-7	No Trend
	Diss. zinc	10	0.2958	7	No Trend

Not Calculated: insufficient statistical evidence of a significant trend

The results of the Mann-Kendall analysis show that dissolved manganese concentrations are decreasing at SW10-Gar. At SW10-Gort-Discharge dissolved nickel is decreasing and dissolved zinc is likely decreasing. No statistically significant trends were observed in the data for SW12-Gort-Discharge, SW6-Shal and SW14-Gort.

5.3.2 Seasonal Trends

Table 19 shows the seasonal variation between the concentrations of dissolved metals and the calculated loads observed between the high flow sampling events in April 2013 (R1), March 2014 (R3), February 2015 (R5) and February 2016 (R7) and the low flow sampling event in August 2013 (R2), September 2014 (R4), August 2015 (R6) and August 2016 (R8).

Table 19 Seasonal Variation of Concentrations and Calculated Loads of Dissolved Metals in the Main Discharges and on the most downstream location on the Kilmastulla River for the period 2013-2016

Site Description	Round & Date Sampled	Flow l/s	Cadmium		Lead		Manganese		Zinc	
			µg/l	g/day	µg/l	g/day	µg/l	g/day	µg/l	g/day
SW2-SM South	R1 04/04/2013	2.35	4.72	0.958	1.03	0.209	1.55	0.315	1970	400
	R2 29/08/2013	1.5	4.57	0.59	0.838	0.11	0.534	0.07	1840	238
	R3 11/03/2014	3	5.18	1.34	1.1	0.29	1.86	0.48	1940	503
	R4 25/09/2014	1.1	4.65	0.44	0.912	0.09	0.563	0.05	1750	166
	R5 06/02/2015	1.93	5.45	0.907	1.11	0.185	1.02	0.17	2140	356
	R6 28/08/2015	1	4.32	0.39	0.856	0.08	0.547	0.05	1560	139
	R7 12/02/2016	1.6	5.07	0.68	1.12	0.15	0.765	0.1	2070	277
	R8 26/08/2016	0.6	4.9	0.25	0.974	0.05	0.38	0.02	1720	89.2
SW6-SHAL	R1 02/04/2013	5.51	0.905	0.431	236	112	60.7	28.9	179	85.2
	R2 02/09/2013	3.4	0.809	0.24	183	53.7	61	17.9	154	45.2
	R3 05/03/2014	2.208	1.29	0.25	477	91	97.9	18.7	252	48.1
	R4 22/09/2014	4.3	0.799	0.3	320	119	85.5	31.8	221	82.1
	R5 05/02/2015	5.08	1.16	0.508	363	159.2	65.3	28.6	223	97.8
	R6 27/08/2015	3.76	0.903	0.29	211	68.6	46.4	15.1	153	49.8
	R7 10/02/2016	9.2	1.2	0.95	591	470	89.8	71.4	237	188
	R8 24/08/2016	6.2	1.33	0.71	352	189	99	53.2	253	136
SW10-GAR	R1 03/04/2013	5.46	18.8	8.87	1.56	0.736	74.1	35	5390	2540
	R2 28/08/2013	2.12	10.6	1.95	1.04	0.19	321	58.9	2360	433
	R3 06/03/2014	50.7	24.8	109	2.06	9.03	226	990	9320	40800
	R4 23/09/2014	3.1	21.7	5.81	8.51	2.28	255	68.3	7150	1920
	R5 04/02/2015	16.8	30.1	43.7	1.21	1.76	148	215.1	13000	18893
	R6 26/08/2015	4.4	12	4.52	3.98	1.5	141	53.1	2590	976
	R7 11/02/2016	27.3	32.6	76.8	0.982	2.31	273	643	12100	28500
	R8 25/08/2016	2.6	16.5	3.69	2.4	0.54	260	58.1	3940	880
SW10-Gort-Disc	R1 27/03/2013	5.13	0.142	0.063	0.209	0.093	64.4	28.5	656	291
	R2 27/08/2013	0.22	0.05	0.001	0.05	0.001	191	3.58	175	3.28
	R3 13/03/2014	6	0.328	0.17	0.276	0.14	91.5	47.4	1040	539
	R4 25/09/2014	1.7	0.5	0.07	0.137	0.02	308	45.2	301	44.2
	R5 03/02/2015	7.22	0.199	0.12	0.095	0.059	47.1	29.4	895	558.5
	R6 25/08/2015	0.13	0.05	0	0.21	0	349	3.79	252	2.73
	R7 09/02/2016	33.0	0.379	1.08	0.471	1.34	46.3	132	607	1730
	R8 23/08/2016	4.5	0.04	0.02	0.05	0.02	808	314	590	229
SW12-Gort-Disc	R1 26/03/2013	7.14	0.102	0.063	0.069	0.043	165	102	332	205
	R2 27/08/2013	2.05	0.05	0.01	0.04	0.01	1070	190	99.9	17.7
	R3 13/03/2014	7.826	0.462	0.31	0.061	0.04	269	182	585	396
	R4 25/09/2014	2.6	0.5	0.11	0.022	0.0	453	102	124	27.9
	R5 03/02/2015	9.63	0.5	0.41	0.01	0.008	217	181	597	497
	R6 25/08/2015	1.86	0.106	0.02	0.073	0.01	910	146	169	27.1
	R7 09/02/2016	22.0	0.781	1.48	0.109	0.21	285	542	849	1610
	R8 23/08/2016	7.5	0.111	0.0719	0.05	0.0324	2500	1620	189	122.4
SW14-Gort	R1 26/03/2013	-	0.271	-	1.71	-	68.6	-	108	-
	R2 27/08/2013	-	0.104	-	1.17	-	70.4	-	42.1	-
	R3 13/03/2014	-	0.542	-	2.21	-	50.7	-	245	-
	R4 25/09/2014	-	0.145	-	2.9	-	105	-	102	-
	R5 03/02/2015	-	0.563	-	1.74	-	36.8	-	233	-
	R6 25/08/2015	-	0.106	-	1.19	-	38.6	-	51.1	-
	R7 09/02/2016	-	0.441	-	2.58	-	19.6	-	163	-
	R8 23/08/2016	-	0.238	-	16.2	-	47.6	-	82.9	-
DS-Gort	R7 09/02/2016	11360	0.509	500	2.37	2330	25.1	24600	175	17200
	R8 23/08/2016	1695	0.226	33.1	14.2	2080	50.6	7410	81.1	11900

Notes

- is not measured / calculated

As can be observed from Table 19 the concentrations of dissolved cadmium, lead, manganese and zinc are generally at similar concentrations in both low flow and high flow conditions. However, in some cases the concentrations were significantly lower during low flow conditions, particularly in August 2013. An example includes dissolved zinc in SW10-Gort-Disc. and SW12-Gort-Disc., where values of dissolved zinc in these discharges ranged from 99.9 to 301 µg/l in low flow compared to 597 to 1,040 µg/l in high flow. However, dissolved manganese concentrations were found to be higher in August 2016 compared to the seven previous monitoring rounds with values of 808 µg/l for SW10-Gort-Discharge and 2,500 µg/l for SW12-Gort-Disc.

This difference in the concentrations and loadings of dissolved zinc was reflected in the Kilmastulla River at SW14-Gort where the ecological assessment criterion of 100 µg/l was exceeded during high flows with reported values of 108 µg/l in April 2013, 245 µg/l in March 2014, 233 µg/l in February 2015 and 163 µg/l in February 2016. Concentrations were significantly lower than the assessment criterion in August 2013 (42.1 µg/l), August 2015 (51.1 µg/l) and August 2016 (82.9 µg/l). This was not the case in September 2014 during low flow as dissolved zinc was detected at 102 µg/l, which is likely due to the high concentration of dissolved zinc in SW10-Gar (7,150 µg/l). The calculated loads of dissolved cadmium, lead, manganese and zinc were all significantly lower in August 2013, September 2014, August 2015 and August 2016 due to the low flow conditions. However, relatively high flow conditions in August 2016 at both wetland discharges in Gortmore resulted in high dissolved manganese and zinc loads as shown in Table 19.

Section 6

Groundwater Levels

Groundwater levels were measured at the two wells outside the Gortmore TMF and seven additional wells located within the TMF near the perimeter of the tailings surface, using a portable electronic water level recorder. Table 20 displays the measured depth to groundwater and calculated groundwater elevations.

The groundwater elevations outside the TMF decreased from 48.58 m Ordnance Datum (OD) at the upgradient location TMF1 to 46.12 m OD at the downgradient location TMF2. These elevations are consistent with the groundwater flow in the bedrock being south-westerly towards the Kilmastulla River. The groundwater gradient was calculated to be 0.003, however the level of the river is unknown. The groundwater elevations at TMF1 and TMF2 are similar to the elevations measured on 24/8/2015 and between 0.15 and 0.29 metres lower than the elevations measured in spring (11/2/2016).

Within the tailings area, measured water levels ranged from 3.29 to 4.56 m below the top of the tailings surface. The exceptions were in BH3A-GORT-06 and BH6A-GORT-06 where deeper water levels were recorded. The groundwater elevations within the TMF varied between 48.64 to 53.12 m OD. These groundwater elevations are similar to the elevations measured during low flow (24/8/2015) which ranged from 48.54 to 53.02 m OD and between 0.55 to 1.3 metres lower than the elevations measured during high flow (11/2/2016).

Table 20 Measures Groundwater Levels August 2016

Borehole Identifier	Location Description	Date	Time	Depth to Groundwater (m bgl)	Depth to Groundwater (m bTOC)	Groundwater Elevation (m OD)
TMF1	Outside the perimeter of the TMF	8/22/2016	12:30	0.42	1.01	48.58
TMF2		8/22/2016	10:30	1.88	2.34	46.12
BH1A-GORT-06	Located within the TMF, near the perimeter of the tailings surface	8/22/2016	15:10	2.64	3.29	53.12
BH2A-GORT-06		8/22/2016	14:45	3.39	3.92	52.37
BH3A-GORT-06		8/22/2016	15:40	7.96	8.29	48.64
BH4A-GORT-06		8/22/2016	14:05	4.02	4.54	52.14
BH5A-GORT-06		8/22/2016	15:25	4.13	4.56	52.08
BH6A-GORT-06		8/22/2016	15:00	4.91	5.60	51.17
BH6B-GORT-06		8/22/2016	14:55	3.18	3.90	52.77

Notes:

m is metres

OD is Ordnance Datum

bgl is below ground level

bTOC is below top of casing

Section 7

Summary and Recommendations

7.1 Summary of Findings

Two groundwater monitoring wells were sampled and analysed in August 2016 and water levels were measured in seven additional monitoring wells. Thirty surface water locations were sampled and analysed in August 2016 with flows measured at 22 of the locations. The field QA/QC sample results were reviewed for accuracy and precision. The laboratory QA/QC samples and laboratory reports were also reviewed. Overall the data quality is considered acceptable and the data can be used to compare to the assessment criteria and for evaluation of loads.

Statistical summaries of the analytical results for surface water were prepared and results were compared to assessment criteria. Analyses of metal loadings and groundwater levels were also provided.

The overall conclusions are as follows:

- Dissolved metal concentrations in the two groundwater monitoring wells that were sampled exceeded the assessment criteria for dissolved barium and manganese, with higher concentrations in the downgradient monitoring well TMF2 (618 and 1,080 µg/l, respectively). Dissolved barium exceeded the ecological health criteria and dissolved manganese exceeded the human health criteria in both monitoring wells. Dissolved iron also exceeded the human health criteria of 200 µg/l with a value of 220 µg/l at TMF2. The groundwater flow in the bedrock was south-westerly towards the Kilmastulla River.
- Surface water locations SW1-SM and SW17-Gort are located upstream of the mining areas of Ballygown and Gortmore respectively and have significantly lower concentrations of zinc than the rest of the rivers and streams sampled in the Silvermines area (6.2 and 1.58 µg/l, respectively) and are both well below the ecological assessment criteria of 100 µg/l.
- In the Garryard area some of the highest concentrations of dissolved metals were observed. For example, SW5-Gar (Knights Shaft) had the highest concentrations of dissolved iron (1,470 µg/l), nickel (135 µg/l) and zinc (17,000 µg/l). Each location in Garryard, with the exception of SW7-Gar, exceeded the dissolved zinc ecological assessment criteria of 100 µg/l with values ranging from 1,820 to 17,000 µg/l. With the exception of SW7-Gar, all locations exceeded both the ecological (0.9 µg/l) and human health (5 µg/l) assessment criteria for cadmium (ranging from 7.7 to 40.7 µg/l). Dissolved manganese was above the criteria for human health (50 µg/l) but below the ecological assessment criteria (1,100 µg/l) at all locations with values ranging from 215 to 442 µg/l. One exception was for SW5-Gar which exceeded both the human and ecological health assessment criteria with a value of 1,370 µg/l.
- At Shallee dissolved lead exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria at all locations, except SW13-Shal (drainage channel). The highest concentration was from the Field Shaft discharge (SW6-Shal) at 352 µg/l.

- Dissolved zinc exceeded the ecological assessment criteria of 100 µg/l at the majority of the drainages and discharges ranging from 189 to 17,000 µg/l at SW5-Gar. The concentration of zinc increased on the Kilmastulla River from 1.58 µg/l at the upstream location SW17-Gort to 113 µg/l at SW12-Gort-DS. This location is downstream of the wetland discharges and the Yellow Bridge Tributary which drains Garryard and Shallee. The concentration at DS-Shal on the Yellow River tributary was significantly higher at 403 µg/l.
- The dissolved metal with the highest mass loading was zinc, ranging from 0.59 to 11,900 g/day with an average of 959 g/day overall. The largest mass load of zinc (11,900 g/day) was found at DS-Gort which is located on the Kilmastulla River, downstream of Gortmore TMF. The highest load of dissolved lead was also found at DS-Gort (2,080 g/day). Measured flows ranged from 0.1 l/s at SW4-Shal to 1,695 l/s at DS-Gort with an average of 95 l/s overall.
- Livestock should be prevented from drinking water in the stream in the Shallee mining area due to the elevated lead levels (>50 µg/l).

7.2 Recommendations for the Monitoring Programme

Overall, the reduced monitoring programme implemented during Round 8 was sufficient in meeting the objectives outlined in the Summary Report (Document Ref: 95735/40/DG/25, dated 20 January 2016). Detailed recommendations concerning any future monitoring programme have been outlined in a separate memorandum (DG_34 Recommendations for Future Monitoring) issued on 11 November 2016.

Section 8

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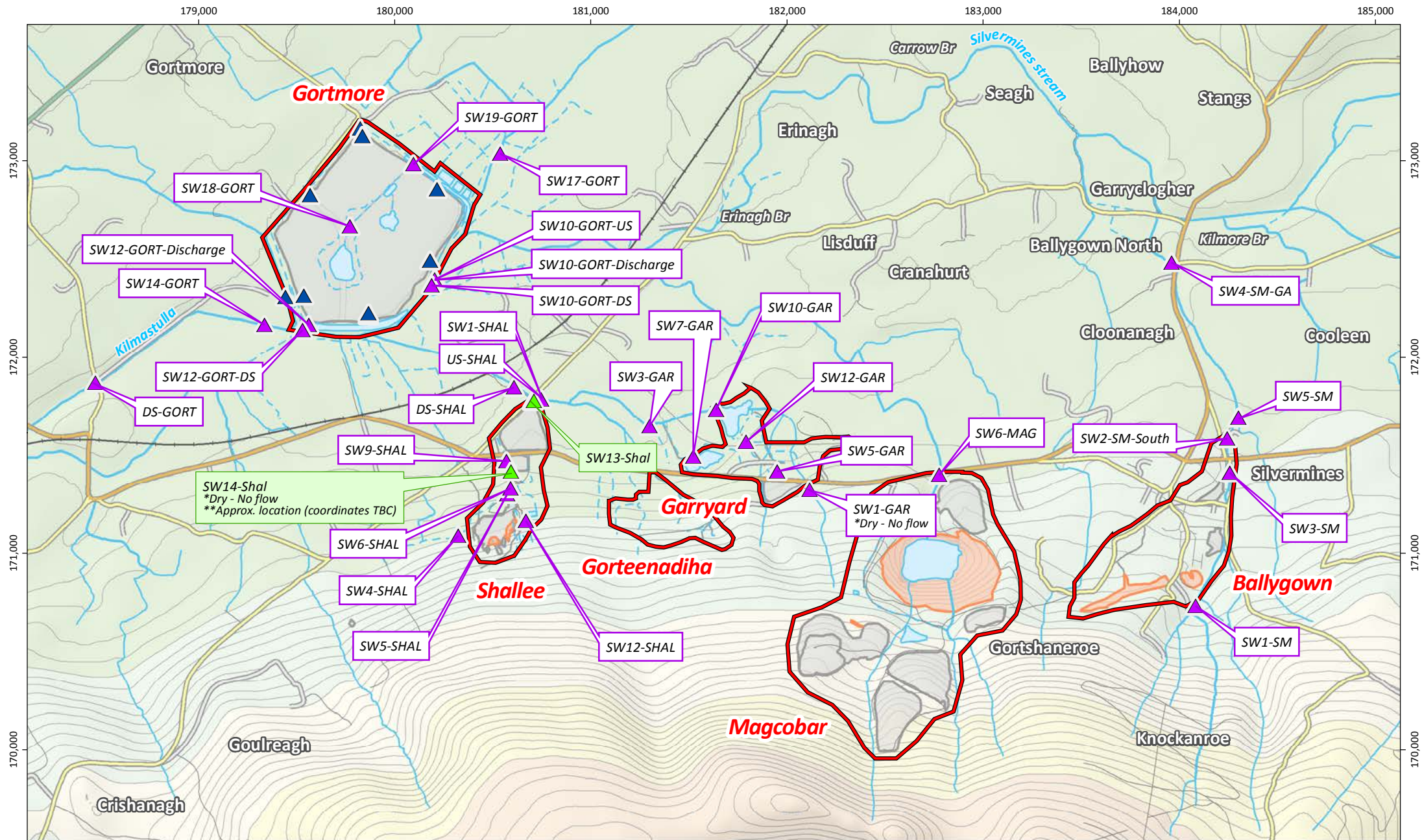
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Appendix A

Figures






Map 1 - Silvermines - Overview



Drawn by: OC Date: 07/11/2016
Internal Project Reference: Q:\95500-95999\95735\
40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\MXD\
01_SilverMon1.mxd
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Legend

Sampling Locations

-  Surface water
-  Surface water (*New point*)
-  Groundwater

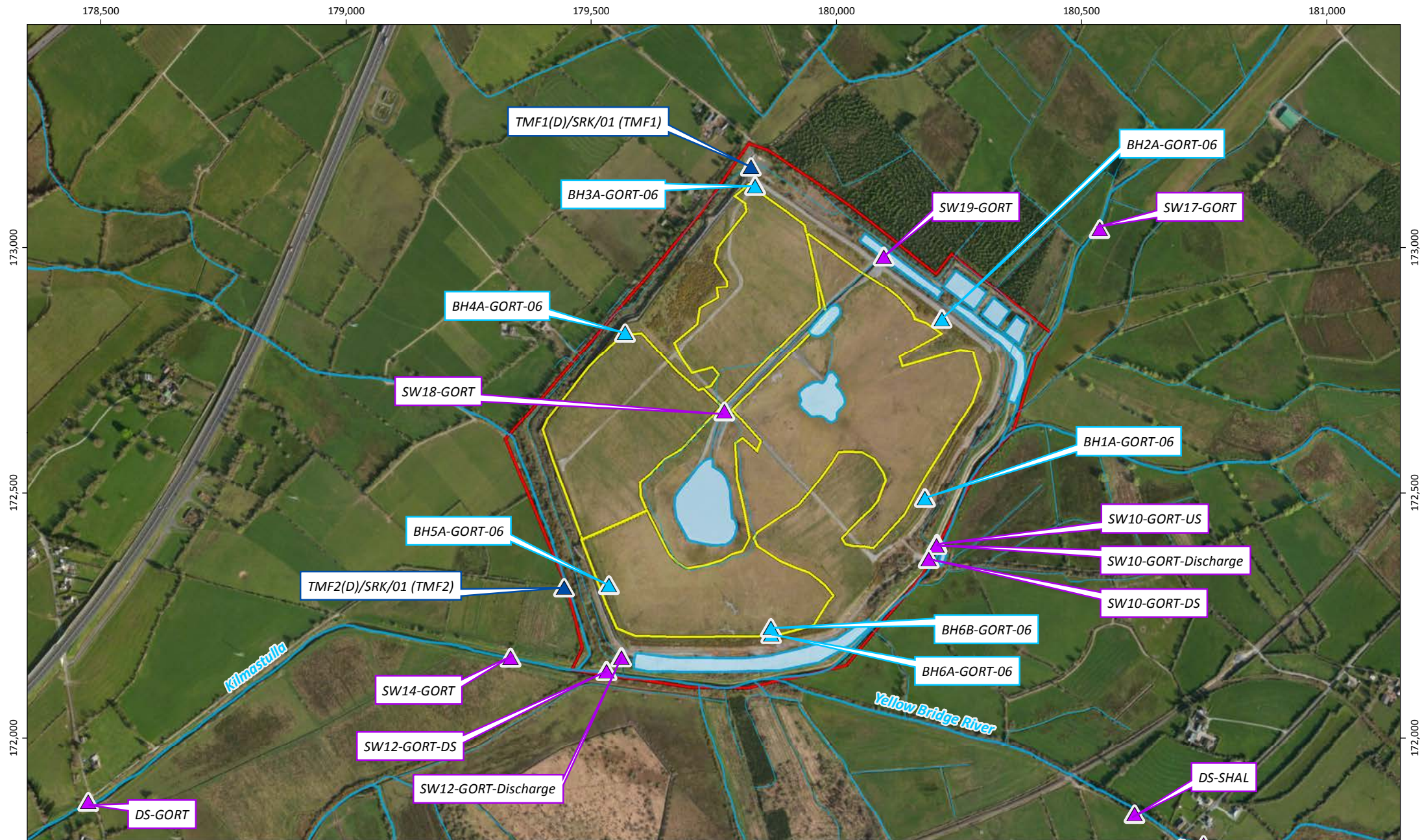
- Rivers
 Streams
 Pond / Wetland / Pit Lake

Mines

-  Mining Areas
 Spoil Heap / Stockpile Dump / Waste Drum Dump / Tailings / Tailings Pond
 Open Pit

Scale is 1:25,000





Map 2 - Silvermines - Gortmore TMF

Drawn by: OC Date: 07/11/2016

Internal Project Reference: Q:\95500-95999\95735\
40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\MXD\
02_SilverMonGM.mxd

Source: ESRI World Imagery ©ESRI (UC-G image courtesy of Microsoft,
acquired on 11/6/2011)



Legend

Sampling Locations

- ▲ Surface water
- ▲ Groundwater
- ▲ Groundwater (Levels only)

- Rivers
- Streams
- Pond / Wetland / Pit Lake

Mines

- Mining Areas

Scale is 1:10,000

0 100 200
m





Map 3 - Silvermines - Shallee South

Drawn by: OC Date: 07/11/2016

Internal Project Reference: Q:\95500-95999\95735\
40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\MXD\
03_SilverMonSh.mxd

Source: ESRI World Imagery ©ESRI (UC-G image
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Legend

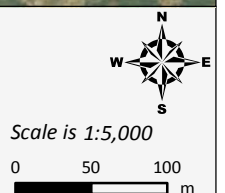
Sampling Locations

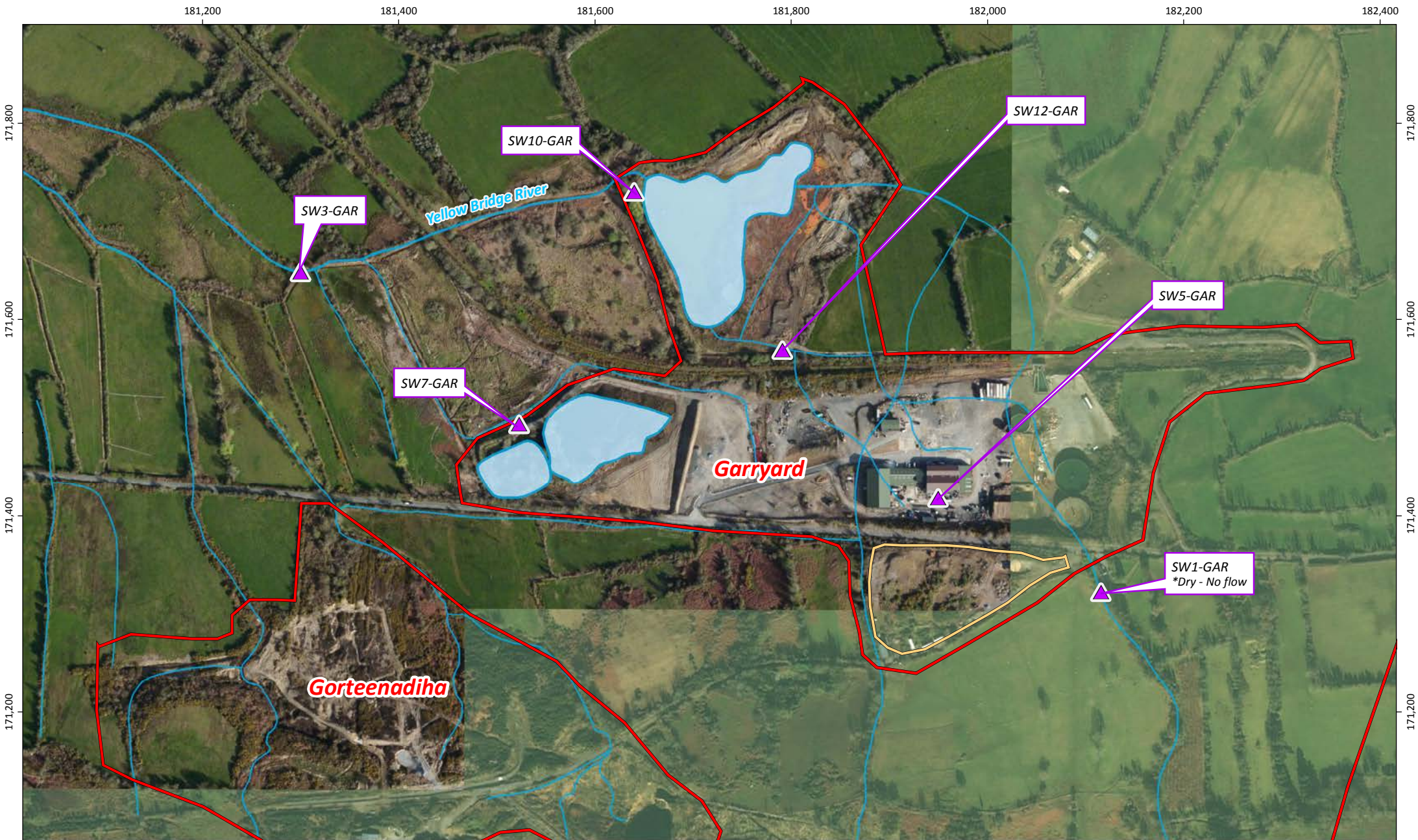
- ▲ Surface water
- ▲ Surface water (New point)

- Rivers
- Streams
- Pond / Wetland

Mines

- Mining Areas
- Tailings / Tailings Pond
- Spoil Heap / Waste Drum Dump





Map 4 - Silvermines - Garryard

Drawn by: OC Date: 07/11/2016

Internal Project Reference: Q:\95500-95999\95735\
40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\MXD\
04_SilverMonGAR.mxd

Source: ESRI World Imagery ©ESRI (UC-G image courtesy of Microsoft,
acquired on 11/6/2011)

**CDM
Smith**

Legend

Sampling Locations

▲ Surface water

— Rivers
— Streams
Pond / Wetland

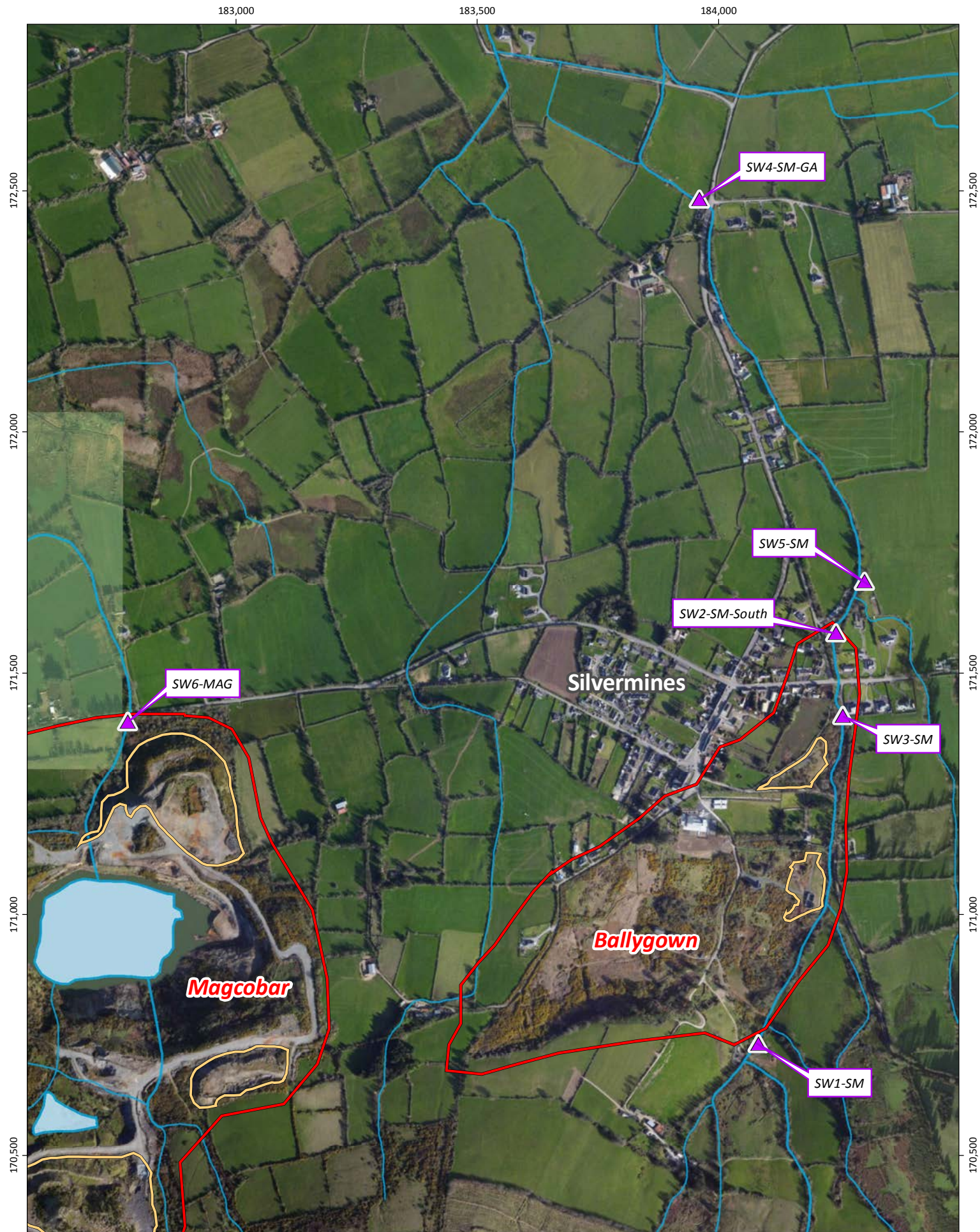
Mines

Mining Areas
Stockpile Dump

Scale is 1:5,000

0 50 100
m





Map 5 - Silvermines - Magcobar and Ballygown

Drawn by: OC Date: 07/11/2016

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\MXD\05_SilverMonMaBG.mxd

Source: ESRI World Imagery ©ESRI (UC-G image courtesy of Microsoft, acquired on 11/6/2011)

CDM Smith

Legend

Sampling Locations

▲ Surface water

— Rivers

— Streams

— Pond / Wetland

Mines

— Mining Areas

— Spoil Heap / Waste Drum Dump



Scale is 1:10,000

0 100 200 m

Appendix B

Analytical Data Tables and Assessment Criteria

Table B-1 Comparison of Groundwater and Surface Water Results to Assessment Criteria R8

				Water Quality Parameters													
Sample Description	Type	Area	Date Sampled	Ammoniacal	Oxygen,	Specific			Aluminium	Antimony	Arsenic	Barium	Cadmium	Chromium	Cobalt	Copper	
				Nitrogen as N	dissolved (field)	pH (field)	Conductance @ deg.C (field)	Sulphate	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)
				Units	mg/l	mg/l	pH Units	mS/cm	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Ecological Criteria				0.14	80 to 120*	4.5 to 9	-	-	1,900	-	25	4	0.9	3.4	5.1	30	
Human Health Criteria				0.3	-	6.5 to 9.5	2.5	250	200	5	10	-	5	50	-	2000	
TMF1	Groundwater	GM	22/08/2016	0.1	6.94	6.94	0.481	34.3	6.52	1.1	2.42	174	0.04	0.6	0.95	0.425	
TMF2	Groundwater	GM	22/08/2016	0.1	6.85	6.85	0.498	1	1	0.08	4.55	618	0.04	0.6	0.648	0.425	
DS-GORT	River/Stream	GM	23/08/2016	0.1	93.2	7.1	0.297	42	37.8	0.279	0.878	139	0.226	0.6	0.222	4.53	
SW10-GORT-DISCHARGE	Discharge	GM	23/08/2016	0.1	71.7	6.95	2.105	1130	1	0.08	0.642	18.5	0.04	0.6	0.075	0.425	
SW10-GORT-DS	River/Stream	GM	23/08/2016	0.1	101	7.19	0.376	56.3	13.4	0.08	0.637	117	0.04	0.6	0.075	2.01	
SW10-GORT-US	River/Stream	GM	23/08/2016	0.1	97.9	6.86	0.331	39.1	13.7	0.08	0.666	117	0.0881	0.6	0.075	2.03	
SW12-GORT-DISCHARGE	Discharge	GM	23/08/2016	0.298	39	6.88	1.487	662	1	0.08	0.577	115	0.111	0.6	0.741	0.425	
SW12-GORT-DS	River/Stream	GM	23/08/2016	0.1	103.2	7.1	0.344	53.8	29.6	0.281	0.672	143	0.29	0.6	0.209	4.69	
SW14-GORT	River/Stream	GM	23/08/2016	0.329	104.1	7.21	0.288	40.2	44.4	0.267	0.748	138	0.238	0.6	0.217	4.05	
SW17-GORT	River/Stream	GM	23/08/2016	0.1	81.7	7.33	0.364	7.4	27.7	0.379	1.29	217	0.04	0.6	0.236	4.02	
SW18-GORT	Drainage	GM	22/08/2016	0.1	97.7	7.63	1.864	1080	1	1.39	1.17	61.6	3.66	0.6	0.075	5.62	
SW19-GORT	Drainage	GM	22/08/2016	0.1	106.2	7.6	1.668	936	1	1.44	1.16	77.2	2.58	0.6	0.075	4.25	
SW6-MAG	River/Stream	GM	23/08/2016	0.1	113	7.39	0.428	159	1	0.369	0.255	58.5	0.874	0.6	0.075	6.19	
DS-Shal	River/Stream	Shal	24/08/2016	0.1	86.1	7.14	0.224	44.8	42.6	0.954	0.676	223	1.22	0.6	0.552	10.6	
SW12-Shal	Drainage	Shal	24/08/2016	0.1	83.9	4.84	0.033	1	117	0.417	0.599	216	0.04	0.6	0.316	1.66	
SW13-Shal	Drainage	Shal	24/08/2016	0.1	60.4	7.1	0.268	28	1	1.66	0.727	146	0.25	0.6	0.075	1.79	
SW1-Shal	River/Stream	Shal	24/08/2016	0.1	90.6	7.07	0.157	23.2	33.1	1.88	0.531	211	2.16	0.6	1.19	9.37	
SW4-Shal	River/Stream	Shal	24/08/2016	0.1	69.3	6.99	0.094	1	19.9	0.513	0.255	379	0.437	0.6	0.456	3.08	
SW5-Shal	River/Stream	Shal	24/08/2016	0.1	90.2	6.78	0.213	65.2	103	0.38	0.255	370	14.6	0.6	3.76	16.8	
SW6-Shal	Discharge	Shal	24/08/2016	0.1	63.7	6.64	0.138	20.1	26.3	1.37	0.77	193	1.33	0.6	2.19	12.8	
SW9-Shal	River/Stream	Shal	24/08/2016	0.1	91.5	6.9	0.156	25	25.6	1.74	0.711	183	2.71	0.6	1.56	10.6	
US-Shal	River/Stream	Shal	24/08/2016	0.1	91.8	7.03	0.096	20.8	61.4	0.528	0.623	277	0.424	0.6	0.179	16.3	
SW10-GAR	Discharge	Gar	25/08/2016	0.1	92.3	7.65	0.928	329	1	0.278	0.666	24.7	16.5	0.6	1.81	1.47	
SW12-GAR	Drainage	Gar	25/08/2016	0.1	81.3	7.19	1.57	844	1	1.78	0.255	20.9	40.7	0.6	2.33	1.32	
SW3-GAR	River/Stream	Gar	25/08/2016	0.1	105.2	7.63	0.853	210	1	0.331	0.823	97.8	7.7	0.6	1.26	1.53	
SW5-GAR	Discharge	Gar	25/08/2016	0.1	26.6	6.88	1.906	991	1	0.72	2.08	29.5	8.66	0.6	9.36	0.425	
SW7-GAR	Drainage	Gar	25/08/2016	0.1	63	6.84	0.627	145	1	5.04	0.605	82.1	0.102	0.6	0.075	0.425	
SW1-SM	River/Stream	Bg	25/08/2016	0.1	93.9	7.19	0.174	20.3	1	2.46	0.255	68.8	0.04	0.6	0.075	0.425	
SW2-SM-SOUTH	Discharge	Bg	26/08/2016	0.1	70.4	6.26	0.495	35.2	1	0.178	0.255	153	4.9	0.6	0.075	0.425	
SW3-SM	River/Stream	Bg	26/08/2016	0.1	101.1	7.45	0.153	1	1	0.08	0.255	49.8	0.04	0.6	0.075	0.425	
SW4-SM-GA	River/Stream	Bg	26/08/2016	0.1	96.3	6.89	0.208	1	1	0.607	0.255	84.8	0.24	0.6	0.075	0.425	
SW5-SM	River/Stream	Bg	26/08/2016	0.1	95.1	7.2	0.204	2.6	1	0.676	0.255	75.2	0.311	0.6	0.075	0.425	

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

xx Less than the Limit of Detection (LOD) - Value taken to be 0.5 of the LOD

- Not analysed or no assessment criteria

* Only applies to rivers or streams (i.e. not discharges)

Table B-1 Comparison of Groundwater and Surface Water Results to Assessment Criteria R8

Sample Description	Type	Area	Date Sampled			Manganese	Molybdenum	Nickel	Vanadium	Zinc
					(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)	(diss.filt)
			Units		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Ecological Criteria				-	7.2	1100	-	20	-	100
Human Health Criteria				200	10	50	-	20	-	-
TMF1	Groundwater	GM	22/08/2016	0.03	0.05	62.6	1.54	1.7	0.65	0.65
TMF2	Groundwater	GM	22/08/2016	220	0.58	1080	1.12	1.33	0.65	4.14
DS-GORT	River/Stream	GM	23/08/2016	163	14.2	50.6	0.31	2.38	0.65	81.1
SW10-GORT-DISCHARGE	Discharge	GM	23/08/2016	22.3	0.05	808	0.31	8.17	0.65	590
SW10-GORT-DS	River/Stream	GM	23/08/2016	110	1.88	35.4	0.31	1.63	0.65	55.4
SW10-GORT-US	River/Stream	GM	23/08/2016	122	1.88	22.6	0.31	1.51	0.65	44.9
SW12-GORT-DISCHARGE	Discharge	GM	23/08/2016	369	0.05	2500	0.31	4.2	0.65	189
SW12-GORT-DS	River/Stream	GM	23/08/2016	133	21.3	77.3	0.31	2.37	0.65	113
SW14-GORT	River/Stream	GM	23/08/2016	176	16.2	47.6	0.31	2.05	0.65	82.9
SW17-GORT	River/Stream	GM	23/08/2016	183	0.5	29.8	0.621	1.56	0.65	1.58
SW18-GORT	Drainage	GM	22/08/2016	0.0095	11	106	0.31	7.19	0.65	789
SW19-GORT	Drainage	GM	22/08/2016	0.0095	1.46	12.4	1.75	6.43	0.65	1000
SW6-MAG	River/Stream	GM	23/08/2016	0.0715	1.03	9.66	1.4	5.06	0.65	370
DS-Shal	River/Stream	Shal	24/08/2016	104	84.2	40.6	0.31	5.24	0.65	403
SW12-Shal	Drainage	Shal	24/08/2016	296	56.3	64	0.31	1.52	0.65	17.6
SW13-Shal	Drainage	Shal	24/08/2016	0.0095	5.43	14.9	0.31	1.42	0.65	21.3
SW1-Shal	River/Stream	Shal	24/08/2016	110	191	59.6	0.31	11	0.65	532
SW4-Shal	River/Stream	Shal	24/08/2016	44.5	16.8	69.1	0.31	4.16	0.65	47.9
SW5-Shal	River/Stream	Shal	24/08/2016	46.1	34.6	528	0.31	32.7	0.65	4750
SW6-Shal	Discharge	Shal	24/08/2016	138	352	99	0.31	13.5	0.65	253
SW9-Shal	River/Stream	Shal	24/08/2016	109	249	71.1	0.31	14	0.65	674
US-Shal	River/Stream	Shal	24/08/2016	149	49.4	16	0.31	2.22	0.65	65.2
SW10-GAR	Discharge	Gar	25/08/2016	19.9	2.4	260	4.45	13.5	0.65	3940
SW12-GAR	Drainage	Gar	25/08/2016	45.1	3.05	442	1.51	41	0.65	12100
SW3-GAR	River/Stream	Gar	25/08/2016	48.1	1.43	290	0.31	8.47	0.65	1820
SW5-GAR	Discharge	Gar	25/08/2016	1470	9.11	1370	2.64	135	0.65	17000
SW7-GAR	Drainage	Gar	25/08/2016	29.2	0.05	215	2.79	1.73	0.65	34.2
SW1-SM	River/Stream	Bg	25/08/2016	34.6	0.05	8.4	1.2	0.22	0.65	6.2
SW2-SM-SOUTH	Discharge	Bg	26/08/2016	0.0095	0.974	0.38	0.31	5.73	0.65	1720
SW3-SM	River/Stream	Bg	26/08/2016	43.6	0.674	2.17	4.33	0.631	0.65	22.8
SW4-SM-GA	River/Stream	Bg	26/08/2016	43.6	1.04	5.03	0.31	0.78	0.65	94.7
SW5-SM	River/Stream	Bg	26/08/2016	37	0.671	3.12	0.31	0.695	0.65	101

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

xx Less than the Limit of Detection (LOD) - Value taken to be 0.5 of the LOD

- Not analysed or no assessment criteria

* Only applies to rivers or streams (i.e. not discharges)

Table B-2 Comparison of Surface Water Results to Assessment Criteria for Livestock Drinking Water R8

Sample Description	Area	Type	Date Sampled	Sulphate	Aluminium (diss.filt)	Arsenic (diss.filt)	Cadmium (diss.filt)	Chromium (diss.filt)	Cobalt (diss.filt)	Copper (diss.filt)	Lead (diss.filt)	Vanadium (diss.filt)	Zinc (diss.filt)
			Units	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Livestock Criteria				500	5000	200	50	1000	1000	500	100	100	24000
DS-GORT	River/Stream	GM	23/08/2016	42	37.8	0.795	0.226	0.6	0.222	4.25	14.2	0.65	80.2
SW10-GORT-DISCHARGE	Discharge	GM	23/08/2016	1130	1	0.642	0.04	0.6	0.075	0.425	0.05	0.65	590
SW10-GORT-DS	River/Stream	GM	23/08/2016	56.3	13.4	0.637	0.04	0.6	0.075	2.01	1.88	0.65	55.4
SW10-GORT-US	River/Stream	GM	23/08/2016	39.1	13.7	0.666	0.0881	0.6	0.075	2.03	1.88	0.65	44.9
SW12-GORT-DISCHARGE	Discharge	GM	23/08/2016	662	1	0.577	0.111	0.6	0.741	0.425	0.05	0.65	189
SW12-GORT-DS	River/Stream	GM	23/08/2016	53.8	29.6	0.672	0.29	0.6	0.209	4.69	21.3	0.65	113
SW14-GORT	River/Stream	GM	23/08/2016	40.2	44.4	0.748	0.238	0.6	0.217	4.05	16.2	0.65	82.9
SW17-GORT	River/Stream	GM	23/08/2016	7.4	27.7	1.29	0.04	0.6	0.236	4.02	0.5	0.65	1.58
SW18-GORT	Drainage	GM	22/08/2016	1080	1	1.17	3.66	0.6	0.075	5.62	11	0.65	789
SW19-GORT	Drainage	GM	22/08/2016	936	1	1.16	2.58	0.6	0.075	4.25	1.46	0.65	1000
SW6-MAG	River/Stream	GM	23/08/2016	159	1	0.255	0.874	0.6	0.075	6.19	1.03	0.65	370
DS-Shal	River/Stream	Shal	24/08/2016	44.8	42.6	0.676	1.22	0.6	0.552	10.6	84.2	0.65	403
SW12-Shal	Drainage	Shal	24/08/2016	1	114	0.599	0.04	0.6	0.303	1.49	54.8	0.65	16.4
SW13-Shal	Drainage	Shal	24/08/2016	28	1	0.727	0.25	0.6	0.075	1.79	5.43	0.65	21.3
SW1-Shal	River/Stream	Shal	24/08/2016	23.2	33.1	0.531	2.16	0.6	1.19	9.37	191	0.65	532
SW4-Shal	River/Stream	Shal	24/08/2016	1	19.9	0.255	0.437	0.6	0.456	3.08	16.8	0.65	47.9
SW5-Shal	River/Stream	Shal	24/08/2016	65.2	103	0.255	14.6	0.6	3.76	16.8	34.6	0.65	4750
SW6-Shal	Discharge	Shal	24/08/2016	20.1	26.3	0.77	1.33	0.6	2.19	12.8	352	0.65	253
SW9-Shal	River/Stream	Shal	24/08/2016	25	25.6	0.711	2.71	0.6	1.56	10.6	249	0.65	674
US-Shal	River/Stream	Shal	24/08/2016	20.8	61.4	0.623	0.424	0.6	0.179	16.3	49.4	0.65	65.2
SW10-GAR	Discharge	Gar	25/08/2016	329	1	0.666	16.5	0.6	1.81	1.47	2.4	0.65	3940
SW12-GAR	Drainage	Gar	25/08/2016	844	1	0.255	40.7	0.6	2.33	1.32	3.05	0.65	12100
SW3-GAR	River/Stream	Gar	25/08/2016	210	1	0.823	7.7	0.6	1.26	1.53	1.43	0.65	1820
SW5-GAR	Discharge	Gar	25/08/2016	991	1	2.08	8.66	0.6	9.36	0.425	9.11	0.65	17000
SW7-GAR	Drainage	Gar	25/08/2016	145	1	0.605	0.102	0.6	0.075	0.425	0.05	0.65	34.2
SW1-SM	River/Stream	Bg	25/08/2016	20.3	1	0.255	0.04	0.6	0.075	0.425	0.05	0.65	3.78
SW2-SM-SOUTH	Discharge	Bg	26/08/2016	35.2	1	0.255	4.9	0.6	0.075	0.425	0.974	0.65	1720
SW3-SM	River/Stream	Bg	26/08/2016	1	1	0.255	0.04	0.6	0.075	0.425	0.674	0.65	22.8
SW4-SM-GA	River/Stream	Bg	26/08/2016	1	1	0.255	0.24	0.6	0.075	0.425	1.04	0.65	94.7
SW5-SM	River/Stream	Bg	26/08/2016	2.6	1	0.255	0.311	0.6	0.075	0.425	0.671	0.65	101

xx Exceeds Livestock Assessment Criteria
xx Less than the Limit of Detection (LOD) - Value taken to be 0.5

