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 1 (2017)

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earth & water resources

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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 May 2017. This report should be read alongside the Silvermines Data Report (Document Ref: 95735/40/DG/35, dated May 2017) which contains all field observations and laboratory analytical results collected during the monitoring programme.

Concurrent with this monitoring, an investigation was undertaken into high lead values in soil and sediments in a number of fields in the area. The results of these investigations are contained in a stand-alone report.

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: Ll (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.

Ll 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 8 May 2017, as listed in Table 1 and shown on Map 2 in Appendix A. Water levels were measured at an additional seven monitoring wells on 9 May 2017, 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 they were either found buried or believed to be destroyed in the first round of sampling (2013).

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 the well was 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 May 2017, 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

Twenty-eight surface water locations were sampled between 5 and 10 May 2017, as listed in Table 2 and shown on Maps 2 to 5 in **Appendix A**. Six samples were not obtained because the stream bed was dry: SW14-SHAL, SW4-SHAL, SW5-SHAL, SW19-GORT, SW18-Gort 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	No	Dry - No flow
SW19-GORT	GM	180097	172982	Discharge to TMF wetlands. DS of decant.	No	Dry - No flow
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
SW6-SM	BG	184121	172051	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	Not possible due to grating

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	Flow Meter
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	Very low flow – insufficient to measure
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.	No	Dry – No flow
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.	No	Dry - No Flow
SW6-SHAL	ShS	180591	171331	Stream emanating from flooded Field Shaft	Yes	Flow Meter
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	Dry - No flow
DS-Gorteenadiha	GTD	180749	171785	Stream downgradient of Gorteenadiha	Yes	Flow meter

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

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 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). 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 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 routine vegetation or soil sampling was undertaken at Gortmore TMF in May 2017.

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
Groundwater and Surface water		
SMGD01.9	GW Duplicate	Duplicate of TMF2
SMDB01.9	GW Decontamination blank	DI water (Lennox Lab Supplies: Batch No. 701-5839) pumped through groundwater pump after final decon at site TMF2
SMSD01.9	SW Duplicate	Duplicate of SW7-GAR
SMSD02.9	SW Duplicate	Duplicate of SW14-GORT
SMSD03.9	SW Duplicate	Duplicate of SW6-SHAL
SMDB02.9	SW Decontamination blank	DI water (Lennox Lab Supplies: Batch No: 701-5715) poured over SW composite sample bottle after final decon at SW14-Gort
SMSR01.9	Standard Reference Material	Water ERA “Trace Metals” Lot #P256-740D
SMSR02.9	Standard Reference Material	Water ERA “Trace Metals” Lot #P256-740D
WB01.9	Filtration blank	Deionised water filtered onsite (Lennox Lab Suppliers. Batch No: 701-5715)
WB02.9	Water blank	Deionised water (Lennox Lab Suppliers. Batch No: 701-5717)

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 SMSR01.9 and SMSR02.9) to evaluate laboratory accuracy. The certified SRM was supplied by ERA Certified Reference Materials and was Lot #P256-740D (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: Antimony (0 to 33.8%), arsenic (3.4 to 7.3%), barium (2.8 to 5.1%), cadmium (0 to 11.4%), chromium (0 to 8.8%), cobalt (0 to 2.3%), copper (0 to 3.1%), lead (0 to 18.5%), manganese (1.9 to 14.5%), molybdenum (0%), nickel (0.3 to 6.3%), vanadium (0%) and zinc (0.8 to 5.2%).

RPDs above 50% were calculated for dissolved aluminium and iron. For aluminium, SW7-Gar and SMGD01.9 (98.3 % RPD), SW14-Gort and SMSD02.9 (100.6 % RPD) and SW6-Shal and SMSD03.9 (136.2 % RPD). For iron, SW14-Gort and SMSD02.9 (77.6 % RPD). 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)	TMF2	SMGD01.9	% RPD	SW7-GAR	SMSD01.9	% RPD	SW14-GORT	SMSD02.9	% RPD	SW6-SHAL	SMSD03.9	% RPD
Aluminium	<2	<2	<2	0	15.4	5.25	**-98.3**	6.05	2	**-100.6**	18	94.8	**136.2**
Antimony	<0.16	<0.16	<0.16	0	<0.16	<0.16	0	<0.16	<0.16	0	0.475	0.668	33.8
Arsenic	<0.51	4.77	4.61	-3.4	0.531	<0.51	-4.0	0.578	0.622	7.3	0.792	0.741	-6.7
Barium	<0.2	578	562	-2.8	92.5	97.6	5.4	169	163	-3.6	242	230	-5.1
Cadmium	<0.08	<0.08	<0.08	0	0.972	1.09	11.4	0.241	0.226	-6.4	0.968	0.877	-9.9
Chromium	<1.2	1.31	1.2	-8.8	<1.2	<1.2	0	<1.2	<1.2	0	<1.2	<1.2	0
Cobalt	<0.15	0.581	0.592	1.9	<0.15	<0.15	0	<0.15	<0.15	0	1.3	1.33	2.3
Copper	<0.85	<0.85	<0.85	0	<0.85	<0.85	0	<0.85	<0.85	0	12.8	13.2	3.1
Iron	<19	178	176	-1.1	<0.019	<0.019	0	47.2	107	**77.6**	54.1	55.5	2.6
Lead	<0.1	1.65	1.63	-1.2	0.367	0.442	18.5	1.4	1.28	-9.0	248	248	0.0
Manganese	<0.76	1,040	1,020	-1.9	20.5	23.7	14.5	33.1	31.5	-5.0	52	50.9	-2.1
Molybdenum	<0.62	<0.62	<0.62	0	<0.62	<0.62	0	<0.62	<0.62	0	<0.62	<0.62	0
Nickel	<0.44	1.43	1.39	-2.8	1.68	1.79	6.3	1.06	1.07	0.9	7.78	7.8	0.3
Vanadium	<1.3	<1.3	<1.3	0	<1.3	<1.3	0	<1.3	<1.3	0	<1.3	<1.3	0
Zinc	<1.3	6.1	6.05	-0.8	299	314	4.9	81.1	77	-5.2	164	160	-2.5

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 µg/l except for iron with a detection limit of 19 µg/l.

Detections were observed for six dissolved metals (excluding detections recorded in the DI filtration blank) ranging from 0.16 to 49.3 µg/l. Dissolved aluminium was also detected in the DI water filtration blank (2.42 µg/l) with a similar concentration to the surface water decon blank, SMDB02.9 (3.03 µg/l). The concentration of dissolved aluminium in the groundwater decon blank, SMDB01.9 (49.3 µg/l), was over 20 times greater than the detection in the DI water filtration blank. This result was checked and confirmed by ALcontrol. Dissolved zinc (1.44 µg/l) were detected in the DI water filtration blank but not in the decontamination blanks.

In total, there were eight detections of dissolved metals in the decontamination blanks. Only dissolved aluminium in SMDB01.9 (49.3 µg/l) was greater than 10 times the detection limit (2 µg/l). However, the concentration of dissolved aluminium in SMDB01.9 was significantly less than the assessment criteria outlined in Section 4; therefore, these relatively 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 (1.36 µg/l) for Sample Batch 170330-75. However, no detections were recorded in the associated DI blank samples.

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 chromium (3.54 µg/l) and nickel (2.47 µg/l) in SMDB01.9 were greater than 100% of the preceding sample respectively. However, these values were significantly less than the assessment criteria. Dissolved aluminium (49.3 µg/l) and molybdenum (0.713 µg/l) were detected in SMDB01.9; however, neither metal was detected in the preceding sample indicating potential cross contamination within the laboratory. Dissolved lead was also detected in SMDB01.9 with a value of 0.16 µg/l which was less than 10% of the preceding sample and significantly less than the ecological assessment criteria of 7.2 µg/l.

In SMDB02.9, aluminium (3.03 µg/l), antimony (1.12 µg/l) and molybdenum (1.17 µg/l) were detected at a higher concentration than the preceding sample. Dissolved aluminium was approximately 50% of the preceding sample but significantly less than the assessment criteria for ecological health (1,900 µg/) and human health (200 µg/l). As discussed, dissolved aluminium in SMDB02.9 was similar to the concentration detected in the filtration blank (2.42 µg/l). Antimony and molybdenum were below the detection limit in the preceding sample but had reported values of 1.12 µg/l and 1.17 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 May 2017 and concentrations of dissolved antimony and molybdenum were below the detection limit at this location. Therefore, the interpretation of results is not affected.

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 WB01.9 (µg/l)	Water Blank WB02.9 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank SMDB01.9 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank SMDB02.9 (µg/l)	Laboratory Method Blank (µg/l)
	Sample batch:		***170330-75***		***170511-45***		**170512-141**	
Aluminium	<2	**2.42**	<2	<2	**49.3**	<2	**3.03**	<2
Antimony	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	**1.12**	<0.16
Arsenic	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51
Barium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cadmium	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Chromium	<1.2	<1.2	<1.2	<1.2	**3.54**	<1.2	<1.2	<1.2
Cobalt	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15
Copper	<0.85	<0.85	<0.85	<0.85	<0.85	<0.85	<0.85	<0.85
Iron	<19	<19	<19	<19	<19	<19	<19	<19
Lead	<0.1	<0.1	<0.1	<0.1	**0.16**	<0.1	<0.1	<0.1
Manganese	<0.76	<0.76	<0.76	<0.76	<0.76	<0.76	<0.76	<0.76
Molybdenum	<0.62	<0.62	<0.62	1.36	**0.713**	<0.62	**1.17**	<0.62
Nickel	<0.44	<0.44	<0.44	<0.44	**2.47**	<0.44	<0.44	<0.44
Vanadium	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Zinc	<1.3	**1.44**	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3

Notes:
Bold indicates a detection. ***Bold and italics*** indications 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 SMSR01.9 and SMSR02.9) 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, arsenic, barium, chromium, copper, iron, lead, manganese and zinc are in good agreement with the certified value (%R ranged from 92 to 110%). One of the reported values for dissolved antimony (127%), cadmium (114%), cobalt (92%), nickel (89%) and vanadium (116%) 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 molybdenum (89% and 88%) were outside of the acceptable range (low) but very near the 90% acceptance limit. This indicates that values for molybdenum 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		SMSR01.9 (μg/l)	% R	SMSR02.9 (μg/l)	% R
		Lower (%)	Upper (%)				
Aluminium	1630	87	114	1740	107	1610	99
Antimony	814	87	111	843	104	1030	**127**
Arsenic	254	87	111	234	92	280	110
Barium	827	91	109	833	101	846	102
Cadmium	256	89	106	246	96	292	**114**
Chromium	870	91	109	819	94	807	93
Cobalt	413	93	111	390	94	382	**92**
Copper	587	90	109	555	95	539	92
Iron	545	90	111	520	95	522	96
Lead	413	90	110	417	101	416	101
Manganese	793	92	109	816	103	817	103
Molybdenum	577	90	109	516	**89**	508	**88**
Nickel	531	91	109	490	92	472	**89**
Vanadium	1640	91	107	1560	95	1910	**116**
Zinc	1770	90	110	1840	104	1810	102

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. 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. No exceedances of the warning or failure limit were reported.

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%. Over 85% 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 Lab (pH Units)	pH Field (pH Units)	% RPD
SW1-SM	7.49	8.08	7.6
SW2-SM-SOUTH	7.56	7.25	-4.2
SW3-SM	7.76	7.8	0.5
SW4-SM-GA	8.09	7.88	-2.6
SW5-SM	7.55	7.84	3.8
SW6-SM	7.92	7.81	-1.4
SW10-GAR	8.09	8.05	-0.5
SW12-GAR	8.01	7.73	-3.6
SW3-GAR	8.11	8.04	-0.9
SW5-GAR	7.4	6.51	-12.8
SW6-MAG	7.49	7.95	6.0
SW7-GAR	7.97	8.0	0.4
DS-GORT	8.42	8.15	-3.3
SW17-GORT	7.97	7.63	-4.4
SW10-GORT-DISC	7.85	7.46	-5.1
SW10-GORT-DS	8.19	7.88	-3.9
SW10-GORT-US	8.19	7.84	-4.4
SW12-GORT-DISC	7.79	7.28	-6.8
SW12-GORT-DS	8.18	7.9	-3.5
SW14-GORT	8.17	7.94	-2.9
DS-GORTEENADIHA	7.84	7.63	-2.7
DS-SHAL	7.88	6.77	-15.2
SW12-SHAL	6.44	6.75	4.7
SW13-SHAL	8.09	7.54	-7.0
SW1-SHAL	7.67	7.56	-1.4
SW6-SHAL	6.87	5.53	-21.6
SW9-SHAL	7.65	6.99	-9.0
US-SHAL	8.02	7.62	-5.1

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	0	1	1	-
Antimony	<0.16	2	1	0.08	0.261	-
Arsenic	<0.51	2	1	2.55	4.77	-
Barium	<0.2	2	1	0.1	578	-
Cadmium	<0.08	2	0	0.04	0.04	-
Chromium	<1.2	2	1	0.6	1.31	-
Cobalt	<0.15	2	1	0.075	0.592	-
Copper	<0.85	2	0	0.425	0.425	-
Iron	<19	2	2	116	178	147
Lead	<0.1	2	1	0.05	1.65	-
Manganese	<0.76	2	1	0.38	1,040	-
Molybdenum	<0.62	2	0	0.31	0.31	-
Nickel	<0.44	2	1	0.22	1.43	-
Vanadium	<1.3	2	0	0.65	0.65	-
Zinc	<1.3	2	1	0.65	6.1	-

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

Elevated concentrations of dissolved barium (578 µg/l), iron (178 µg/l) and manganese (1,040 µg/l) were recorded at TMF2 (downgradient of the TMF), and were significantly higher than the concentrations at TMF1 (upgradient of the TMF). The concentrations of dissolved arsenic, lead and zinc were higher in TMF2 compared to TMF1.

4.1.2 Surface Water Sample Results

Surface water samples were collected for two major categories: the first comprised of mine adit discharges and discharges from wetlands as well as some drainage ditches, and the second comprised of rivers and streams. Table 9 provides a summary of the results of the 10 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	10	7	1	346	78.2	122
Antimony	<0.16	10	6	0.08	0.67	0.51	0.19
Arsenic	<0.51	10	8	0.255	3.41	1.3	0.68
Barium	<0.2	10	10	14.9	242	101	79
Cadmium	<0.08	10	8	0.04	20.2	7.76	7.47
Chromium	<1.2	10	0	0.6	0.6	-	-
Cobalt	<0.15	10	5	0.075	8.13	2.38	3.25
Copper	<0.85	10	6	0.425	13.2	3.71	4.74
Iron	<19	10	4	9.5	3,610	959	1,767
Lead	<0.1	10	8	0.05	248	34.4	84.4
Manganese	<0.76	10	10	0.847	1,130	257	264
Molybdenum	<0.62	10	2	0.31	1.55	0.93	-
Nickel	<0.44	10	9	0.22	338	45.6	74.6
Vanadium	<1.3	10	0	0.65	0.65	-	-
Zinc	<1.3	10	9	0.65	60,900	8,493	13,549

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

SW5-GAR (Knights Shaft) had the highest concentrations of dissolved nickel (338 µg/l) and zinc (60,900 µg/l). The highest dissolved lead was recorded at SW6-Shal (Field Shaft) with a value of 248 µg/l. SW5-GAR had the highest concentration of dissolved manganese (1,130 µg/l) and SW12-GAR had the highest concentration of dissolved cadmium (20.2 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	14	1	120	30.8	29
Antimony	<0.16	18	9	0.08	0.848	0.48	0.21
Arsenic	<0.51	18	12	0.255	1.08	0.724	0.286
Barium	<0.2	18	18	49.5	334	158	81.1
Cadmium	<0.08	18	14	0.04	12.2	2.45	4.46
Chromium	<1.2	18	1	0.6	1.22	-	-

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Cobalt	<0.15	18	6	0.075	1.1	0.668	0.417
Copper	<0.85	18	12	0.425	9.68	3.67	3.75
Iron	<19	18	10	9.5	107	53.5	29.4
Lead	<0.1	18	17	0.05	190	25.5	64.3
Manganese	<0.76	18	18	4.03	136	45.5	239
Molybdenum	<0.62	18	2	0.31	1.34	0.825	-
Nickel	<0.44	18	17	0.22	13	3.63	7.18
Vanadium	<1.3	18	0	0.65	0.65	-	-
Zinc	<1.3	18	17	0.65	4,060	601	11,700

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 notably lower concentrations of zinc than the rest of the rivers and streams sampled in the Silvermines area (3.56 and 0.65 µg/l, respectively). SW1-SM and SW17-Gort had background concentrations of barium of 65.5 µg/l and 230 µg/l, respectively.

US-Shal had the highest concentrations of cadmium (12.2 µg/l), nickel (13 µg/l) and zinc (4,060 µg/l). The highest concentration of manganese was found at SW3-GAR (136 µg/l). SW9-Shal (downstream of field shaft) had the highest concentrations of lead (190 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 as the assessment criteria, where possible, because it is the most appropriate threshold when assessing only 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 is 165 mg/l $CaCO_3$ (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 (2007) 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 some surface waters are intermittently above the standard.

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 CaCO3 (Class 1: <40 mg CaCO3/l, Class 2: 40 to <50 mg CaCO3/l, Class 3: 50 to <100 mg CaCO3/l, Class 4: 100 to <200 mg CaCO3/l and Class5: ≥200 mg CaCO3/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 CaCO3 is ≤ 100; 30 µg/l applies where the water hardness > 100 mg/l CaCO3.
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 CaCO3; 50 µg/l for water hardness >10 mg/l CaCO3 and ≤ 100 mg/l CaCO3; 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 *et. al.* 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-1 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-2 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

The groundwater pH was 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 6.83. The specific conductance ranged from 0.448 to 0.500 mS/cm, which was well below the threshold for human health of 2.5 mS/cm.

Sulphate was within normal ranges, with values ranging from <2 to 13.3 mg/l, which was well below the criteria for human health of 250 mg/l. Ammonia was less than the limit of detection in both monitoring wells.

For dissolved metal concentrations, barium and manganese exceeded the assessment criteria in TMF2, the downgradient monitoring well. Barium was recorded at a concentration of 578 µg/l, which exceeded the ecological health criteria of 4 µg/l. Manganese exceeded the human health criteria of 50 µg/l with a concentration of 1,010 µg/l in TMF2. Note that manganese is not an important criterion for human health (see Section 4.2.1).

4.3.2 Surface Water Assessment

The pH in surface waters (rivers/streams, drainage and discharges) in the Silvermines mining area ranged from 5.53 to 8.15 with an average of 7.55. There was one exceedance of the assessment criteria for pH at SW6-Shal (pH 5.53), which was below the acceptable range for human health (pH 6.5 to 9.5). The conductivity ranged from 0.035 to 3.02 mS/cm with an average of 0.721 mS/cm, and one exceedance of the human health criteria (2.5 mS/cm) which was recorded at SW5-GAR (3.02 mS/cm). Dissolved oxygen at DS-Gort (148.4%) exceeded the range for ecological health (80-120%). Excessive vegetation in the Kilmastulla River channel is the likely cause of this exceedance.

The ecological and human health assessment criteria for ammonia (0.14 mg/l and 0.3 mg/l, respectively) were exceeded at two locations, SW5-SM and SW6-SM, where ammonia was recorded at 0.619 mg/l and 0.485 mg/l, respectively. Waste water discharge was observed, as clouding of the water accompanied by a foul smell, at SW5-SM (which is upstream of SW6-SM) at the time of sampling. The elevated ammonia concentrations at these two sites may be due to the impact of waste water effluent on this river in general, and particularly at the time of sampling.

The waste water is likely discharging from a waste water treatment plant (A0178-01), located upstream of SW5-SM.

Sulphate exceeded the criteria for human health (250 mg/l) at both wetland discharges in the Gortmore area (1,380 mg/l at SW10-Gort-Discharge and 770 mg/l at SW12-Gort-Discharge). With the exception of SW7-Gar, the sulphate threshold was exceeded at all locations within the Garryard area with values ranging from 279 to 1,910 mg/l. One river/stream site in the Shallee area, US-Shal, exceeded the threshold, with a sulphate concentration of 299 mg/l. The highest sulphate result was recorded at SW5-Gar (1,910 mg/l).

Dissolved Metals Assessment

There were exceedances of dissolved barium, cadmium, cobalt, iron, lead, manganese, nickel and zinc, as discussed below, and see the Table B-1 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 (65.5 µg/l) and SW17-Gort (230 µg/l). These barium concentrations are similar to those recorded at these locations in previous monitoring rounds. Exceedances of dissolved barium are not discussed further. Dissolved arsenic was detected at the majority of the surface water locations but was notably lower than both the ecological (25 µg/l) and human health (10 µg/l) assessment criteria. The highest dissolved arsenic concentration was recorded at SW5-Gar (3.41 µg/l).

In the Ballygown area (Map 5 of **Appendix A**) where the Silvermines stream is located, in addition to dissolved barium, there were exceedances of dissolved cadmium and zinc. There were no exceedances at the upstream site, SW1-SM (except barium). The concentration of zinc at all downstream sites exceeded the ecological assessment criteria threshold (100 µg/l). At the southern Adit (SW2-SM-South), concentrations of dissolved cadmium (5.06 µg/l) and dissolved zinc (1,870 µg/l) exceeded the ecological assessment criteria of 0.9 µg/l and 100 µg/l, respectively. The concentration of zinc at SW3-SM, located upstream of the southern Adit discharge (SW2-SM-South) was elevated (141 µg/l) but notably lower than the dissolved zinc concentration at the three sites downstream of the discharge (SW4-SM-GS, SW5-SM and SW6-SM), which ranged from 431 µg/l to 675 µg/l. The concentration of dissolved zinc recorded at the three sites downstream of the discharge decreased spatially from the point of discharge.

The concentrations of dissolved zinc and cadmium at SW6-Mag, which is downstream of the Magcobar area, was also above the ecological assessment criteria, at 665 µg/l and 1.52 µg/l, respectively.

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

Area	Sample Description	Sample Location	Date Sampled / Units	Ammoniacal Nitrogen as N (mg/l)	pH (field)	Cadmium (diss.filt) (µg/l)	Lead (diss.filt) (µg/l)	Manganese (diss.filt) (µg/l)	Nickel (diss.filt) (µg/l)	Zinc (diss.filt) (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	04/05/2017	*<0.2*	8.08	*<0.08*	*0.233*	7.16	*<0.44*	3.56
	SW3-SM	DS (workings & Adits)	04/05/2017	*<0.2*	7.8	*0.391*	2.0	4.03	0.921	141
	SW5-SM	DS (workings & Adits)	04/05/2017	0.619	7.84	1.64	1.49	8.55	2.21	675
	SW6-SM	DS (workings & Adits)	04/05/2017	0.485	7.81	1.17	2.6	15.6	1.85	514
	SW4-SM-GA	Downstream (all incl. tailings deposit)	04/05/2017	*<0.2*	7.88	0.779	2.6	11.1	1.71	431
Magcobar	SW6-Mag	Downstream	05/05/2017	*<0.2*	7.95	1.52	0.173	14.7	6.73	665
Garryard	SW1-GAR	Upstream	No Flow	-	-	-	-	-	-	-
	SW3-GAR	Downstream (all)	05/05/2017	*<0.2*	8.04	8.44	1.27	136	5.64	1370
Shallee	SW4-SHAL	Upstream	No Flow	-	-	-	-	-	-	-
	SW5-SHAL	DS (drum dump)	No Flow	-	-	-	-	-	-	-
	SW9-SHAL	Downstream	10/05/2017	*<0.2*	6.99	1.07	190	43.6	7.57	223
	SW1-SHAL	Downstream (all)	10/05/2017	*<0.2*	7.56	1.13	158	41.4	7.5	222
Garryard/ Shallee	US SHAL	Downstream of SW3-GAR	10/05/2017	*<0.2*	7.62	12.2	2.02	134	13	4060
	DS SHAL	Downstream of SW3-GAR and SW1-SHAL	10/05/2017	*<0.2*	6.77	4.36	55.5	71.1	7.15	1430
GTD	DS-Gorteenadiha	Downstream of GTD	10/05/2017	*<0.2*	7.63	0.923	12.6	63.4	1.89	166
Gortmore	SW17-GORT	Upstream	09/05/2017	*<0.2*	7.63	*<0.08*	*<0.10*	75.6	0.487	*<1.3*
	SW12-GORT-DS	Downstream (TMF)	09/05/2017	*<0.2*	7.9	0.266	1.54	34.5	1.22	101
	SW14-GORT	Downstream (TMF and Yellow River)	09/05/2017	*<0.2*	7.94	0.241	1.4	33.1	1.07	81.1
	DS-Gort	Downstream (TMF and Yellow River)	09/05/2017	*<0.2*	8.15	0.165	1.2	9.46	1	45.1

Notes:

xx Exceeds Ecological Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

xx Exceeds Human Health Assessment Criteria

Metals are dissolved

At Gortmore TMF (Map 2 of Appendix A), dissolved zinc and manganese exceeded the assessment criteria at a number of locations. Dissolved manganese exceeded the human health assessment criteria (50 µg/l) at five locations; SW10-Gort-Disc. (303 µg/l), SW10-Gort-DS (57.9 µg/l), SW10-Gort-US (57.4 µg/l), SW12-Gort-Disc. (249 µg/l) and SW17-Gort (75.6 µg/l). Dissolved zinc exceeded the ecological assessment criteria at both wetland discharges; 790 µg/l at SW10-Gort-Discharge and 229 µg/l at SW12-Gort-Discharge. Dissolved nickel was detected at all sampling locations but was lower than the assessment criteria.

The concentration of zinc increased on the Kilmastulla River from <LOD (0.65 µg/l) at the upstream location, SW17-Gort, to 229 µg/l at the downstream location SW12-Gort-DS; the latter exceeding the ecological assessment criteria (100 µg/l). SW12-Gort-DS 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 four locations, with concentrations ranging from 55.5 to 248 µg/l. The highest concentration (248 µg/l) was recorded at the Field Shaft discharge (SW6-Shal). With the exception of SW12-Shal (stone lined drainage channel) and SW13-Shal (drainage channel), dissolved zinc exceeded the ecological assessment criteria of 100 µg/l with values ranging from 164 to 4,060 µg/l. Manganese was found to be above the criteria for human health (50 µg/l) upstream (US Shal: 134 µg/l) and downstream (DS-Shal: 71.1 µg/l) of the Shallee Mining Area. Dissolved cadmium exceeded the ecological criteria (0.9 µg/l) at four locations, with values ranging from 0.968 µg/l to 4.36 µg/l, and exceeded both the ecological criteria and human health criteria (5 µg/l) at one location, US-Shal (12.2 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 55.5 µg/l. The dissolved zinc exceeded the ecological assessment criteria (100 µg/l) with a concentration of 1,430 µg/l.

Sampling location DS-Gorteenadiha is located downstream of the Gorteenadiha mining area and upstream the Shallee mining area. Elevated concentrations of dissolved cadmium (0.923 µg/l; exceeded the ecological assessment criteria of 0.9 µg/l), lead (12.6 µg/l; exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria), manganese (63.4 µg/l; exceeds human health criteria of 50 µg/l) and zinc (166 µg/l; exceeds ecological health criteria of 100 µg/l) were recorded at this location.

Some of the highest concentrations of dissolved metals were observed in the Garryard area (Map 4 of Appendix A). All sites in Garryard exceeded the dissolved zinc ecological assessment criteria of 100 µg/l, ranging from 314 to 60,900 µg/l. Four locations exceeded both the ecological (0.9 µg/l) and human health (5 µg/l) assessment criteria for cadmium (ranging from 8.44 to 20.2 µg/l), while one site, SW7-Gar, was above the cadmium ecological assessment criterion but below the human health assessment criterion, with a concentration of 1.09 µg/l. At SW5-Gar (Knights Shaft), dissolved lead (9.72 µg/l) exceeded the ecological assessment criteria (7.2 µg/l), dissolved nickel exceeded both the ecological and human health assessment criteria of 20 µg/l, with a value of 338 µg/l, dissolved cobalt exceeded the ecological assessment criterion value of 5.1 µg/l, with a concentration of 8.13 µg/l, and dissolved iron was above the human health assessment criteria

(200 µg/l), with a concentration of 3,610 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, and SW7-Gar which did not exceed the assessment criteria.

4.3.3 Livestock Water Quality Assessment

Recommendations on the levels of toxic substances in drinking water for livestock are provided in Table 13. The National Academy of Sciences (1972) recommend a limit of 100 µg/l for lead in drinking water for livestock. However, lead is accumulative and problems may begin at threshold value of 50 µg/l. The Field Shaft (SW6-Shal) had a dissolved lead concentration of 248 µg/l and the sampling location on the stream SW9-Shal, which is just downstream of the Field Shaft, had concentration of 190 µg/l. Further downstream at SW1-Shal, which is located downgradient of the Shallee tailings impoundment, the concentration of dissolved lead was 158 µg/l. Therefore, livestock should be prevented from drinking water in the stream in the Shallee mining area.

The water quality results of all the sampling locations at Gortmore TMF were assessed against the recommendations for levels of toxic substances in drinking water for livestock from the National Academy of Sciences (1972). Note that the streams on top of the TMF (SW18-Gort and SW19-Gort) were dry in March 2017 and therefore, no assessment was carried out at these locations. Findings based on the results obtained in March 2017, are as follows:

- 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; SW10-Gort-Disc (1,380 µg/l) and SW12-Gort-Disc (770 µg/l); and
- The guidelines for sulphates in water are not well defined but high concentrations cause diarrhoea; however, at the levels typically found in the waterbodies at Gortmore TMF it is likely that livestock are accustomed to them. 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 exist within the Silvermines mining area. The nearest gauge is on the Kilmastulla River at Coole (EPA station 25044) which is approximately 10 km downstream of the Silvermines mining area. The flow record between 30 August 2016 and the 10 May 2017 at Station 25044 is reproduced in Figure 1. The flow ranged from a maximum of 10.4 m^3/s following rainfall events to less than 0.50 m^3/s during low-flow, with a median flow of approximately 1.2 m^3/s. The Coole gauging station data show that there were high flows during two days in February and three days in March that were at or above the estimated 5%-ile (high flow) of 6.84 m^3/s following rainfall (note: the 5%-ile (high flow) value is calculated from the dataset 1970 to 2017). The flow during these periods shows a flashy response to rainfall. The highest recorded flow in the monitoring period was on 4 March 2017 with a mean daily flow of 10.4 m^3/s. The lowest flows were recorded on three days in May and one day in November; these flows were less than 0.5 m^3/s but greater than the the 95%-ile (low flow) of 0.33 m^3/s. All other flows over the period ranged between 0.50 m^3/s and 8.24 m^3/s. Overall, the flows were relatively low during 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. This estimated 95%-ile flow (low flow) is 0.16 m^3/s. This tool was also used to calculate the 5%-ile flow (high flow) of the Kilmastulla River at the location just downstream of the Gortmore TMF, which was 4.36 m^3/s.

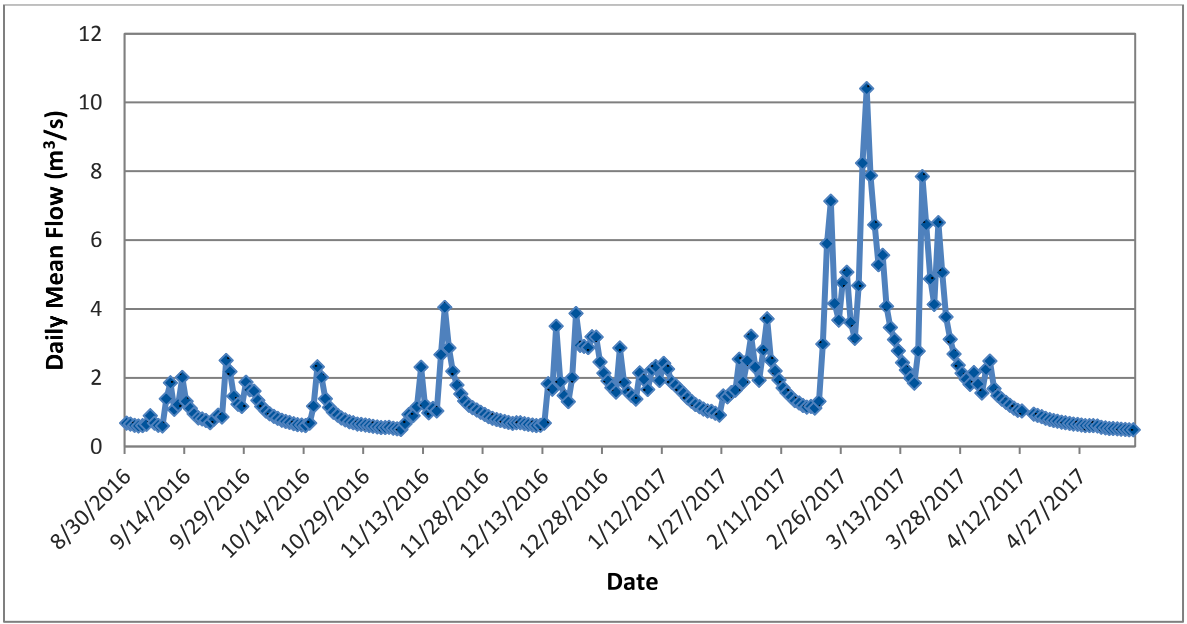

Figure 1 Mean Daily Flow (m^3/s) at Coole, Kilmastulla (Station 25044) from 30 Aug 2016 to 10 May 2017

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 May 2017 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 May 2017

Site Name	Flow l/s	Date
DS-GORT	461	08/05/17
DS-Gorteenadiha	2.9	10/05/17
SW10-GORT-DISCHARGE	0.30	09/05/17
SW12-GORT-DISCHARGE	3.1	09/05/17
SW18-GORT	Dry - No Flow	09/05/17
SW19-GORT	Dry - No Flow	09/05/17
DS-Shal	12.2	10/05/17
SW12-Shal	0.07	10/05/17
SW13-Shal	0	10/05/17
SW1-Shal	6.5	10/05/17
SW4-Shal	Insufficient flow to measure	10/05/17
SW5-Shal	Dry - No Flow	10/05/17
SW6-Shal	5.3	10/05/17
SW9-Shal	6.7	10/05/17
SW14-Shal	Dry - No Flow	10/05/17
US-Shal	5.3	10/05/17
SW10-GAR	3.5	04/05/17
SW12-GAR	Insufficient flow to measure	04/05/17
SW3-GAR	5.0	04/05/17
SW5-GAR	Immeasureable Flow (grating)	04/05/17
SW7-GAR	0.04	04/05/17
SW1-SM	3.6	04/05/17
SW2-SM-SOUTH	1.04	04/05/17
SW3-SM	5.1	04/05/17
SW4-SM-GA	12.7	04/05/17
SW5-SM	9.7	04/05/17
SW6-SM	9.5	04/05/17

5.2 Loading Analysis

5.2.1 Loading Analysis Methodology, Results and Discussion

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

Load (g/day) = [C (µg/L) * F (L/day)] / 1,000,000 µg/g

where: C = the concentration of the parameter in the water
F = the flow rate of the input

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	Sulphate		Cadmium		Lead		Manganese		Nickel		Zinc	
			Units	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	08/05/2017	461	8.2	53500	2130000	0.165	6.57	1.2	47.8	9.46	377	1	39.8	45.1	1800
SW10-Gort-Disc.	09/05/2017	0.3	7.5	1380000	36200	0.04	0	0.05	0	303	7.94	9.34	0.24	790	20.7
SW12-Gort-Disc.	09/05/2017	3.1	7.3	770000	205000	0.141	0.04	0.05	0.01	249	66.2	3.19	0.85	229	60.8
DS-Shal	10/05/2017	12.2	6.8	107000	113000	4.36	4.59	55.5	58.4	71.1	74.8	7.15	7.53	1430	1510
SW12-Shal	10/05/2017	0.1	6.8	1000	5.98	0.04	0	5.43	0.03	1.45	0.01	0.22	0	0.65	0
SW1-Shal	10/05/2017	6.5	7.6	15100	8460	1.13	0.63	158	88.5	41.4	23.2	7.5	4.2	222	124
SW6-Shal	10/05/2017	5.3	5.5	11600	5330	0.968	0.44	248	114	52	23.9	7.78	3.57	164	75.3
SW9-Shal	10/05/2017	6.7	7.0	14000	8100	1.07	0.62	190	110	43.6	25.2	7.57	4.38	223	129
US-Shal	10/05/2017	5.3	7.6	299000	137000	12.2	5.6	2.02	0.93	134	61.5	13	5.97	4060	1860
DS-Gorteenadiha	10/05/2017	2.9	7.6	18200	4560	0.923	0.23	12.6	3.16	63.4	15.9	1.89	0.47	166	41.6
SW10-Gar	05/05/2017	5.0	8.05	380000	115000	15.2	4.6	2.71	0.82	126	38.1	9.67	2.92	2260	683
SW3-Gar	05/05/2017	5.0	8.0	279000	120000	8.44	3.64	1.27	0.55	136	58.7	5.64	2.44	1370	591
SW7-Gar	05/05/2017	0.04	8.0	169000	644	1.09	0	0.442	0	23.7	0.09	1.79	0.01	314	1.2
SW1-SM	04/05/2017	3.6	8.1	7500	2340	0.04	0.01	0.233	0.07	7.16	2.23	0.22	0.07	3.56	1.11
SW2-SM-South	04/05/2017	1.0	7.3	27900	2520	5.06	0.46	1.31	0.12	0.847	0.08	5.36	0.48	1870	169
SW3-SM	04/05/2017	5.1	7.8	8200	3640	0.391	0.17	2	0.89	4.03	1.79	0.921	0.41	141	62.5
SW4-SM-GA	04/05/2017	12.7	7.9	19400	21200	0.779	0.85	2.6	2.85	11.1	12.2	1.71	1.87	431	472
SW5-SM	04/05/2017	9.7	7.8	29100	24300	1.64	1.37	1.49	1.24	8.55	7.13	2.21	1.84	675	563
SW6-SM	04/05/2017	9.5	7.8	20900	17200	1.17	0.96	2.6	2.14	15.6	12.8	1.85	1.52	514	423

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

Where 0 g/day reported, the range of actual values are as follows:
Cadmium: 0.0002 – 0.004 g/day
Lead: 0.0013 – 0.002 g/day
Nickel: 0.0013 g/day
Zinc: 0.006 g/day

The dissolved metal with the highest mass loading was zinc ranging from 0 to 1,860 g/day with an average of 467 g/day overall. The largest mass load of zinc (1,860 g/day) was found at US-Shal, located directly upstream of the Shallee mining area on the Yellow Bridge River which drains the Garryard mining area.

SW10-Gar (the discharge from the tailings lagoon) had a zinc load of 683 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 591 g/day. The decrease in zinc load between both locations is likely due to metal precipitation. Flow was observed in the channels draining the western section of the Mogul yard resulting in an increase in flow between SW10-Gar (3.5 l/s) and SW3-Gar (5 l/s). 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 1.11 g/day, which increases to 62.5 g/day downstream of the mine workings (SW3-SM). The zinc load at SW5-SM which is located downstream of the southern (169 g/day zinc) and northern adit (not sampled) would be expected to be 232 g/day. However, the calculated zinc load at SW5-SM was 563 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. Additionally, between collecting the sample at SW5-SM and conducting the flow measurement, waste water effluent was observed within the stream. Note that a WWTP (A0178-01) is located upstream of the sampling location. Accordingly, the increase in flow may have resulted in an overestimation of dissolved zinc load at SW5-SM. Further downstream the calculated mass load at SW6-SM (new sampling location) was 423 g/day which is a decrease of 140 g/day. This decrease is primarily due to the overestimation of zinc load at SW5-SM. Between SW6-SM and SW4-SM-GA, the zinc load increases by 12% from 423 g/day to 472 g/day. The increase in dissolved zinc load along this stretch was also identified in R7 (February 2016) and R8 (August 2016) and indicates an additional source of dissolved zinc load. The likely source of this increase is an old tailings deposit located directly east of the stream downgradient of SW6-SM. The Silvermines stream contributes this load to the Kilmastulla River.

The streams emerging from the Garryard mining area (US-Shal) and the Gorteenadiha mining area (DS-Gorteenadiha) area had dissolved zinc loads of 1,860 and 41.6 g/day, respectively. The stream emerging from the Shallee mining area contributed a zinc load of 124 g/day. Therefore, it would be expected that the dissolved zinc load at DS-Shal would be 2,026 g/day. However, the calculated zinc load at DS-Shal was 1,510 g/day indicating significant precipitation of dissolved zinc. A sample (SW13-Shal) was also collected from the stream draining the eastern section of the tailings impoundment which joins the Shallee stream downstream of SW1-Shal. A very minor flow was observed but too minor to be measured by the flow measurement equipment. Additionally, between Garryard (SW3-Gar) and Shallee (US-Shal), there was an increase in dissolved zinc load from 591 to 1,860 g/day. This increase indicates that a diffuse contribution of dissolved lead is likely along this stretch of river.

The highest load of dissolved lead (114 g/day) was found at SW6-Shal (Field shaft). Between SW6-Shal and SW1-Shal, located further downstream there was a 22% decrease in lead load (114 to 88.5 g/day). A further decrease was identified between SW1-Shal and DS-Shal (88.5 to 58.4 g/day). The mass load of dissolved lead at US-Shal and DS-Gorteenadiha, located directly upstream of the Shallee mining area was calculated to be 0.93 and 3.16 g/day, respectively. The decrease in lead load in this area is due to a decrease in concentrations, likely caused by precipitation of dissolved zinc.

The calculated dissolved zinc load at DS-Gort was 1,800 g/day. 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, SW12-Gort-Discharge had the highest loading of dissolved zinc at 60.8 g/day. SW10-Gort-Discharge had 20.7 g/day of zinc. Discharges from the Garryard and Shallee area (DS-Shal – 1,510 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 <= p < 0.05	Decreasing
	0.05 <= p < 0.1	Likely Decreasing
	p >= 0.1	No Trend
Increasing	0 <= p < 0.05	Increasing
	0.05 <= p < 0.1	Likely Increasing
	p >= 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 May 2017

Sample Location	Parameter	Reported values (n)	p value	s value	Trend
SW10-Gar	Diss. cadmium	14	0.125	-22	No Trend
	Diss. lead	14	0.27	-11	No Trend
	Diss. manganese	14	0.009	-44	Decreasing
	Diss. nickel	14	0.114	-23	No Trend

Sample Location	Parameter	Reported values (n)	p value	s value	Trend
	Diss. zinc	14	0.456	-3	No Trend
SW10-Gort-Discharge	Diss. cadmium	11	0.044	-20	Decreasing
	Diss. lead	11	0.5	1	No Trend
	Diss. manganese	11	0.106	17	No Trend
	Diss. nickel	11	0.106	-17	No Trend
	Diss. zinc	11	0.106	-17	No Trend
SW12-Gort-Discharge	Diss. cadmium	10	0.174	10	No Trend
	Diss. lead	10	0.451	2	No Trend
	Diss. manganese	10	0.429	3	No Trend
	Diss. nickel	10	0.037	-21	Decreasing
	Diss. zinc	10	0.6	5	No Trend
SW6-Shal	Diss. cadmium	12	0.316	8	No Trend
	Diss. lead	12	0.473	2	No Trend
	Diss. manganese	12	0.152	-16	No Trend
	Diss. nickel	12	0.269	-10	No Trend
	Diss. zinc	12	0.269	-10	No Trend
SW14-Gort (Kilmastulla River)	Diss. cadmium	11	n/a	n/a	Not Calculated
	Diss. lead	11	0.267	9	No Trend
	Diss. manganese	11	0.175	-13	No Trend
	Diss. nickel	11	0.106	-17	No Trend
	Diss. zinc	11	0.175	-13	No Trend

Not Calculated: Iinsufficient statistical evidence of a significant trend

The results of the Mann-Kendall test show that dissolved manganese concentrations are decreasing at SW10-Gar. At SW10-Gort-Discharge, dissolved cadmium is decreasing, while dissolved nickel shows a deceasing trend at SW12-Gort-Discharge. No statistically significant trends were observed in the data for 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), February 2016 (R7) and May 2017 (R9) 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 2013-2017

Site Description	Round & Date Sampled	Flow	Cadmium		Lead		Manganese		Zinc	
		l/s	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
	R9 04/05/2017	1.04	5.06	0.46	1.31	0.12	0.847	0.08	1870	169
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

Site Description	Round & Date Sampled	Flow	Cadmium		Lead		Manganese		Zinc	
		l/s	µg/l	g/day	µg/l	g/day	µg/l	g/day	µg/l	g/day
	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
	R9 10/05/2017	5.3	0.968	0.44	248	114	52	23.9	164	75.3
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
	R9 05/05/2017	3.5	15.2	4.6	2.71	0.82	126	38.1	2260	683
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
	R9 09/05/2017	0.30	0.04	0	0.05	0	303	7.94	790	20.7
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	122.47
	R9 09/05/2017	3.1	0.141	0.04	0.05	0.01	249	66.2	229	60.8
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	-
	R9 09/05/2017	-	0.241	-	1.4	-	33.1	-	81.1	-
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
	R9 08/05/2017	461	0.165	6.57	1.2	47.8	9.46	377	45.1	1800

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. One exception is for SW12-Gort-Disc. in May 2017 (R9) where the concentration of dissolved zinc was 229 µg/l. 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. One exception (81.1 µg/l) to this trend was in May 2017, where low flow conditions were observed. 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.

The calculated mass loads of dissolved metals in Round 9 (May 2017) were significantly lower than previous high flow sampling rounds which is due to the low flow conditions observed during the sampling event. For example, the dissolved zinc load at SW10-Gar was 683 g/day in May 2017. The average zinc load recorded at this location during high flow sampling is 22,683 g/day.

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 48.33 m Ordnance Datum (OD) at the upgradient location TMF1 to 46.00 m OD at the downgradient location TMF2. These elevations are consistent with south-westerly groundwater flow through the bedrock being, 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 were 0.40 and 0.41 meters, respectively, lower than the elevations measured in spring 2016 (11/02/16), and 0.25 and 0.12 meters, respectively, lower than the elevations measured during low flow in August 2016 (22/08/16).

Within the tailings area, the water levels generally ranged from 2.65 to 3.98 m below the top of the tailings surface. The exceptions were in BH3A-GORT-06 and BH6A-GORT-06 (see Map 2 of Appendix A) where deeper water levels were recorded. The groundwater elevations within the TMF varied between 49.03 to 53.17 m OD. These groundwater elevations are similar to the elevations measured during low flow in 2016 (22/8/2016), which ranged from 48.64 to 53.22 m OD, and between 0.16 to 1.28 metres lower than the elevations measured during high flow (11/02/2016).

Table 20 Measures Groundwater Levels May 2017

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	08/05/2017	14.00	0.67	1.27	48.33
TMF2		08/05/2017	10:30	2.01	2.47	46.00
BH1A-GORT-06	Located within the TMF, near the perimeter of the tailings surface	09/05/2017	11.44	2.65	3.30	53.11
BH2A-GORT-06		09/05/2017	12.30	3.29	3.82	52.47
BH3A-GORT-06		09/05/2017	12.48	7.57	7.90	49.03
BH4A-GORT-06		09/05/2017	12.20	3.95	4.47	52.21
BH5A-GORT-06		09/05/2017	12.10	3.98	4.41	52.24
BH6A-GORT-06		09/05/2017	11.35	5.54	6.23	50.55
BH6B-GORT-06		09/05/2017	11.40	2.78	3.50	53.17

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 May 2017 and water levels were measured in seven additional monitoring wells. Twenty eight surface water locations were sampled and analysed in May 2017 with flows measured at 20 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:

- No exceedances in dissolved metals were recorded at TMF1, located upgradient of the Gortmore TMF. Dissolved metal concentrations at TMF2 (downgradient of the TMF) exceeded the ecological assessment criteria for dissolved barium (578 µg/l) and the human health criteria for dissolved manganese (1,040 µg/l). 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 (3.56 and <1.3 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 (3,610 µg/l), nickel (338 µg/l) and zinc (60,900 µg/l). Each location in Garryard exceeded the dissolved zinc ecological assessment criteria of 100 µg/l with values ranging from 314 to 60,900 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 8.44 to 20.2 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 SW10-Gar, SW12-Gar and SW3-Gar with values ranging from 126 to 664 µg/l. The concentration of dissolved manganese at SW5-Gar exceeded both the human and ecological health assessment criteria with a value of 1,130 µg/l.

- Within the Shallee mining area, dissolved lead exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria at all locations, except SW13-Shal and SW12-Shal (drainage channels). The highest concentration was from the Field Shaft discharge (SW6-Shal) at 248 µg/l.

- Dissolved zinc exceeded the ecological assessment criteria of 100 µg/l at the majority of the drainages and discharges, ranging from 164 to 60,900 µg/l at SW5-Gar. The concentration of zinc increased on the Kilmastulla River from <1.3 µg/l at the upstream location SW17-Gort to 101 µg/l at SW12-Gort-DS. This location is downstream of the wetland discharges and the Yellow Bridge Tributary which drains Garryard, Shallee and Gorteenadiha. The concentration at DS-Shal on the Yellow River tributary was significantly higher at 1,430 µg/l.

- The dissolved metal with the highest mass loading was zinc, ranging from 0.004 to 1,860 g/day with an average of 452 g/day overall. The largest mass load of zinc (1,860 g/day) was found at US-Shal which is located on the Yellow Bridge River, downstream of Garryard. The highest load of dissolved lead was found at SW6-shal (114 g/day). Measured flows ranged from 0.04 l/s at SW7-Gar to 461 l/s at DS-Gort with an average of 29 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

No recommendations for the monitoring programme are proposed at this time.

Section 8

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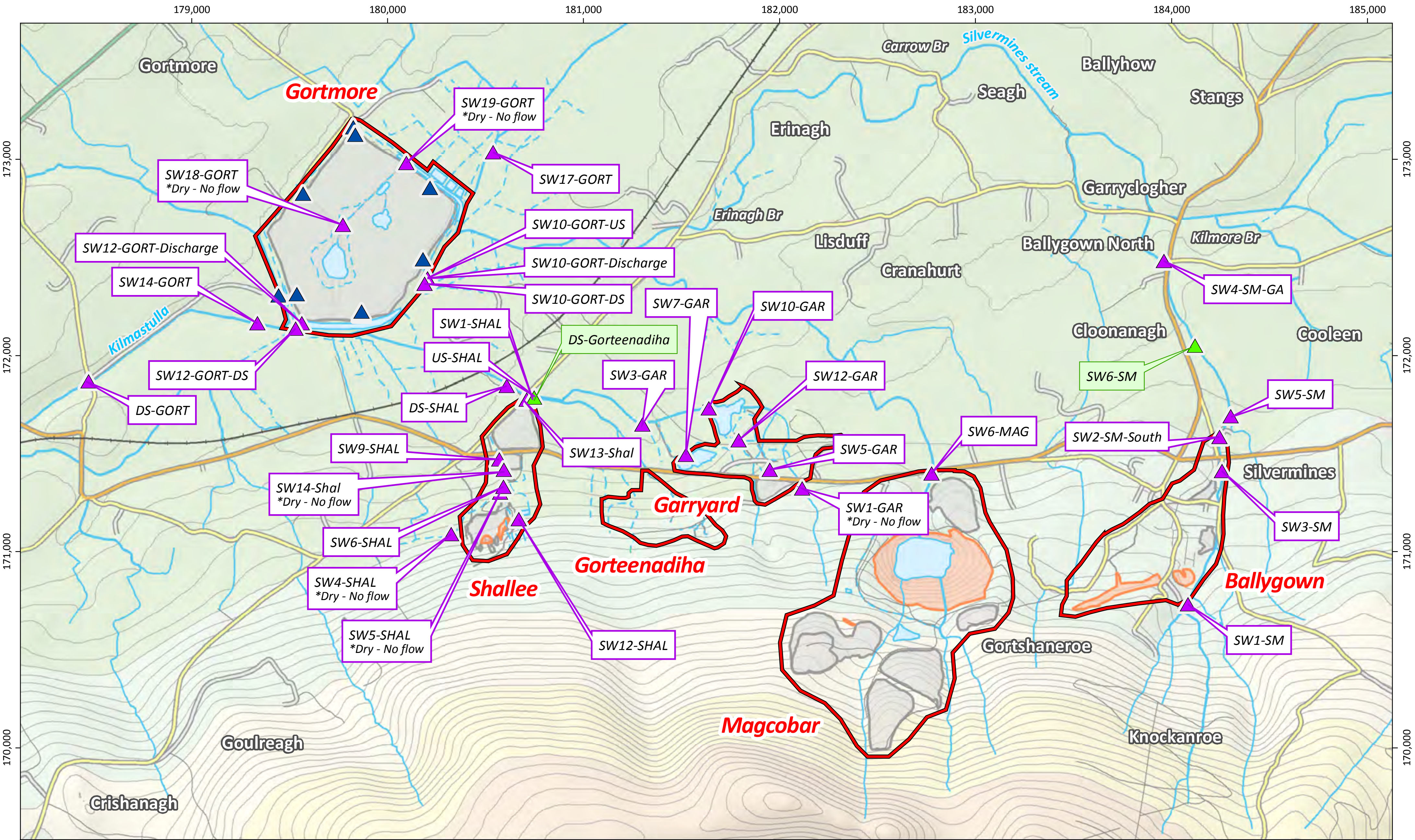
Appendix A

Figures



Map 1 - Silvermines - Overview

Drawn by: OC Date: 26/06/2017

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\22_MonRptR9\MXD\01_SilverMon1.mxd

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CDM Smith

Legend

Sampling Locations

- Surface water
- Surface water *(New point)*
- Groundwater
- Rivers
- Streams
- Pond / Wetland / Pit Lake

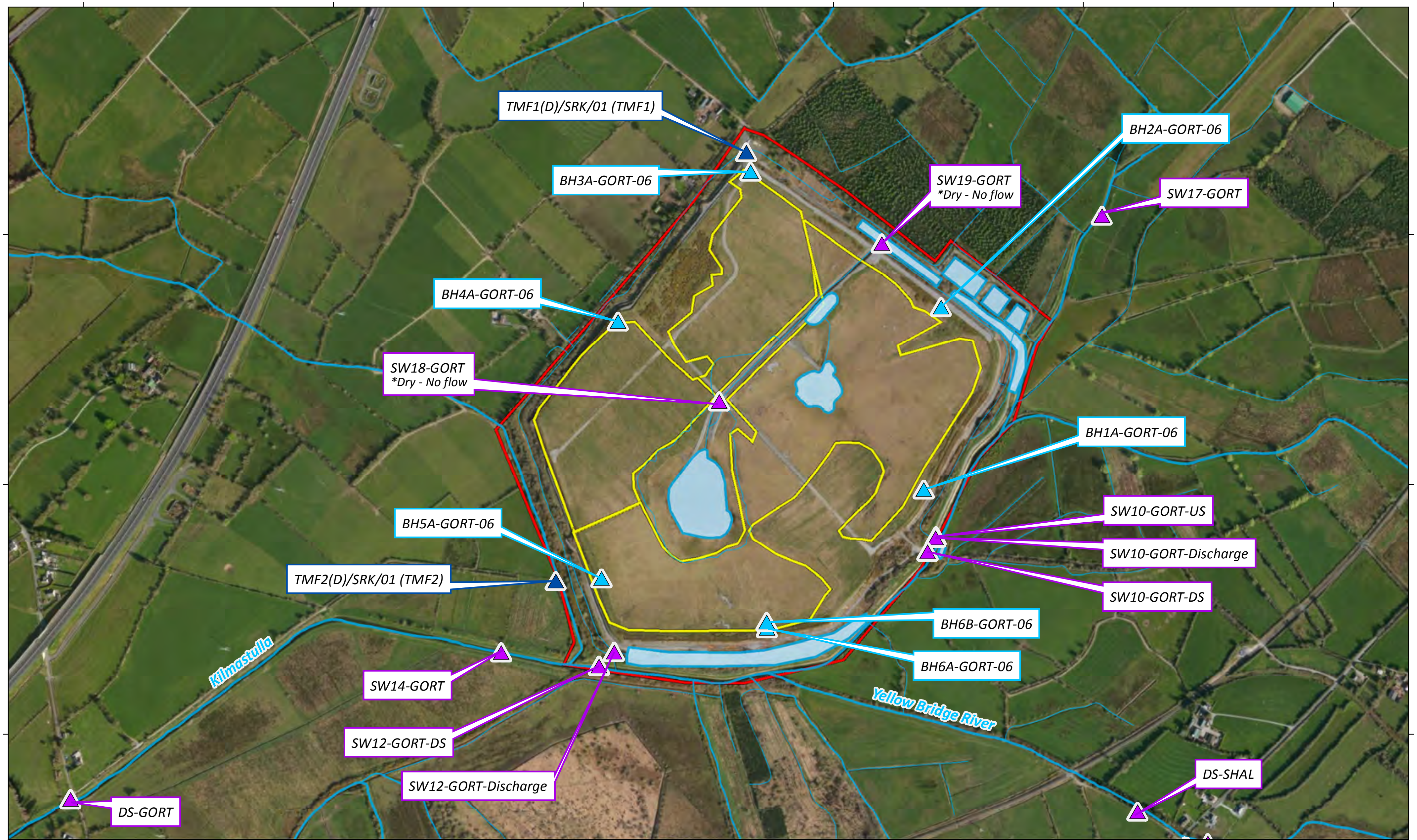
Mines

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

Scale is 1:25,000

0 125 250 500 m

N W E S



Map 2 - Silvermines - Gortmore TMF

Drawn by: OC Date: 26/06/2017

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\22_MonRptR9\MXD\02_SilverMonGM.mxd

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

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Legend

Sampling Locations
- Surface water
- Groundwater
- Groundwater (Levels only)

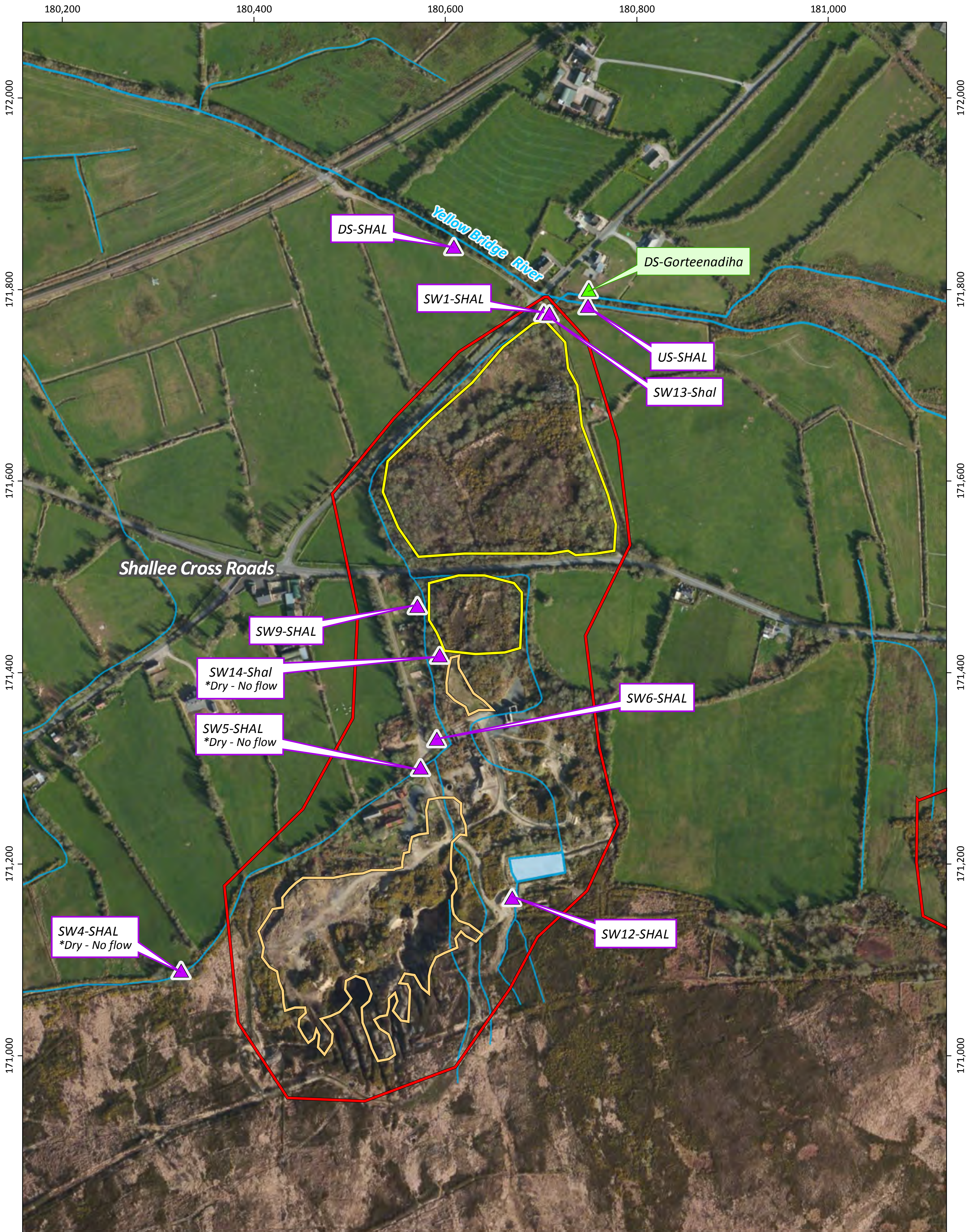
- Rivers
- Streams
- Pond / Wetland / Pit Lake

Mines
- Mining Areas

Scale is 1:10,000

0 100 200 m

N E S W



Map 3 - Silvermines - Shallee South

Drawn by: OC *Date: 26/06/2017*

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\22_MonRptR9\MXD\03_SilverMonSh.mxd

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

CDM Smith

Legend

Sampling Locations
- Surface water
- Surface water *(New point)*

- Rivers
- Streams
- Pond / Wetland

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

N W E S

Scale is 1:5,000

0 50 100 m

Map 4 - Silvermines - Garryard

Drawn by: OC Date: 26/06/2017

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\22_MonRptR9\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

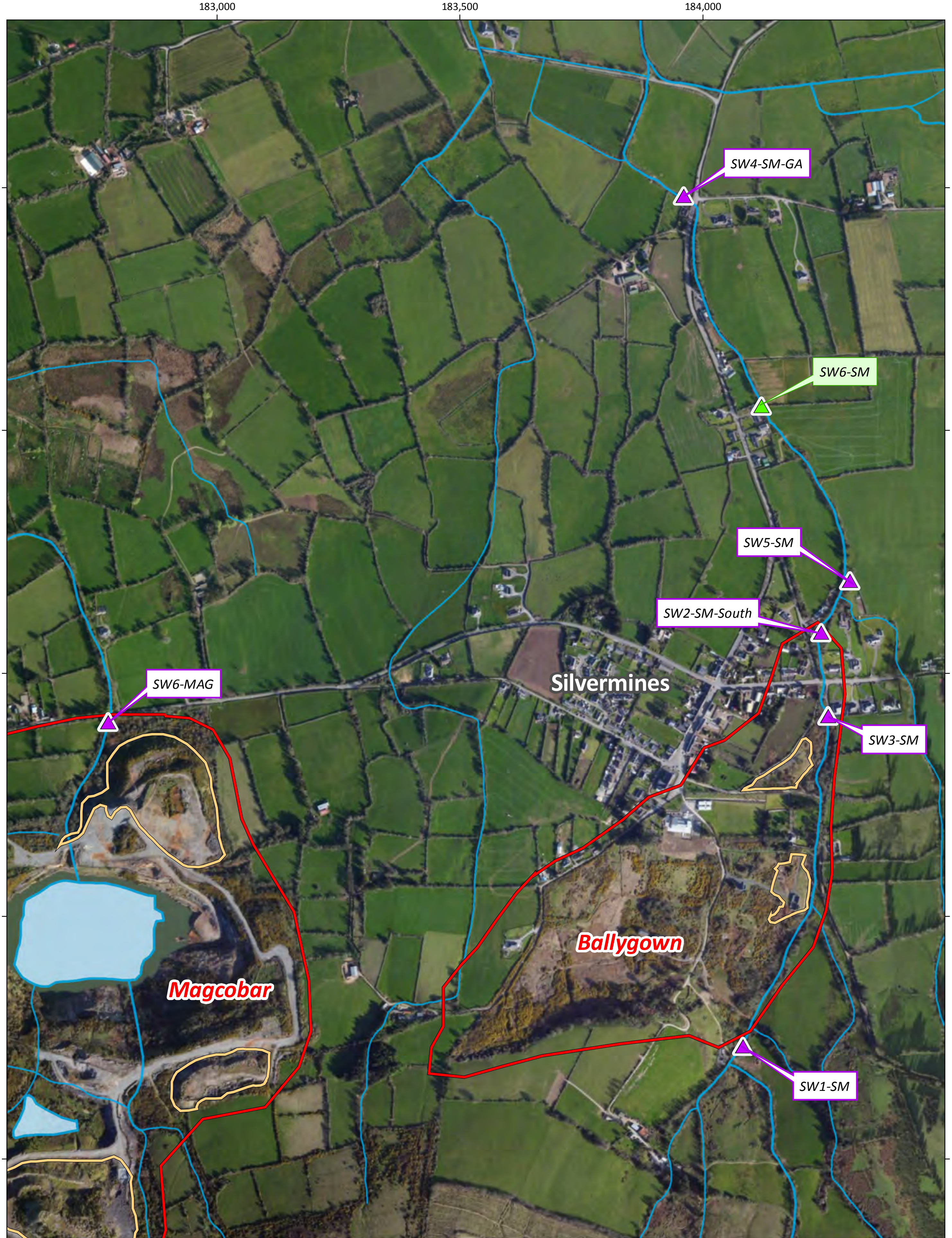
Mining Areas

Stockpile Dump

Scale is 1:5,000

0 50 100 m

N W E S



Map 5 - Silvermines - Magcobar and Ballygown

Drawn by: OC   Date: 26/06/2017

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\22_MonRptR9\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
- Surface water *(New point)*

- Rivers
- Streams
- Pond / Wetland

Mines
- Mining Areas
- Spoil Heap / Waste Drum Dump

N W E S

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 R9

Sample Description	Type	Area	Date Sampled	Ammoniacal Nitrogen as N	Oxygen, dissolved (field)	pH (field)	Specific Conductance @ deg.C (field)	Sulphate	Aluminium (diss.filt)	Antimony (diss.filt)	Arsenic (diss.filt)	Barium (diss.filt)	Cadmium (diss.filt)	Chromium (diss.filt)	Cobalt (diss.filt)	Copper (diss.filt)
			Units	mg/l	% Sat	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	08/05/2017	0.1	7.6	7.05	0.448	13.1	1	0.261	0.255	0.1	0.04	0.6	0.075	0.425
TMF2	Groundwater	GM	08/05/2017	0.1	4.3	6.61	0.5	1	1	0.08	4.77	578	0.04	1.31	0.592	0.425
DS-GORT	River/Stream	GM	08/05/2017	0.1	148.4	8.15	0.547	53.5	59.1	0.08	0.664	165	0.165	0.6	0.075	0.884
SW10-GORT-DISCHARGE	Discharge	GM	09/05/2017	0.1	74.5	7.46	2.262	1380	12.6	0.199	1.59	24.9	0.04	0.6	0.075	0.425
SW10-GORT-DS	River/Stream	GM	09/05/2017	0.1	92.2	7.88	0.603	46.1	15.5	0.08	0.69	166	0.04	0.6	0.075	0.425
SW10-GORT-US	River/Stream	GM	09/05/2017	0.1	91.7	7.84	0.605	42.7	1	0.08	0.708	166	0.04	0.6	0.075	0.425
SW12-GORT-DISCHARGE	Discharge	GM	09/05/2017	0.1	63.4	7.28	1.687	770	1	0.08	1.2	143	0.141	0.6	0.174	0.425
SW14-GORT	River/Stream	GM	09/05/2017	0.1	111.9	7.94	0.549	52.8	6.05	0.08	0.622	169	0.241	0.6	0.075	0.425
SW17-GORT	River/Stream	GM	08/05/2017	0.1	104.2	7.63	0.456	11.6	3.54	0.08	1.08	230	0.04	0.6	0.075	0.425
SW12-GORT-DS	River/Stream	GM	09/05/2017	0.1	99.8	7.9	0.67	62.7	1	0.08	0.71	171	0.266	0.6	0.075	0.853
SW6-MAG	River/Stream	Mag	05/05/2017	0.1	96.9	7.95	0.549	225	28.8	0.168	0.255	49.5	1.52	0.6	0.075	3.57
SW13-Shal	Drainage	Shal	10/05/2017	0.1	70.7	7.54	0.705	98.2	346	0.609	0.744	222	0.25	0.6	0.075	1.27
SW1-Shal	River/Stream	Shal	10/05/2017	0.1	95.5	7.56	0.161	15.1	120	0.848	0.579	224	1.13	1.22	1.05	8.26
SW6-Shal	Discharge	Shal	10/05/2017	0.1	46.8	5.53	0.143	11.6	94.8	0.668	0.792	242	0.968	0.6	1.33	13.2
SW9-Shal	River/Stream	Shal	10/05/2017	0.1	94.2	6.99	0.155	14	43.6	0.629	0.761	235	1.07	0.6	1.1	9.68
SW12-Shal	Drainage	Shal	10/05/2017	0.1	116.4	6.75	0.035	1	32.3	0.08	0.255	59.6	0.04	0.6	0.075	1.05
DS-Shal	River/Stream	Shal	10/05/2017	0.1	93.3	6.77	0.475	107	7.67	0.557	0.634	182	4.36	0.6	0.553	4.68
US-Shal	River/Stream	Shal	10/05/2017	0.1	91	7.62	0.904	299	1	0.401	0.684	63.3	12.2	0.6	0.433	2.18
SW10-GAR	Discharge	Gar	05/05/2017	0.1	91.2	8.05	0.982	380	38	0.34	1.01	25.2	15.2	0.6	0.884	2.68
SW12-GAR	Drainage	Gar	05/05/2017	0.1	92.4	7.78	1.664	792	1	0.616	1.09	15.2	20.2	0.6	1.4	3.1
SW3-GAR	River/Stream	Gar	05/05/2017	0.1	104	8.04	0.861	279	7.8	0.373	0.701	80.3	8.44	0.6	0.599	2.34
SW5-GAR	Discharge	Gar	05/05/2017	0.1	26.7	6.51	3.02	1910	8.62	0.611	3.41	14.9	19.3	0.6	8.13	0.946
SW7-GAR	Drainage	Gar	05/05/2017	0.1	78.9	8	0.627	169	15.4	0.08	0.531	97.6	1.09	0.6	0.075	0.425
SW1-SM	River/Stream	Bg	04/05/2017	0.1	84.1	8.08	0.207	7.5	5.64	0.08	0.255	65.5	0.04	0.6	0.075	0.425
SW2-SM-SOUTH	Discharge	Bg	04/05/2017	0.1	62.7	7.25	0.509	27.9	1	0.08	0.255	163	5.06	0.6	0.075	0.425
SW3-SM	River/Stream	Bg	04/05/2017	0.1	81.3	7.8	0.254	8.2	26.7	0.08	0.255	87.9	0.391	0.6	0.075	0.425
SW4-SM-GA	River/Stream	Bg	04/05/2017	0.1	83.6	7.88	0.411	19.4	36.1	0.402	0.255	161	0.779	0.6	0.075	0.858
SW5-SM	River/Stream	Bg	04/05/2017	0.619	68.3	7.84	0.547	29.1	1	0.08	0.255	130	1.64	0.6	0.075	1.54
SW6-SM	River/Stream	Bg	04/05/2017	0.485	85.2	7.81	0.405	20.9	50.6	0.381	0.255	159	1.17	0.6	0.075	1.79
DS-GORTEENADIHA	River/Stream	Gtd	10/05/2017	0.1	86.6	7.63	0.198	18.2	20.2	0.565	0.85	334	0.923	0.6	0.272	7.35

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
- 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 R9

Sample Description	Type	Area	Date Sampled	Iron (diss.filt)	Lead (diss.filt)	Manganese (diss.filt)	Molybdenum (diss.filt)	Nickel (diss.filt)	Vanadium (diss.filt)	Zinc (diss.filt)
			Units	µg/l	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	08/05/2017	116	0.05	0.38	0.31	0.22	0.65	0.65
TMF2	Groundwater	GM	08/05/2017	178	1.65	1040	0.31	1.43	0.65	6.1
DS-GORT	River/Stream	GM	08/05/2017	40.7	1.2	9.46	0.31	1	0.65	45.1
SW10-GORT-DISCHARGE	Discharge	GM	09/05/2017	9.5	0.05	303	0.31	9.34	0.65	790
SW10-GORT-DS	River/Stream	GM	09/05/2017	53.4	0.53	57.9	0.31	0.947	0.65	43
SW10-GORT-US	River/Stream	GM	09/05/2017	41	0.476	57.4	0.31	0.889	0.65	41.1
SW12-GORT-DISCHARGE	Discharge	GM	09/05/2017	100	0.05	249	0.31	3.19	0.65	229
SW14-GORT	River/Stream	GM	09/05/2017	107	1.4	33.1	0.31	1.07	0.65	81.1
SW17-GORT	River/Stream	GM	08/05/2017	43.5	0.05	75.6	0.31	0.487	0.65	0.65
SW12-GORT-DS	River/Stream	GM	09/05/2017	39.3	1.54	34.5	0.31	1.22	0.65	101
SW6-MAG	River/Stream	Mag	05/05/2017	9.5	0.173	14.7	0.737	6.73	0.65	665
SW13-Shal	Drainage	Shal	10/05/2017	9.5	2.94	19.7	0.31	1.14	0.65	37.8
SW1-Shal	River/Stream	Shal	10/05/2017	53.1	158	41.4	0.31	7.5	0.65	222
SW6-Shal	Discharge	Shal	10/05/2017	55.5	248	52	0.31	7.78	0.65	164
SW9-Shal	River/Stream	Shal	10/05/2017	48.8	190	43.6	0.31	7.57	0.65	223
SW12-Shal	Drainage	Shal	10/05/2017	72	5.43	1.45	0.31	0.22	0.65	0.65
DS-Shal	River/Stream	Shal	10/05/2017	30.2	55.5	71.1	0.31	7.15	0.65	1430
US-Shal	River/Stream	Shal	10/05/2017	9.5	2.02	134	1.34	13	0.65	4060
SW10-GAR	Discharge	Gar	05/05/2017	9.5	2.71	126	0.31	9.67	0.65	2260
SW12-GAR	Drainage	Gar	05/05/2017	9.5	4.28	664	0.31	34.3	0.65	9870
SW3-GAR	River/Stream	Gar	05/05/2017	9.5	1.27	136	0.31	5.64	0.65	1370
SW5-GAR	Discharge	Gar	05/05/2017	**3610**	9.72	1130	0.87	338	0.65	60900
SW7-GAR	Drainage	Gar	05/05/2017	9.5	0.442	23.7	0.31	1.79	0.65	314
SW1-SM	River/Stream	Bg	04/05/2017	9.5	0.233	7.16	0.31	0.22	0.65	3.56
SW2-SM-SOUTH	Discharge	Bg	04/05/2017	9.5	1.31	0.847	1.55	5.36	0.65	1870
SW3-SM	River/Stream	Bg	04/05/2017	9.5	2	4.03	0.31	0.921	0.65	141
SW4-SM-GA	River/Stream	Bg	04/05/2017	9.5	2.6	11.1	0.31	1.71	0.65	431
SW5-SM	River/Stream	Bg	04/05/2017	9.5	1.49	8.55	0.31	2.21	0.65	675
SW6-SM	River/Stream	Bg	04/05/2017	9.5	2.6	15.6	0.31	1.85	0.65	514
DS-GORTEENADIHA	River/Stream	Gtd	10/05/2017	77.6	12.6	63.4	0.31	1.89	0.65	166

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

- Not analysed or no assessment criteria

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

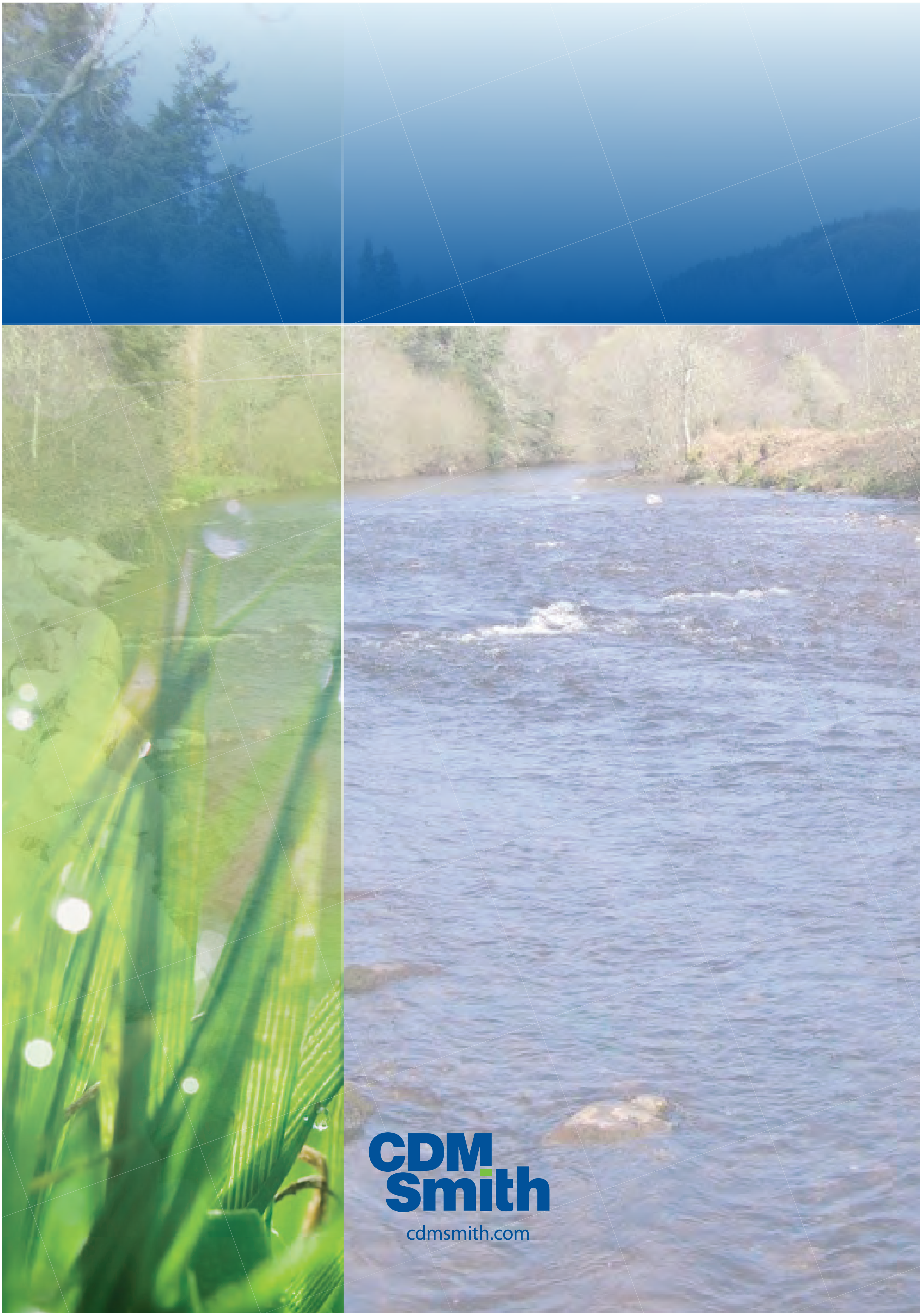
Table B-2 Comparison of Surface Water Results to Assessment Criteria for Livestock Drinking Water R9

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	08/05/2017	53.5	59.1	0.664	0.165	0.6	0.075	0.884	1.2	0.65	45.1
SW10-GORT-DISCHARGE	Discharge	GM	09/05/2017	1380	12.6	1.59	0.04	0.6	0.075	0.425	0.05	0.65	790
SW10-GORT-DS	River/Stream	GM	09/05/2017	46.1	15.5	0.69	0.04	0.6	0.075	0.425	0.53	0.65	43
SW10-GORT-US	River/Stream	GM	09/05/2017	42.7	1	0.708	0.04	0.6	0.075	0.425	0.476	0.65	41.1
SW12-GORT-DISCHARGE	Discharge	GM	09/05/2017	770	1	1.2	0.141	0.6	0.174	0.425	0.05	0.65	229
SW12-GORT-DS	River/Stream	GM	09/05/2017	62.7	1	0.71	0.266	0.6	0.075	0.853	1.54	0.65	101
SW14-GORT	River/Stream	GM	09/05/2017	52.8	6.05	0.622	0.241	0.6	0.075	0.425	1.4	0.65	81.1
SW17-GORT	River/Stream	GM	08/05/2017	11.6	3.54	1.08	0.04	0.6	0.075	0.425	0.05	0.65	0.65
SW6-MAG	River/Stream	GM	05/05/2017	225	28.8	0.255	1.52	0.6	0.075	3.57	0.173	0.65	665
DS-Shal	River/Stream	Shal	10/05/2017	107	7.67	0.634	4.36	0.6	0.553	4.68	55.5	0.65	1430
SW12-Shal	Drainage	Shal	10/05/2017	1	32.3	0.255	0.04	0.6	0.075	1.05	5.43	0.65	0.65
SW13-Shal	Drainage	Shal	10/05/2017	98.2	346	0.744	0.25	0.6	0.075	1.27	2.94	0.65	37.8
SW1-Shal	River/Stream	Shal	10/05/2017	15.1	120	0.579	1.13	1.22	1.05	8.26	158	0.65	222
SW6-Shal	Discharge	Shal	10/05/2017	11.6	94.8	0.792	0.968	0.6	1.33	13.2	248	0.65	164
SW9-Shal	River/Stream	Shal	10/05/2017	14	43.6	0.761	1.07	0.6	1.1	9.68	190	0.65	223
US-Shal	River/Stream	Shal	10/05/2017	299	1	0.684	12.2	0.6	0.433	2.18	2.02	0.65	4060
SW10-GAR	Discharge	Gar	05/05/2017	380	38	1.01	15.2	0.6	0.884	2.68	2.71	0.65	2260
SW12-GAR	Drainage	Gar	05/05/2017	792	1	1.09	20.2	0.6	1.4	3.1	4.28	0.65	9870
SW3-GAR	River/Stream	Gar	05/05/2017	279	7.8	0.701	8.44	0.6	0.599	2.34	1.27	0.65	1370
SW5-GAR	Discharge	Gar	05/05/2017	1910	8.62	3.41	19.3	0.6	8.13	0.946	9.72	0.65	60900
SW7-GAR	Drainage	Gar	05/05/2017	169	15.4	0.531	1.09	0.6	0.075	0.425	0.442	0.65	314
SW1-SM	River/Stream	Bg	04/05/2017	7.5	5.64	0.255	0.04	0.6	0.075	0.425	0.233	0.65	3.56
SW2-SM-SOUTH	Discharge	Bg	04/05/2017	27.9	1	0.255	5.06	0.6	0.075	0.425	1.31	0.65	1870
SW3-SM	River/Stream	Bg	04/05/2017	8.2	26.7	0.255	0.391	0.6	0.075	0.425	2	0.65	141
SW4-SM-GA	River/Stream	Bg	04/05/2017	19.4	36.1	0.255	0.779	0.6	0.075	0.858	2.6	0.65	431
SW5-SM	River/Stream	Bg	04/05/2017	29.1	1	0.255	1.64	0.6	0.075	1.54	1.49	0.65	675
SW6-SM	River/Stream	Bg	04/05/2017	20.9	50.6	0.255	1.17	0.6	0.075	1.79	2.6	0.65	514
DS-GORTEENADIHA	River/Stream	Gtd	10/05/2017	18.2	20.2	0.85	0.923	0.6	0.272	7.35	12.6	0.65	166

GTD - Gorteenadiha

xx Exceeds Livestock Assessment Criteria

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



CDM Smith

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