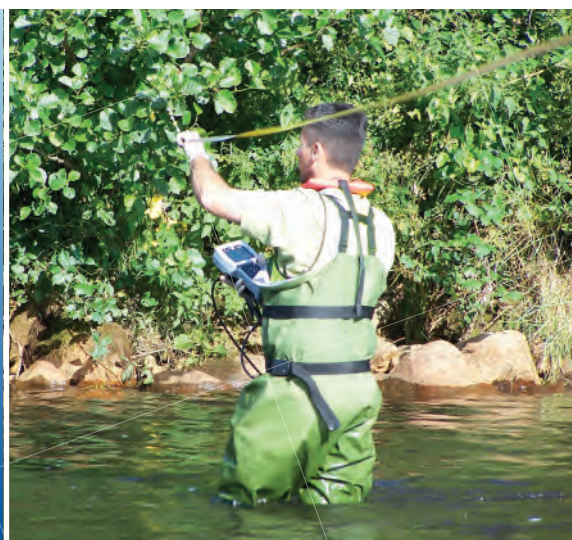


Department of Communications,
Energy & Natural Resources



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

**Avoca Monitoring Report
- Round 1 (2016)**

Final



**CDM
Smith**



Document Control Sheet

Client		Department of Communications, Energy and Natural Resources		
Project		Environmental Monitoring of Former Mining Areas of Silvermines and Avoca		
Project No		95735		
Report		Monitoring Report for the Former Mining Area of Avoca – February 2016		
Document Reference:		95735/40/DG/27		
Version	Author	Checked	Reviewed	Date
1	P Barrett	R O'Carroll	R L Olsen	June 2016

Distribution	Copy No.

Table of Contents

Section 1	Introduction	1
1.1	Objectives and Scope	1
1.2	Background of Avoca Mining Area	1
1.3	Catchment Description	1
1.4	Geology and Hydrogeology	2
1.4.1	Geology.....	2
1.4.2	Hydrogeology	2
1.5	Description of Adit Discharges.....	3
Section 2	Methodology	5
2.1	Field Sampling Methods	5
2.1.1	Groundwater Sampling	5
2.1.2	Surface Water Sampling	6
2.1.3	Field QA/QC Samples.....	7
2.2	Sample Handling	8
2.3	Laboratory Sample Analysis.....	8
Section 3	Data Quality and Usability Evaluation	10
3.1	Introduction	10
3.1.1	Accuracy	10
3.1.2	Precision	10
3.1.3	Blanks	11
3.1.4	Field QA/QC Samples.....	11
3.2	Results of Field QA/QC Samples	12
3.2.1	Duplicates	12
3.2.2	Decontamination Blanks	12
3.2.3	Standard Reference Material	13
3.3	Laboratory QA/QC Samples	14
3.3.1	ALcontrol	14
3.4	Summary of Data Checks	15
3.4.1	Field Physico-chemical Versus Laboratory Data	15
Section 4	Results and Evaluations.....	17
4.1	Statistical Summary of Analytical Results	17
4.1.1	Surface Water Sample Results	17
4.2	Assessment Criteria	18
4.2.1	Groundwater and Surface Water Assessment Criteria	18
4.3	Comparison to Assessment Criteria.....	21
4.3.1	Surface Water Assessment.....	21
Section 5	Flows, Loads and Trend Analysis	24
5.1	Surface Water Flows.....	24
5.2	Loading Analysis	26
5.2.1	Loading Analysis Methodology.....	26
5.2.2	Loading Results and Discussion	26
Section 6	Groundwater Levels and Groundwater-Surface Water Interaction	35
6.1	Groundwater Levels.....	35
6.2	Surface Water Levels	37
6.3	Groundwater-Surface Water Interaction	37

6.4	Summary of Diffuse Loading	42
6.5	Surface Water Flow Data at the EPA Gauging Stations	42
Section 7	Summary and Recommendations.....	44
7.1	Summary of Findings	44
7.2	Recommendations for the Monitoring Programme.....	45
Section 8	References.....	46

Appendices

Appendix A Figures

Appendix B Analytical Data Tables and Assessment Criteria

List of Tables

Table 1	Location of Avoca Groundwater Monitoring Points in February 2016	5
Table 2	Location of Surface Water Monitoring Points	6
Table 3	Field QA/ QC Sample IDs and Descriptions	8
Table 4	Duplicate Pair Reported Values (µg/l) and Calculated % RPD	12
Table 5	Water Blank and Decontamination Blank Reported Values and Laboratory Method Blanks (µg/l)	13
Table 6	SRM Reported Values (µg/l) and Calculated % R	14
Table 7	Field physico-chemical data and Laboratory Reported Values and Calculated % RPD	16
Table 8	Summary of Dissolved Metal Concentrations in the Adit Discharges	17
Table 9	Summary of Dissolved Metal Concentrations in Surface Water	18
Table 10	Surface Water and Groundwater Assessment Criteria for Biological Elements	20
Table 11	Surface Water and Groundwater Assessment Criteria for Drinking Water	21
Table 12	Summary of Reported Values for the Avoca River and the Surface Water Assessment Criteria	23
Table 13	Surface Water Flow Value Measured in February 2016	26
Table 14	Summary of Measured Flows and Concentrations and Calculated Loads of Sulphate and Dissolved Metals in kg/day in the Adits and Avoca River	27
Table 15	Reporting the Mann-Kendall Results	32
Table 16	Mann-Kendall Trend Analysis of data for Deep Adit, Road Adit and Avoca Bridge	32
Table 17	Seasonal Variation of Concentrations and Calculated Loads of Dissolved Metals in the Adits and at Avoca Bridge from 2013-2016.....	33
Table 18	Measured Groundwater Levels and Calculated Elevation February 2016.....	35
Table 19	Calculated Groundwater Gradients for February 2016	38

List of Figures

Figure 1 Location of the Deep Adit Confluence Discharge (February 2016).....	4
Figure 2 Mean Daily Flow (m^3/s) at Whites Bridge (Station 10044) from 1 Sept 2015 to 27 Feb 2016.....	24
Figure 3 Mean Daily Flow (m^3/s) at Wicklow County Council Maintenance Yard (Station 10045) from 1 Sept 2015 to 10 Feb 2016	25
Figure 4 Calculated Loads (kg/day) of Dissolved Metals in the Avoca River in February 2016.....	29
Figure 5 Concentration trends for dissolved copper, zinc and iron within the Deep Adit Discharge (Oct 2001 to Feb 2016).....	30
Figure 6 Concentration trends for dissolved copper, zinc and iron within the Road Adit Discharge (Oct 2001 to Feb 2016).....	31
Figure 7 Concentration trends for dissolved copper and zinc at Avoca Bridge compared with the environmental quality objective (EQS) (Oct 2001 to Feb 2016)	31
Figure 8 Groundwater Elevations in the Avoca Mining Area from 12 Aug 2015 to 15 Feb 2016	36
Figure 9 Groundwater Elevation at Shelton Abbey from 12 Aug 2015 to 15 Feb 2016.....	36
Figure 10 Elevation of the Avoca River at GS 10044 and GS 10045 at the Deep Adit Area from 12 Aug 2015 to 15 Feb 2016	37
Figure 11 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044) at the Deep Adit Area from 12 Aug 2015 to 16 Feb 2016	40
Figure 12 Calculated Groundwater Gradient to the Avoca River at the Deep Adit Area from 12 Aug 2015 to 16 Feb 2016	40
Figure 13 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044 & 10045) at the Emergency Tailings Area from 12 August 2015 to 16 February 2016	41
Figure 14 Calculated Groundwater Gradient to the Avoca River at the Emergency Tailings Area from 12 August 2015 to 16 February 2016	41

Section 1

Introduction

1.1 Objectives and Scope

The Department of Communications, Energy and Natural Resources (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 Avoca Mining Area presents an evaluation of the results of the field investigations carried out in February 2016. This report should be read alongside the Avoca Data Report (Document Ref: 95735/40/DG/26, issued March 2016) which contains all field observations and laboratory analytical results collected during the monitoring programme.

1.2 Background of Avoca Mining Area

The Avoca mining area is located in the eastern foothills of the Wicklow Mountains, some 55 kilometres south of Dublin. The site includes the East and West Avoca mining areas and the Shelton Abbey Tailings Management Facility (TMF) which is located approximately 8 km to the south. The Avoca River divides the East and West Avoca mine sites and runs along the base of TMF.

The Avoca Mine site was worked intermittently for approximately 250 years with the extraction of 16 Mt of copper and pyrite ore and on-site processing of concentrates. The mine went into receivership and closed in 1982. Mineral extraction left an environmental legacy that comprises three open pits, over 70 shafts and adits, numerous spoil piles and 25 mine buildings/structures. A number of spoil piles which have elevated metal levels and some pit high walls are physically unstable with the potential to collapse. In addition, unstable ground is present which has the potential for subsidence. Seeps and the water discharges from adits are acidic and metal laden. These discharges impact water quality in the Avoca River.

1.3 Catchment Description

The Avoca Mines are located within the Avoca River Catchment which includes an area of 650 km². The East and West Avoca Mines are separated by the Avoca River, which flows through the Vale of Avoca, a noted tourist attraction. To the north of the mines, the Avoca River is formed at the Meeting of the Waters by the confluence of the Avonbeg and Avonmore Rivers, while 6.5 km to the south, it is joined by the Aughrim River and flows an additional 7.5 km to the sea at the fishing

port of Arklow. Several smaller tributaries join the Avoca River close to the mine water discharges, including Sulphur Brook to the south of East Avoca Mines, and the Vale View and Red Road streams to the north and south respectively of West Avoca Mines.

1.4 Geology and Hydrogeology

1.4.1 Geology

The mineralised zone at Avoca is hosted in the Ordovician Avoca Formation that consists of tuffs (consolidated volcanic ash) and felsites (volcanic or extrusive igneous rocks) interbedded with slaty mudstones. The rocks trend northeast/southwest and are generally steeply-dipping to the southeast. Tight folds a few hundred metres wide are also present. The main ore zones, from which copper and pyrite (FeS_2) were extracted, occur as generally stratiform lenses up to a few tens of metres thick at the top of a sequence of tuffs and felsites.

Numerous shear zones exist and a series of north-south trending faults, one of which (the Great Fault) runs close to the Avoca River and displaces the western orebodies southward relative to the eastern ones.

There are three main ore types:

- Banded sulphides with more than 95% pyrite (FeS_2) accompanied by chalcopyrite (CuFeS_2), sphalerite (ZnS), and galena (PbS);
- Vein or disseminated ore invariably associated with silicification and containing pyrite and chalcopyrite; and
- Lead-zinc ore (galena and sphalerite) with banded pyrite.

All three ore types have minor quantities of arsenic and bismuth minerals.

The uppermost 30 to 60 m of the deposits have been oxidised. The most important minerals include iron oxides, chalcocite (Cu_2S) and covellite (CuS) together with various copper and iron oxides.

1.4.2 Hydrogeology

The bedrock is overlain by subsoils derived from glacial till and weathering of bedrock. Subsoils are thin (<2 metres) or absent on hilltops and thicker (>2 metres) along valley floors. The Avoca River valley itself comprises a thick (10-30 metres) sequence of coarse-grained alluvial sediments.

In terms of groundwater yield, the GSI classifies the bedrock in the Avoca mines area as poorly productive: PI - Poor aquifer, generally unproductive except for local zones and Pu - Poor aquifer, generally unproductive.

Overall water movement consists of three primary pathways:

- Surface runoff (overland flow). Within the mines area, surface drainage is influenced by the spoil piles and open pits on both sides of the river. The open pits collect rainwater (directly) and runoff (indirectly);
- Interflow or transition zone (flow in subsoils and/or along the top of bedrock). Near the Avoca River, interflow will enter the alluvium and the Avoca River or emerge as seeps or

springs. The transition zone may be only a few metres thick, and is regarded as being more permeable or transmissive than deeper bedrock; and

- "Deep" groundwater flow at Avoca occurs in discrete fractures or fracture zones which represent zones of enhanced permeability. Deep groundwater will also be captured by underground mine workings in the mine area. Near the Avoca River, deep groundwater will also enter the alluvium.

1.5 Description of Adit Discharges

Map 1 in [Appendix A](#) shows the adits with active discharge that were sampled and are described in this section.

The **Cronebane Intermediate Adit** (also known as Fathom Stope 43) flows from an opening in the southeast wall of the East Avoca Pit and across the bottom of the pit forming a lake on the southwest end.

The **Cronebane Shallow Adit** discharges on the side of a hill southeast of the East Avoca Pit. The adit is believed to drain the unsaturated workings in the Cronebane and Connary areas. The discharge follows a ferricrete-lined channel which feeds into a culvert and passes under the road. Shortly after passing under the road, the discharge soaks into the ground in a low wooded area (just north of the yellow access gate).

The **Deep Adit** is located northeast of Whites Bridge and is the main mine drainage for East Avoca. The water flows from the portal into a ditch that runs semi-parallel to the Avoca River before discharging into the river. A box culvert was installed at the entrance of the Deep Adit in October 2014 as part of the Avoca Works project. The hydro-morphology of the Deep Adit channel has changed on several occasions in the period 2014-2015 with the full or partial Deep Adit flow being diverted through the Millrace at different times. In February 2016, the deep adit flow was discharging to the Avoca River at its normal discharge point. This was due to completed groundworks which was preventing the flow from being diverted to the Millrace channel. Figure 1 illustrates the changing hydro-morphology of the Deep Adit and Millrace area.

The **850 Adit** is also located northeast of Whites Bridge. In 2009 a significant volume of water was observed issuing from the adit for the first time since more routine investigations began in 2007. This was investigated on behalf of the Department by GWP Consultants who concluded that the water flow is most likely to be due to a collapse inside the mine, diverting water from the Deep Adit to higher levels. The flow from 850 Adit passes through a culvert (the "northwest culvert") under the railway embankment and then joins the Deep Adit discharge channel. Since the initial discharge in 2009, flow has been intermittently observed from the 850 Adit and it was added to the sampling programme in February 2014.

In October 2014, an initial survey of the 850 Adit was completed. Water was found to be backed up approximately 1m above ground level behind an earth berm and the adit drained for approximately two days before a survey of the adit could be attempted. When the survey was completed, a drainage pipe was installed and earth berm replaced to prevent access to the 850 Adit.

In January 2016, a structural survey of the entrance of the 850 Adit was completed. It was found that water had again backed up in the adit due to the drainage pipe being too small to handle the

drainage. Larger drainage pipes were installed and the earth berm was replaced. In February 2016, a significant flow was observed with all blockages removed.

The **Road Adit** is located adjacent to Rathdrum Road at the base of the Ballymurtagh landfill (formerly the Pond Lode Pit). Previously the Road Adit discharge ran alongside a ditch beside the road and then discharged to the Avoca River just downstream of the Wicklow County Council Yard Gauging Station. Since about October 2014, the Road Adit no longer flows along the road and instead goes through a pipe underneath the yard and discharges directly into the Avoca River above the Wicklow County Council Gauging Station.

The **Spa Adit** is located in West Avoca on a hillside approximately 150 m northwest of (and approximately 40 m above) the Wicklow County Council recycling centre. The flow discharges from a break in a pipe which was observed soaking into the ground. As the loads are very low and the discharge does not flow into the Avoca or one of the tributaries within the basin, the importance of the Spa Adit is relatively low and was not sampled in February 2016.

The **Ballygahan Adit** discharges through a 100 mm (4 inch) pipe to the Avoca River over a steep bank just north of the Wicklow County Council Maintenance Yard. There are also some seeps from the river bank probably due to the pipe leaking or flow in the adit not captured by the pipe. No visible discharge was issuing from the pipe or seeps in February 2016.

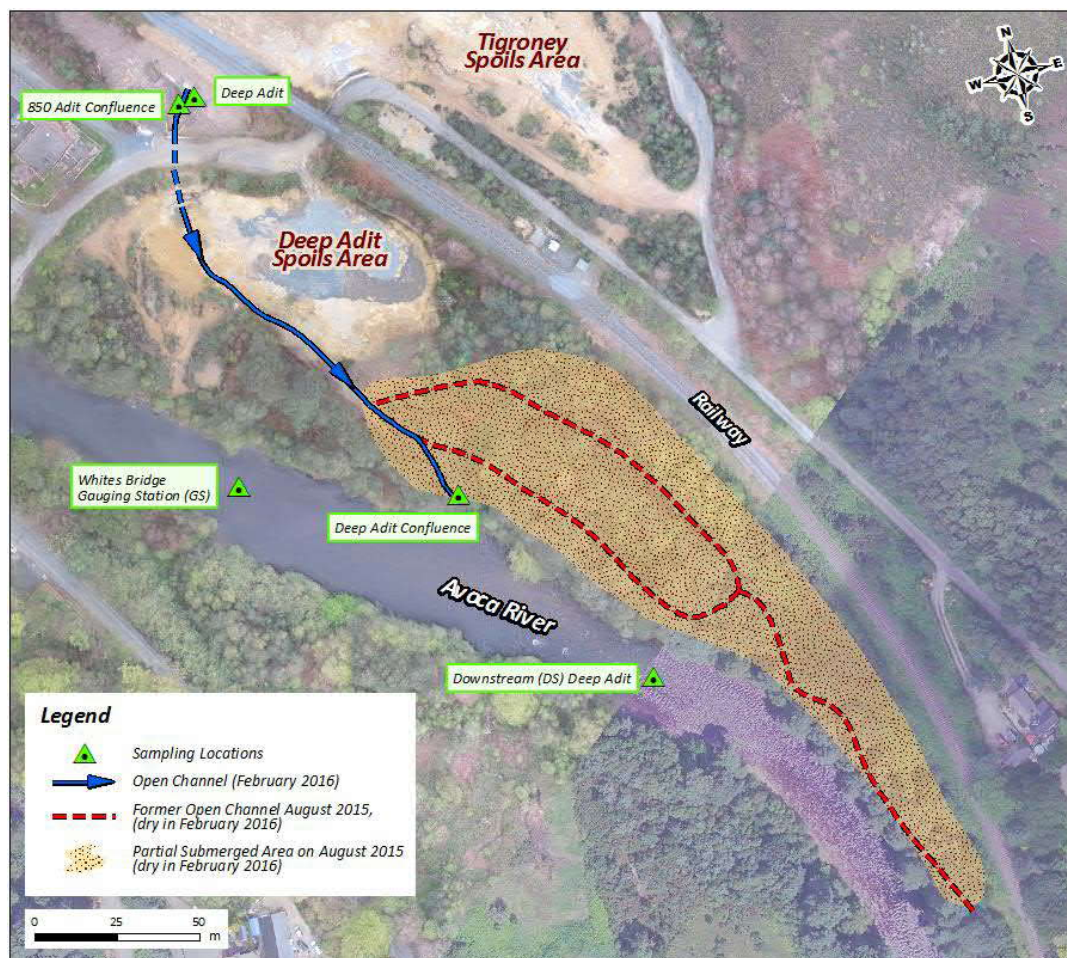


Figure 1 Location of the Deep Adit Confluence Discharge (February 2016)

Section 2

Methodology

2.1 Field Sampling Methods

2.1.1 Groundwater Sampling

No groundwater sampling was undertaken in February 2016. Groundwater levels were measured at the nine wells on 16 and 28 February using a portable electronic water level recorder. Automatic groundwater recorders have been placed in six wells and the data were downloaded. Groundwater level data are discussed in Section 6, shown on Map 2 and 3 in [Appendix A](#) and the data are contained in Appendix C of the Data Report.

Monitoring wells were installed in the alluvium in 2007 as part of the previous study for the Department (CDM, 2008) including:

- Two nested wells in the Emergency Tailings area, downgradient of the West Avoca pit and slightly side-gradient of the Ballymurtagh Landfill (MWET1, shallow, and MWET2, deep);
- Two nested wells in the Tigroney West spoil area near the Deep Adit (MWDA1, shallow, and MWDA2, deep);
- One shallow well upgradient of the Deep Adit area, near the eastern margin of the alluvial sediments (MWPF1); and
- One shallow well immediately adjacent to and downgradient of the tailings dam at Shelton Abbey (MWSA2).
- R3-04 is located on the Tigroney West spoils and was installed in October 2014 as part of the Avoca Works project.

There are also three Wicklow County Council monitoring wells installed for Ballymurtagh Landfill monitoring purposes (GW1/05, GW2/05 and SG104) and are located downgradient of the landfill (in West Avoca) and one located at the toe of the landfill (SG104).

Table 1 Location of Avoca Groundwater Monitoring Points in February 2016

Borehole Identifier	Easting	Northing	Water Level	Field Parameters	Sample for Lab Analysis	Owner	Depth (m bgl)	Screen Interval (m bgl)
MWDA1	319877	182043	Yes	No	No	Dept	12	9.0 – 12
MWDA2	319879	182039	Yes	No	No	Dept	24.9	21.9 – 24.9
MWET1	319916	181778	Yes	No	No	Dept	10.9	7.8 – 10.6
MWET2	319917	181781	Yes	No	No	Dept	21	17 – 20
MWPF1	319678	182296	Yes	No	No	Dept	10	4.7 – 7.7
MWSA2	321566	175292	Yes	No	No	Dept	12.6	8.0 – 11
GW1/05	319880	181673	Yes	No	No	WCC	31	25.0 – 31
GW2/05	319880	181673	Yes	No	No	WCC	10	4.0 – 10
SG104	319806	181523	Yes	No	No	WCC	26.8	-
R3-04	319879	182171	Yes	No	No	Dept	16.1	-

2.1.2 Surface Water Sampling

Surface water sampling was limited to the primary adits/discharges and two Avoca River locations. Nine surface water locations were sampled between 15 and 16 February 2016, as listed in Table 2 and shown on Map 1 and 2 in [Appendix A](#).

Surface water sampling was conducted consistent with the Surface Water Sampling Procedure (SOP 1-1) as detailed in the Monitoring Plan. No sample could be obtained from Ballygahan Adit because it was not discharging water in February 2016.

The predetermined surface water sampling locations were located in the field using a GPS. Photographs were taken of the surface water sampling locations (Appendix D of the Data Report). The adit discharge sampling locations were approached from downstream so that the underlying sediments are not disturbed. Samples taken on the Avoca River were grab samples collected from a well-mixed portion of the River where possible using a telescopic sampling pole. Note that this is different from the previous round (R6) during low flow in August 2015 because composite samples were collected across the channel so that the samples were representative of the Avoca River at a particular location. This does affect the interpretation of the results because the bank samples collected during high flow are not representative of the loadings in the Avoca River. This is discussed in further detail in section 5.2.2 Loading Results and Discussion.

Samples were placed into new laboratory provided bottles with the correct preservatives. The sample bottles that required no filtering (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.

Table 2 Location of Surface Water Monitoring Points

Site Name	Sample Site Description	Easting	Northing	Flow Measurement Method	Sample collected?
Site T1	Avoca River Location (Upstream of Whites Br.)	319239	182805	Equal to flow recorded at Whites Bridge GS Automatic recorder - 10044 (data from EPA) minus flow from Vale View Trib.	Yes
Avoca Bridge	Avoca River (Upstream of Avoca Bridge)	320372	179932	Float method	Yes
850 Adit	Adit Discharge (at portal)	319919	182161	Flow Meter	Yes
850 Adit Confluence	Adit Discharge (before entering Deep Adit Discharge)	319845	182122	Not required	No
Deep Adit	Adit Discharge (at portal)	319850	182123	Flow Meter	Yes
Deep Adit Confluence	Adit Discharge (before entering Avoca River)	319896	181986	Flow Meter	Yes
Road Adit	Adit Discharge (at portal)	319858	181512	Measured from permanent flume	Yes
Road Adit Confluence	Adit Discharge (before entering Avoca River)	319942	181513	Flow Meter	Yes
Cronebane Intermediate Adit	Adit Discharge	320320	182749	Flume	Yes

Site Name	Sample Site Description	Easting	Northing	Flow Measurement Method	Sample collected?
Cronebane Shallow Adit	Adit Discharge	320268	182646	Flume	Yes
Ballygahan Adit	Adit Discharge	319940	181610	No Flow	No

Water quality indicator parameters were monitored during sampling by collecting them directly from the stream or discharge when possible, using a multi-parameter probe. 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 9 locations (see Table 2) 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. In addition, flow data were obtained from the EPA for two automatic recorders. 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. Methods included using a portable flume (for small discharges), a Marsh McBirney meter (flow meter) to measure flow velocities and depths at regular intervals across the streams by wading and for very small discrete discharges, a stop watch and calibrated volume container were used.

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

Data were obtained from the EPA for the existing automatic recorders at Whites Bridge GS (EPA station 10044) and Wicklow County Council Maintenance Yard (EPA Station 10045).

2.1.3 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 (also see Table 3):

- Surface Water:
 - One duplicate surface water sample; and
 - One decontamination blank was collected by pouring DI water over the surface water sampling equipment after decontamination.
- Two certified standard reference materials containing known concentrations of 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 using DI water 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 sample is an independent check on sampling and laboratory precision. The standard reference material is an independent check on laboratory accuracy. The decontamination blank is 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
AVSD01.7	SW Duplicate	Duplicate of Site T1
AVDB01.7	SW Decontamination blank	DI water (Lennox Lab Supplies: Batch No: TE150727W) poured over SW composite sample bottle after final decon at Site T1
AVSR01.7	Standard Reference Material	Water ERA "Trace Metals" Lot #P246-740A
AVSR02.7	Standard Reference Material	Water ERA "Trace Metals" Lot #P246-740A
WB01.7	Filtration blank	Deionised water filtered onsite (Lennox Lab Suppliers. Batch No: TE150727W)
WB02.7	Water blank	Deionised water (Lennox Lab Suppliers. Batch No: TE150727W)

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 of sample collection. Samples were stored appropriately so they remained representative of the time of sampling. Sufficient ice packs and ice were 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 resealable 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 Laboratory Sample Analysis

Analysis of water samples was undertaken by ALcontrol. Water 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 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 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, decontamination blanks were generated in the field to evaluate the sampling equipment decontamination process. DI water blanks and DI filtration blanks were also analysed. 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: A duplicate surface water sample was created in the field and submitted blind to the laboratory (see Table 3 for sample IDs). The result is used to evaluate the combined reproducibility of both the laboratory analyses and field sampling;
- Decontamination Blanks: After the sampling equipment (surface water) was cleaned, DI water was poured over the sampling equipment and collected for laboratory analysis (see Table 3 for sample IDs). Analyses of this sample was used to evaluate the adequacy of the sampling equipment cleaning or decontamination procedure;
- Standard Reference Material (SRM): Two certified water SRMs were sent blind to the laboratory (Sample IDs AVSR01.7 and AVSR02.7) to evaluate laboratory accuracy. The certified SRM was supplied by ERA Certified Reference Materials and was Lot #P246-740A (Metals). The Certificate of Analysis is provided in Appendix G of the Data Report. The use of a blind or unknown SRM is the only method to independently verify the laboratory accuracy.
- One water blank was collected of the DI water during the sampling event. An additional filtration blank using DI water was collected in order to try to quantify any contamination caused by the filtration procedure.

3.2 Results of Field QA/QC Samples

3.2.1 Duplicates

One duplicate sample (surface water) was generated in the field and sent blind to ALcontrol for analysis. Table 4 provides the results of the 15 metals and the calculated RPD between the original and duplicate sample. 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.

14 out of the 15 RPD values were below 50 % and the RPDs for the key parameters were considered very good; aluminium (2.9 %), copper (0 %), manganese (3.4 %) and zinc (2.4). The % RPD for antimony (63.8 %) exceeded 50 % as highlighted in Table 4 and this result was checked and confirmed with ALcontrol. The highest reported value of the duplicate pair is selected for interpretive use in Section 4 therefore providing a conservative evaluation.

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

Dissolved Metal	LOD (µg/l)	Site T1	AVSD01.7	% RPD
Aluminium	<2.9	60.8	62.6	-2.9
Antimony	<0.16	0.364	0.188	63.8
Arsenic	<0.12	0.319	0.286	10.9
Barium	<0.03	5.25	5.23	0.4
Cadmium	<0.1	<0.1	<0.1	0
Chromium	<0.22	0.291	0.297	-2.0
Cobalt	<0.06	0.129	0.144	-11.0
Copper	<0.85	<0.85	<0.85	0
Iron	<19	37.8	50	-27.8
Lead	<0.02	2.45	2.48	-1.2
Manganese	<0.04	20.4	21.1	-3.4
Molybdenum	<0.24	<0.24	<0.24	0
Nickel	<0.15	0.829	0.839	-1.2
Vanadium	<0.24	<0.24	<0.24	0
Zinc	<0.41	20.4	20.9	-2.4

Notes:

Bold indicates an exceedance in the Duplicate RPD acceptance criteria

3.2.2 Decontamination Blanks

One decontamination blank (AVDB01.7) was created by pouring DI water over the surface water sampling equipment (YSI multi-parameter probe) after decontamination and sent to ALcontrol for analysis. Table 5 provides the results of the 15 metals for the decontamination blank sample, the DI water blank and filtration blank samples and the associated laboratory method blank samples. The majority of reported concentrations were below the limits of detection. Most metals were analysed by ICP-MS to achieve the lowest possible detection limits. The limits of detection ranged from 0.02 to 2.9 µg/l except for iron with a detection limit of 19 µg/l.

Detections were observed for five dissolved metals ranging from 0.027 to 0.645 µg/l. The five metals detected in the decontamination blank (antimony, barium, lead, manganese and zinc) were also detected in the DI water blank. Furthermore, the levels of detections in the decontamination blank were similar to those found in the DI water blank. A relatively low concentration of dissolved chromium (0.435 µg/l) was also found in the DI water blank but not the decontamination blank.

None of the parameters which were detected in the decontamination blank were greater than ten times the detection limit. All of the detections were significantly less than the assessment criteria outlined in Section 4; therefore, these low concentrations in the blanks do not affect the interpretation of results. To assess the level of cross contamination between samples in the field, the concentrations in the decontamination blank were compared with the concentrations in the preceding environmental sample. As a percentage of the preceding sample, antimony was 77.7%, barium was 0.8%, lead was 1.1%, manganese was 0.5 % and zinc was 3.2%. Antimony was detected in the DI Water Blank and therefore these findings are not considered to affect the integrity of the overall results.

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 antimony was detected in the method blank (1.13 µg/l) and the decontamination blank sample (0.283 µg/l).

Overall, the decontamination blank samples do not indicate any cross-contamination in the field and the detections were significantly less than the assessment criteria outlined in Section 4 and therefore all the results are considered acceptable and can be used for their intended purposes.

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

Dissolved Metal	LOD (µg/l)	Filtration Blank WB01.7 (µg/l)	Water Blank WB02.7 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank AVDB01.7 (µg/l)	Laboratory Method Blank (µg/l)
<i>Sample batch:</i>		160213-77			160218-99	
Aluminium	<2.9	<2.9	<2.9	<2.9	<2.9	<2.9
Antimony	<0.16	0.189	0.161	0.66	0.283	1.13
Arsenic	<0.12	<0.12	<0.12	<0.12	<0.12	0.19
Barium	<0.03	<0.03	0.05	<0.03	0.041	<0.03
Cadmium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium	<0.22	<0.22	0.435	<0.22	<0.22	<0.220
Cobalt	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Copper	<0.85	<0.85	<0.85	<0.85	<0.85	<0.850
Iron	<19	<19	<19	<19	<19	<0.019
Lead	<0.02	<0.02	0.031	<0.02	0.027	<0.02
Manganese	<0.04	0.056	0.144	<0.04	0.103	<0.04
Molybdenum	<0.24	<0.24	<0.24	0.96	<0.24	0.79
Nickel	<0.15	<0.15	<0.15	<0.15	<0.15	<0.150
Vanadium	<0.24	<0.24	<0.24	<0.24	<0.24	<0.240
Zinc	<0.41	1.21	0.84	<0.41	0.645	<0.410

Notes:

Bold indicates a detection

Bold and italics indicates a detection of a parameter also detected in the laboratory method blank.

Italics indicates a detection 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 Material

As previously discussed, two certified water SRMs were sent blind to the laboratory (Sample IDs AVSR01.7 and AVSR02.7) 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 the majority of the metals were within the acceptable ranges. Dissolved aluminium, arsenic, barium, chromium, cobalt, copper, lead, manganese, vanadium and zinc are in excellent agreement with the certified value (%R ranged from 92 to 107 %).

One of the reported values for dissolved cadmium (114 %), iron (84 %), molybdenum (86 %) and nickel (89 %) were outside the acceptable range, however the corresponding reported values for the second SRM sample were within acceptable ranges and therefore the interpretation of the results are not affected. Both of the reported values for dissolved antimony were low at 85 % and 86 % respectively which fall outside of the acceptable range. This indicates that there may be bias (low) in the results for antimony and any use of these values should be noted with this observation.

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

Dissolved Metal	Certified Value (µg/l)	Acceptance Limits		AVSR01.7 (µg/l)	% R	AVSR02.7 (µg/l)	% R
		Lower (%)	Upper (%)				
Aluminium	1290	88	114	1250	97	1360	105
Antimony	484	87	111	410	85	415	86
Arsenic	814	87	111	751	92	809	99
Barium	1690	91	109	1630	96	1640	97
Cadmium	519	89	106	481	93	591	114
Chromium	548	91	109	540	99	563	103
Cobalt	422	93	111	430	102	453	107
Copper	371	91	109	364	98	373	101
Iron	1870	90	111	1570	84	1750	94
Lead	1180	90	110	1100	93	1110	94
Manganese	806	92	109	797	99	843	105
Molybdenum	306	90	109	288	94	263	86
Nickel	1680	91	109	1490	89	1610	96
Vanadium	500	91	107	493	99	518	104
Zinc	1430	91	110	1410	99	1430	100

Notes:

Bold indicates an exceedance in acceptance limits

3.3 Laboratory QA/QC Samples

3.3.1 ALcontrol

ALcontrol undertakes 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 collected through the entire analytical system;
- Instrumental 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 separately sourced standard to 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 AQC.

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 was exceeded. ALcontrol provided the associated analytical quality control samples (AQC) data. The percentage recovery results for the AQC samples that were analysed with the regular environmental samples were checked against the individual lower control and upper control limits. All AQC samples analysed with the environmental samples were within these upper and lower control limits. In addition, several environmental samples were re-analysed to verify the results. 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 16.9%. The exception was Avoca Bridge where the RPD was 55.6% between the field (3.95) and laboratory (6.99) reading which is likely due to the unstable reading obtained in the field. The pH laboratory result was checked and confirmed with ALcontrol. With the exception of Avoca Bridge, field pH is more representative of actual conditions and is used for interpretive purposes. 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 Field	% RPD
850 Adit	3.07	3.11	-1.3
Cronebane Inter. Adit	3.11	3.14	-1.0
Cronebane Shallow Adit	2.86	2.97	-3.8
Deep Adit	3.53	3.58	-1.4
Deep Adit Confluence	3.12	3.21	-2.8
Road Adit	4.2	4.36	-3.7
Road Adit Confluence	4.21	4.39	-4.2
Avoca Bridge*	6.99	3.95	55.6
Site T1	7.3	6.16	16.9

Notes:

Bold indicates an exceedance in acceptance limits

*pH value had trouble stabilising in the field

Section 4

Results and Evaluations

This section provides a statistical summary of the analytical results and a comparison 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 Surface Water Sample Results

Surface water samples were collected for two major categories: the first includes mine adit discharges and the second includes the Avoca River. Table 8 provides a summary of the reported results of the 7 adit discharge samples and Table 9 provides a summary of the dissolved metals of the 2 river samples. Included in the tables are the minimum, maximum, mean and standard deviation (SDEV). 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.

Adit Discharges

Table 8 Summary of Dissolved Metal Concentrations in the Adit Discharges

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2.9	7	7	12,200	261,000	84,700	83,900
Antimony	<0.16	7	5	0.08	7.13	2.35	2.54
Arsenic	<0.12	7	4	0.06	35.4	6.94	12.9
Barium	<0.03	7	7	4.92	16.1	9.40	4.81
Cadmium	<0.1	7	7	16.5	253	85.6	81.4
Chromium	<0.22	7	4	0.11	7.73	2.07	2.56
Cobalt	<0.06	7	7	75.7	198	99.3	43.9
Copper	<0.85	7	7	350	11,300	4,560	4,320
Iron	<19	7	7	35,300	108,000	68,900	22,600
Lead	<0.02	7	7	305	1,390	787	387
Manganese	<0.04	7	7	2,180	8,100	4,900	2,640
Molybdenum	<0.24	7	3	0.12	7.85	1.94	2.77
Nickel	<0.15	7	7	30.7	110	49.8	27.5
Vanadium	<0.24	7	2	0.12	1.04 (1.2*)	0.89	0.49
Zinc	<0.41	7	7	8,340	79,300	36,500	25,400

Notes:

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

* LOD was raised due to a dilution that was carried out on the sample. Where there were detections the maximum reported value was presented as the maximum value.

Dissolved aluminium, copper, iron, manganese and zinc were found in significantly high concentrations in all of the adit discharges. The Cronebane Shallow Adit had the highest concentrations of dissolved metals including aluminium (261,000 µg/l), copper (11,300 µg/l) iron

(108,000 µg/l) and zinc (79,300 µg/l). The Road Adit Confluence had the highest concentration of manganese (8,100 µg/l). The lowest concentration for the key dissolved metals were recorded at the following locations: aluminium (Road Adit), copper (Deep Adit), iron (850 Adit), manganese (Cronebane Inter. Adit) and zinc (Road Adit Confluence).

Avoca River

Table 9 Summary of Dissolved Metal Concentrations in Surface Water

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)
Aluminium	<2.9	2	2	60.8	154	107
Antimony	<0.16	2	2	0.36	0.43	0.40
Arsenic	<0.12	2	2	0.32	0.32	0.32
Barium	<0.03	2	2	4.76	5.25	5.01
Cadmium	<0.1	2	1	0.05	0.42	0.23
Chromium	<0.22	2	2	0.29	0.34	0.32
Cobalt	<0.06	2	2	0.13	0.64	0.38
Copper	<0.85	2	1	0.43	13	6.71
Iron	<19	2	2	37.8	230	134
Lead	<0.02	2	2	2.45	3.21	2.83
Manganese	<0.04	2	2	20.4	50.1	35.3
Molybdenum	<0.24	2	0	0.12	0.12	0.12
Nickel	<0.15	2	2	0.83	0.97	0.90
Vanadium	<0.24	2	0	0.12	0.12	0.12
Zinc	<0.41	2	2	20.4	122	71.2

Notes:

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

Dissolved metals were detected upstream of the main mining area at Site T1 with concentrations of aluminium at 60.8 µg/l, iron at 37.8 µg/l, manganese at 20.4 µg/l and zinc at 20.4 µg/l. A significant increase in dissolved metals was recorded downstream of the mining areas (Avoca Bridge) with concentrations of aluminium at 154 µg/l, copper at 13 µg/l, iron at 230 µg/l, manganese at 50.1 µg/l and zinc at 122 µg/l.

These findings are discussed further in Section 5 which provides an analysis of dissolved metal loadings.

4.2 Assessment Criteria

4.2.1 Groundwater and Surface Water Assessment Criteria

No groundwater sampling was undertaken in February 2016. However, for completeness the assessment criteria discussed in section 4.2.1 relates to both surface water and groundwater.

To assess the analytical results of groundwater and surface water samples, assessment criteria have been selected to screen reported values for 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 10. These include standards for physico-chemical conditions supporting the biological elements general conditions and standards for specific pollutants. In the case of metals, the EQS refers to the dissolved concentration. Compliance with the standards in

the surface water regulations is either based on an annual average (AA), a maximum allowable concentration (MAC) or a 95 percentile standard. The MAC or 95 percentile (95%-ile) was selected where possible as the assessment criteria because it is the most appropriate for assessment of one value; however, the AA was used in the absence of the MAC or 95%-ile. To supplement the Irish legislation, screening criteria were selected from Oak Ridge National Laboratory (Suter and Tsao, 1996) for certain metals including aluminium, barium, cobalt, manganese and uranium (Table 10).

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 Avoca mining area was determined to be 31 mg/l CaCO₃ (CDM, 2008) and the appropriate ecological assessment criteria are highlighted in bold in Table 10.

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 11. These values are the maximum permissible values for a drinking water source. In the case of metals the standards are for total metals. However, they apply post treatment (including filtration) and therefore the dissolved portion is used in the assessment in Section 4.

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

The two main receptors to groundwater in the Avoca mining area 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 discussed for surface water can be utilised for screening purposes for groundwater (Table 10 and Table 11).

Table 10 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. Only relevant to surface water
Arsenic	µg/l	25	-	S.I. No. 272 of 2009	
Cadmium	µg/l	≤0.08 (Class 1) 0.08 (Class 2) 0.09 (Class 3) 0.15 (Class 4) 0.25 (Class 5)	≤ 0.45 (Class 1) 0.45 (Class 2) 0.6 (Class 3) 0.9 (Class 4) 1.5 (Class 5)	S.I. No. 327 of 2012	Hardness measured in mg/l CaCO ₃ (Class 1: <40 mg CaCO ₃ /l, Class 2: 40 to <50 mg CaCO ₃ /l, Class 3: 50 to <100 mg CaCO ₃ /l, Class 4: 100 to <200 mg CaCO ₃ /l and Class 5: ≥200 mg CaCO ₃ /l)
Chromium	µg/l	3.4	-	S.I. No. 272 of 2009	
Copper	µg/l	5 or 30	-	S.I. No. 272 of 2009	5 µg/l applies where the water hardness measured in mg/l CaCO ₃ is ≤ 100; 30 µg/l applies where the water hardness > 100 mg/l CaCO ₃ .
Lead	µg/l	7.2	-	S.I. No. 327 of 2012	
Nickel	µg/l	20	-	S.I. No. 327 of 2012	
Zinc	µg/l	8 or 50 or 100	-	S.I. No. 272 of 2009	8 µg/l for water hardness with annual average values ≤ 10 mg/l CaCO ₃ ; 50 µg/l for water hardness > 10 mg/l CaCO ₃ and ≤ 100 mg/l CaCO ₃ ; and 100 µg/l elsewhere.
Supplementary standards:					
Aluminium	µg/l	-	1900	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids
Barium	µg/l	-	4	Oak Ridge National Laboratory	Invertebrates and Salmon fish
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 11 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

4.3 Comparison to Assessment Criteria

A comparison of the surface water analytical results was made against the relevant assessment criteria for ecological and human health as described in Section 4.2.

Table B-1 in [Appendix B](#) highlights the exceedances of the assessment criteria. Where exceedances of the ecological assessment criteria exist, 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 exceeded both the ecological and human health criteria and these results are highlighted in pink. The results and exceedances are discussed in this section.

4.3.1 Surface Water Assessment

Adit Discharges

The pH was found to be acidic in all adit discharges with results within the range of 2.97 to 4.39 pH units (field) which exceeded the acceptable ranges for ecological (4.5 to 9 pH units) and human health (6.5 to 9.5 pH units) criteria. The specific conductance ranged from 1.368 to 2.99 mS/cm. There was one exceedance of the human health criteria (2.5 mS/cm) at the Cronebane Shallow Adit (2.99 mS/cm).

Elevated sulphate and ammonia were found at all of the adit discharge locations. Sulphate levels greatly exceeded the criteria for human health of 250 mg/l at all sampling locations with values ranging from 727 to 2,290 mg/l. Ammonia exceeded the ecological assessment criteria (0.14 mg/l) at three locations and both the ecological and human health criteria (0.3 mg/l) at four locations with values ranging from 0.258 to 6.56 mg/l. The highest concentration of sulphate and ammonia was recorded at Cronebane Shallow Adit.

The dissolved metal concentrations were high in all of the adit discharges. Numerous exceedances of ecological, human health criteria or both exist for the majority of metals analysed including dissolved aluminium, cadmium, copper, iron, manganese, lead, nickel and zinc (Table B-1 in [Appendix B](#) includes the full listing).

Dissolved zinc ranged from 8,340 to 79,300 µg/l which exceeded the ecological assessment criteria of 50 µg/l. Dissolved aluminium ranged from 12,200 to 261,000 µg/l which exceeded both the ecological (1,900 µg/l) and human health (200 µg/l) criteria. The concentrations of dissolved copper exceeded the ecological assessment criteria (5 µg/l) in all of the adit discharges and also the human health criteria (2,000 µg/l) in the 850 Adit, Cronebane Shallow Adit, Cronebane Intermediate Adit and the Deep Adit Confluence where concentrations ranged from 5,360 to 11,300 µg/l.

Dissolved cadmium ranged from 16.5 to 253 µg/l which exceeded both the ecological (0.45 µg/l) and human health (5 µg/l) criteria. Dissolved cobalt ranged from 75.7 to 198 µg/l which exceeded the ecological criteria (5.1 µg/l). Dissolved lead ranged from 305 to 1,390 µg/l which exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) criteria. Dissolved nickel ranged from 30.7 to 110 µg/l which exceeded both the ecological and human health criteria of 20 µg/l.

Dissolved arsenic was detected in all of the adit discharges with the exception of the Deep Adit, Road Adit and Road Adit Confluence which were below the limit of detection. The Cronebane Shallow Adit exceeded the criteria for human health (10 µg/l) and ecological health (25 µg/l) with a recorded value of 35.4 µg/l. Dissolved chromium was detected in the 850 Adit, Cronebane Intermediate Adit and the Deep Adit Confluence and exceeded the ecological assessment criteria of 3.4 µg/l in the Cronebane Shallow Adit.

Dissolved iron and manganese were also high in all adit discharges. Iron ranged from 35,300 to 108,000 µg/l, exceeding the human health assessment criteria of 200 µg/l at every location. Manganese ranged from 2,180 to 8,100 µg/l which exceeded the criteria for human health (50 µg/l) and the ecological assessment criteria (1,100 µg/l) in all adit discharges. Note that iron and manganese are not important criteria for human health (see Section 4.2.1).

Avoca River

Table 12 provides a summary of the reported values for upstream (Site T1) and downstream (Avoca Bridge) of the mining area on the Avoca River that exceeded the relevant ecological and human health assessment criteria. The pH was found to be below the human health (6.5 to 9.5 pH units) criteria at Site T1 (6.16 pH units); however, all values were within acceptable ranges for ecological criteria (4.5 to 9 pH units). The specific conductance was well within the criteria for human health of 2.5 mS/cm ranging from 0.068 to 0.076 mS/cm. Concentrations of ammonia were below the limit of detection (<2 mg/l) at both sampling locations.

The dissolved metal concentrations in the Avoca River were low in comparison to the adit discharges; however, several exceedances of both ecological and human health criteria occurred as follows:

- Dissolved copper increased from less than the detection limit (<0.8 µg/l) at Site T1 to 13 µg/l at Avoca Bridge which exceeded the ecological assessment criteria of 5 µg/l;
- Dissolved iron increased from 37.8 µg/l at Site T1 to 230 µg/l at Avoca Bridge which exceeded the human health criteria of 200 µg/l;
- Dissolved manganese increased from 20.4 µg/l at Site T1 to 50.1 µg/l at Avoca Bridge which exceeded the human health criteria of 50 µg/l;

- Dissolved zinc increased from 20.4 at Site T1 to 122 µg/l at Avoca Bridge which exceeded the ecological assessment criteria of 50 µg/l; and
- Dissolved barium exceeded the ecological assessment of 4 µg/l at both locations with values ranging from 4.76 to 5.25 µg/l.

Note that iron and manganese are not important criteria for human health (see Section 4.2.1). No other dissolved metal concentrations on the Avoca River exceeded either the ecological assessment criteria or the human health criteria including aluminium, cadmium, lead and nickel.

Table 12 Summary of Reported Values for the Avoca River and the Surface Water Assessment Criteria

Sample Description	Date Sampled	pH (field)	Copper (diss.filt)	Iron (diss.filt)	Manganese (diss.filt)	Zinc (diss.filt)
	Units	pH Units	µg/l	µg/l	µg/l	µg/l
Ecological Criteria		4.5 to 9	5	-	1100	50
Human Health Criteria		6.5 to 9.5	2000	200	50	-
Site T1	16/02/2016	6.16	<0.85	37.8	20.4	20.4
Avoca Bridge	16/02/2016	6.99*	13	230	50.1	122

Notes

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

Metals are dissolved

* Laboratory reading

Section 5

Flows, Loads and Trend Analysis

5.1 Surface Water Flows

Two EPA stream flow gauges exist on the Avoca River near the mine site: Whites Bridge GS (EPA station 10044) and the Wicklow County Council Maintenance Yard GS (EPA Station 10045). The Whites Bridge GS is located 90 m downstream of the bridge and just upstream of the confluence of the Deep Adit discharge. The Wicklow County Council Maintenance Yard GS is downstream of the Deep Adit and was previously just upstream of the Road Adit confluence. As previously discussed and shown on Map 3 in [Appendix A](#), the new discharge location for the Road Adit to the Avoca River (Road Adit Confluence) is upstream of the Wicklow County Council Maintenance Yard GS.

The flow record from 1 September 2015 to 27 February 2016 of Whites Bridge GS is reproduced in Figure 2 and for Wicklow County Council Maintenance Yard GS from 1 September 2015 to 10 February 2016 in Figure 3. Data are limited for Wicklow Co. Co. Maintenance Yard GS for the period November to January due to battery issues. The figures show the measured flows ranged from $>50 \text{ m}^3/\text{s}$ to approximately $3\text{--}4 \text{ m}^3/\text{s}$ during low-flow. The flashy nature of the river shows a rapid response to rainfall. The median flow for this period of approximately $19.1 \text{ m}^3/\text{s}$ at Whites Bridge GS is higher than the long term median of approximately $8.3 \text{ m}^3/\text{s}$ (CDM Smith, 2015), which reflects the relatively high levels of rainfall during the period November to February. Flow in December was particularly high with the daily mean flow recorded at $67.4 \text{ m}^3/\text{s}$ on 5 December 2015.

The river appears to respond similarly at both gauging stations as can be observed from the peaks in both figures. A discussion of the differences in flow rates between the two gauges is provided in Section 6.5.

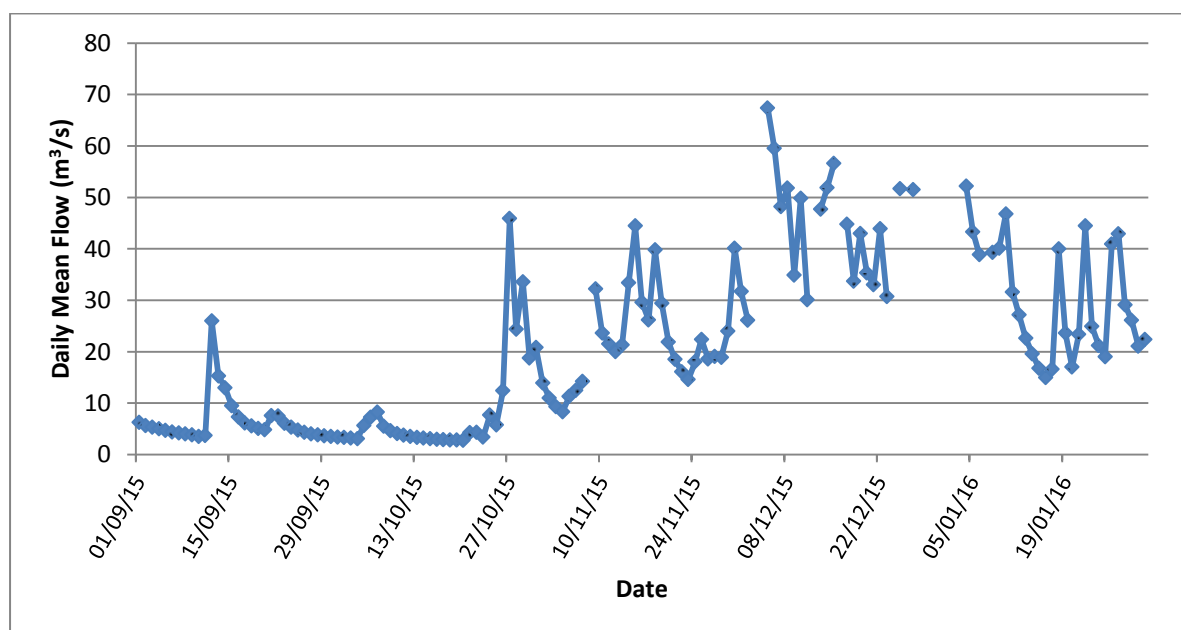


Figure 2 Mean Daily Flow (m^3/s) at Whites Bridge (Station 10044) from 1 Sept 2015 to 27 Feb 2016

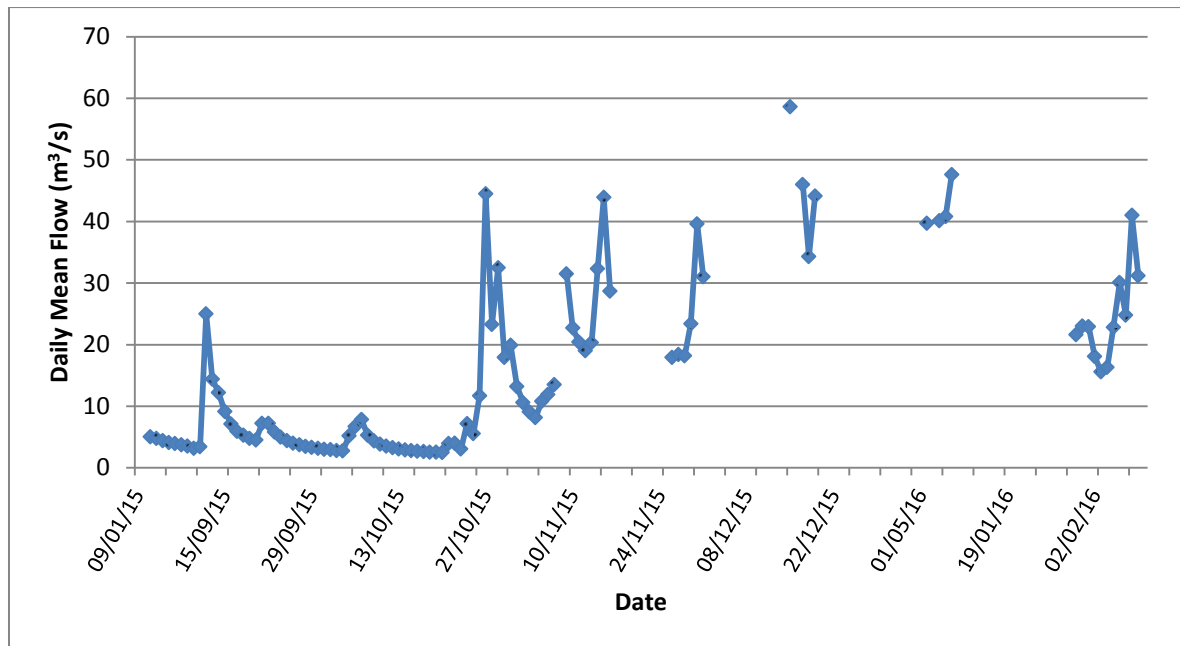


Figure 3 Mean Daily Flow (m³/s) at Wicklow County Council Maintenance Yard (Station 10045) from 1 Sept 2015 to 10 Feb 2016

Flow was measured directly in the field using different methodologies depending upon the quantity of flow to be measured and any safety concerns, as described in Section 2.1.2. Table 13 presents a summary of the results from the flows measured in February 2016 at the time of sampling. The flow measurements at both sampling locations on the Avoca River were performed on the same day which provides a true representation of hydrogeological activity in the Avoca River. Refer to Appendix B of the Data Report for details of methodologies used per site and associated calculations.

The measured flow at the Deep Adit of 12 l/s is considered a low-moderate flow as past records for the Deep Adit ranged from approximately 10 to 37.5 l/s. The flow from the 850 Adit was 19.3 l/s which is considered high. The surface water drainage channel which joins the 850 channel up-gradient of the railway tracks was dry at the time of sampling. The confluence of the 850 Adit and Deep Adit discharge is located directly downstream of the Deep Adit portal and the combined flow was calculated to be 31.3 l/s. The flow was also measured at the Deep Adit Confluence (Deep Adit + 850 Adit) prior to it discharging to the Avoca River and the measured flow was 30.1 l/s which is slightly less than the combined flow of the two adits. Note this location is not ideal for measuring flow as it is not properly channelised and the measurement should be considered an estimate. Note that no flow was being diverted into the Millrace channel in February 2016.

The flow at the Road Adit was measured at 31.5 l/s. Past records for the Road Adit ranged from approximately 6 to 58 l/s (CDM, 2008). The flow was also measured at the Road Adit Confluence prior to the adit discharging to the river and the measured flow was 36.3 l/s. The difference in flow is likely due to two different flow measurement methods being employed.

Table 13 Surface Water Flow Value Measured in February 2016

Site Name	Flow m ³ /s	Flow l/s	Date	Notes
Site T1	17.9	17,942	16/02/2016	
White's Bridge GS	18.0	18,000	16/02/2016	EPA automatic data recorder
Wicklow Co. Co. Maintenance Yard GS	-	-	16/02/2016	EPA automatic data recorder (no data available on 16/02/2016)
Avoca Bridge	18.4	18,400	16/02/2016	
850 Adit	0.02	19.3	15/02/2016	
Deep Adit	0.01	12.0	15/02/2016	
Deep Adit Confluence	0.03	30.1	15/02/2016	
Road Adit	0.03	31.5	15/02/2016	
Road Adit Confluence	0.04	36.3	15/02/2016	
Cronebane Inter. Adit	0.02	15.5	15/02/2016	
Cronebane Shallow Adit	0.001	0.5	15/02/2016	
Ballygahan Adit	-	-	15/02/2016	No flow

Note: Flow at EPA automatic data recorders for reference only - no sample collected in February 2016

5.2 Loading Analysis

5.2.1 Loading Analysis Methodology

Mass loads (kg/day) were calculated for the Avoca River, the adits, and tributaries using measured flow and concentration data, as follows:

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

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

F = the flow rate of the input

5.2.2 Loading Results and Discussion

The calculated mass loads in Table 14 aid with the interpretation of the loading of sulphate and dissolved aluminium, copper, iron, lead and zinc to the Avoca River.

Table 14 Summary of Measured Flows and Concentrations and Calculated Loads of Sulphate and Dissolved Metals in kg/day in the Adits and Avoca River

Sample Description	Date Sampled	Flow l/s	pH Units	Sulphate		Aluminium		Copper		Iron		Lead		Zinc	
				µg/l	kg/day	µg/l	kg/day	µg/l	kg/day	µg/l	kg/day	µg/l	kg/day	µg/l	kg/day
850 Adit	15/02/2016	19.3	3.11	3110	1290	72500	121	7670	12.8	35300	58.9	809	1.35	29000	48.4
Cronebane Inter. Adit	15/02/2016	15.5	3.14	3140	975	61700	82.8	6450	8.65	69200	92.8	957	1.28	31100	41.7
Cronebane Shallow Adit	15/02/2016	0.5	2.97	2970	104	261000	11.8	11300	0.51	108000	4.9	746	0.03	79300	3.59
Deep Adit	15/02/2016	12.0	3.58	3580	993	84500	87.9	350	0.36	79700	82.9	1390	1.45	53800	56
Deep Adit Confluence	15/02/2016	30.1	3.21	3210	2210	88800	231	5360	13.9	51800	135	992	2.58	45600	118
Road Adit	15/02/2016	31.5	4.36	4360	2510	12200	33.2	382	1.04	70400	192	309	0.84	8470	23.1
Road Adit Confluence	15/02/2016	36.3	4.39	4390	2860	12300	38.5	385	1.21	68000	213	305	0.96	8340	26.1
Site T1	16/02/2016	17942	6.16	6160	1550	60.8	94.3	0.43	0.66	37.8	58.6	2.45	3.8	20.4	31.6
Avoca Bridge	16/02/2016	18400	6.99	6990	14600	154	245	13	20.7	230	366	3.21	5.1	122	194

Loading from Adit Discharges

The Deep Adit had aluminium, copper and zinc loads of 87.9, 0.4 and 56 kg/day and the Road Adit had loads of 33.2, 1.04 and 23.1 kg/day, respectively. The Road Adit had a higher load of sulphate with 2,510 kg/day and dissolved iron with 192 kg/day and the Deep Adit had 993 kg/day sulphate and 82.9 kg/day of iron.

The Deep Adit and 850 Adit showed similar loadings for dissolved aluminium (87.9 kg/day and 121 kg/day), lead (1.45 kg/day and 1.35 kg/day) and zinc (56 kg/day and 48.4 kg/day). However compared to the Deep Adit, the 850 Adit had significantly higher loads of dissolved sulphate (1,290 kg/day and 993 kg/day) and copper (12.8 kg/day and 0.36 kg/day). The reverse was true for dissolved iron as the 850 Adit had a load of 58.9 kg/day and the Deep Adit had a load of 82.9 kg/day.

To determine if there was any apparent loss of sulphate or metals loading along the 850 and Deep Adit channels, the flow and loading results were summed up for the Deep Adit and 850 Adit portal samples and compared with the measured loads at the Deep Adit confluence (Table 14). The recorded flow was slightly lower at the Deep Adit Confluence which is likely due to the difficulties in measuring the flows as the discharge was dispersed and flowing several different directions. Also, there is likely infiltration occurring in the channel. In general, the loadings of sulphate and the dissolved metals were similar in the Deep Adit confluence compared to the Deep Adit and 850 portals. However, a slight decrease in loads was recorded for sulphate (2,283 kg/day to 2,210 kg/day), iron (142 kg/day to 135 kg/day) and lead (2.8 kg/day to 2.58 kg/day). The decreases in loads are likely due to the loss of flow which can be attributed to the difficulties in measuring the flows or from infiltration along the ditch.

The Cronebane Intermediate Adit had dissolved metal loads of 82.8 kg/day for aluminium, 92.8 kg/day iron and 41.7 kg/day zinc. The Cronebane Shallow Adit was of minor importance in terms of dissolved metals loads to the Avoca River due to both absence of surface flow to the river and low loads (low flow). Calculated loads were 11.8 kg/day for aluminium, 0.51 kg/day for copper and 3.59 kg/day for zinc. The Ballygahan Adit was dry at the time of sampling.

Avoca River Loadings

Background loads of metals upstream of the Avoca Mining Area were present which is evident from the calculated loads at Site T1. Figure 4 shows the calculated loads of dissolved aluminium, copper, iron and zinc at both locations along the Avoca River from Site T1 upstream of the mining area to Avoca Bridge (see also Map 1 and 3 in [Appendix A](#)). The bar chart illustrates the total mass loading to the Avoca River from Site T1 to Avoca Bridge. An increase in dissolved metal loads from Site T1 to Avoca Bridge was apparent as follows:

- Sulphate loads increased from 1,550 kg/day to 14,600 kg/day;
- Aluminium loads increased from 94.3 kg/day to 245 kg/day;
- Copper loads increased from 0.66 kg/day to 20.7 kg/day;
- Iron loads increased from 58.6 kg/day to 366 kg/day;
- Lead loads increased from 3.8 kg/day to 5.1 kg/day; and
- Zinc loads increased from 31.6 kg/day to 194 kg/day

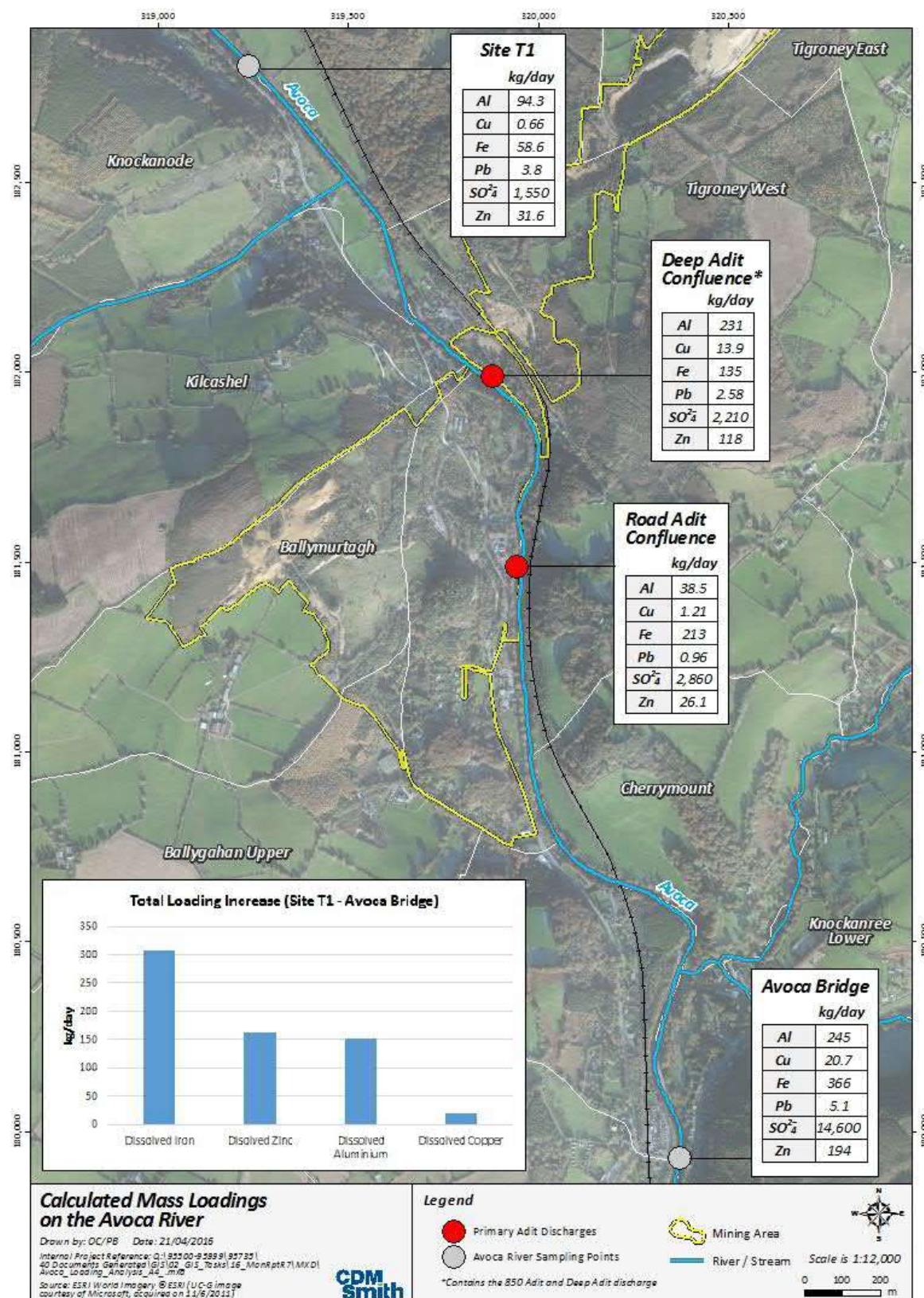


Figure 4 Calculated Loads (kg/day) of Dissolved Metals in the Avoca River in February 2016

5.3 Trend Analysis

5.3.1 Historical Trends

This section discusses concentration time trends for select locations including the Deep Adit, the Road Adit and one location on the Avoca River (Avoca Bridge) for selected parameters including dissolved copper, zinc and iron. The trends are shown graphically in Figure 5 (Deep Adit from Oct 2001 to Feb 2016), Figure 6 (Road Adit from Oct 2001 to Feb 2016) and Figure 7 (Avoca River at Avoca Bridge from Oct 2001 to Feb 2016).

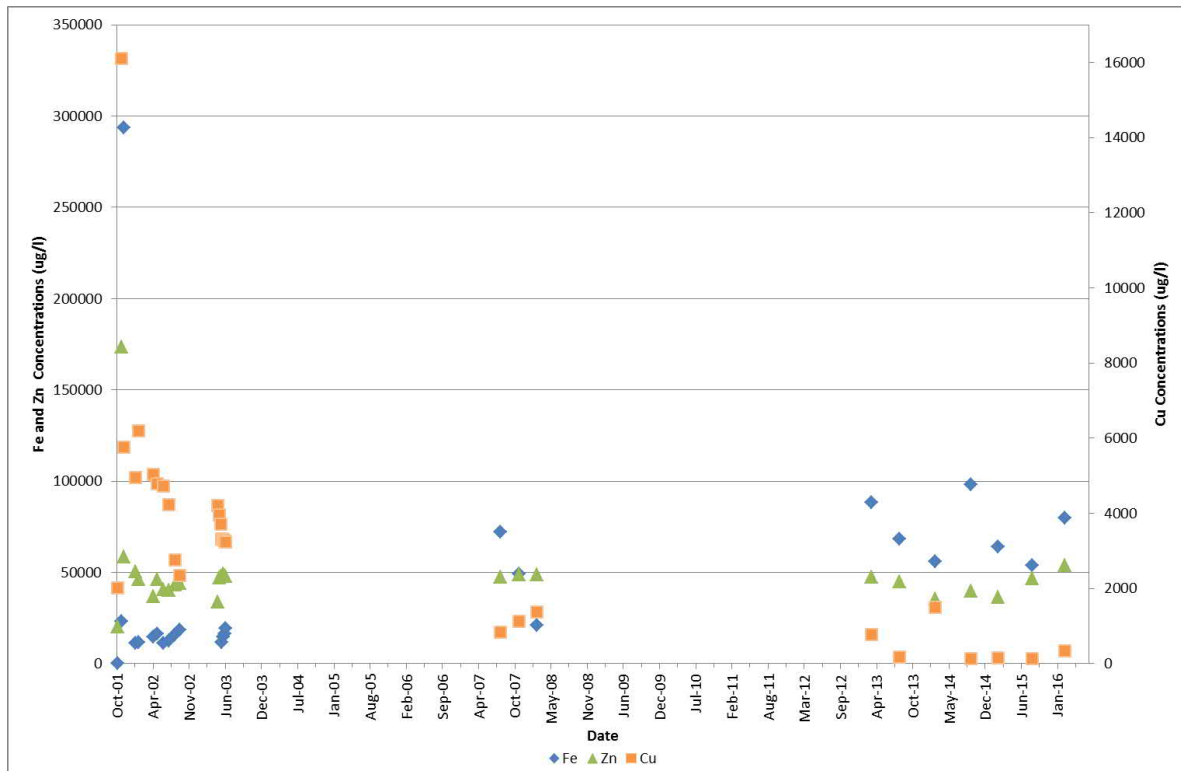


Figure 5 Concentration trends for dissolved copper, zinc and iron within the Deep Adit Discharge (Oct 2001 to Feb 2016)

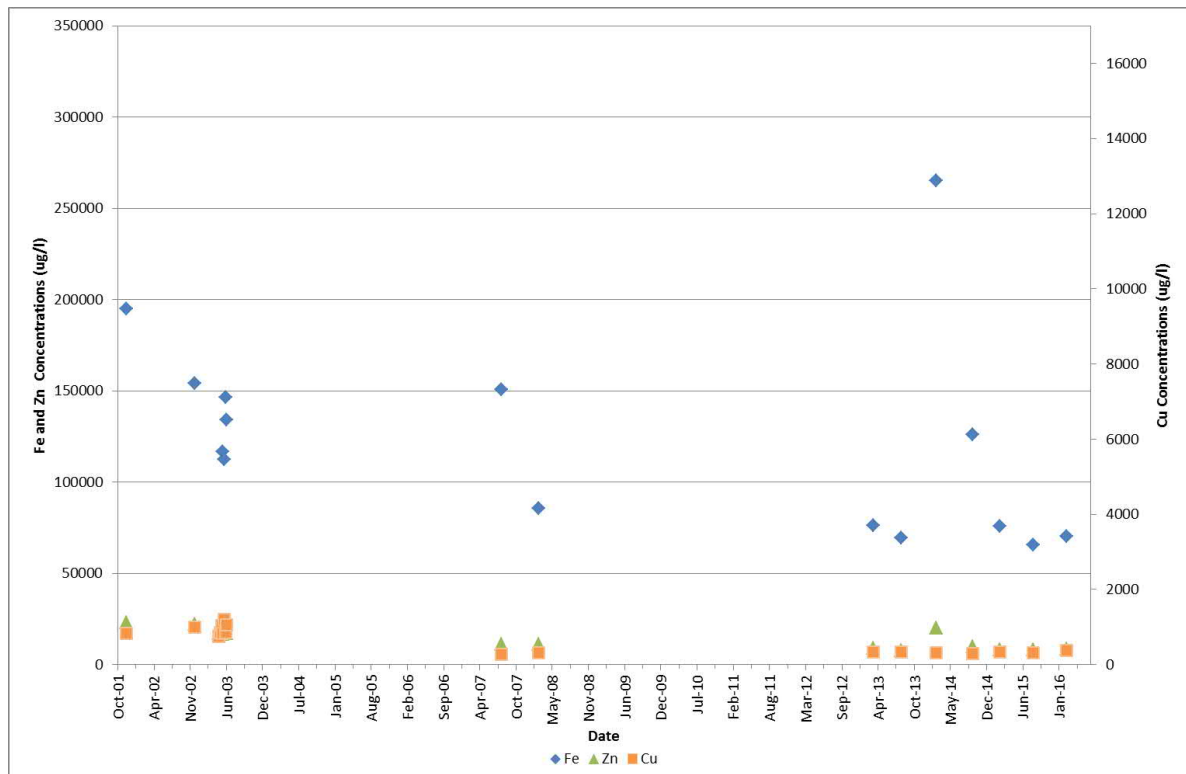


Figure 6 Concentration trends for dissolved copper, zinc and iron within the Road Adit Discharge (Oct 2001 to Feb 2016)

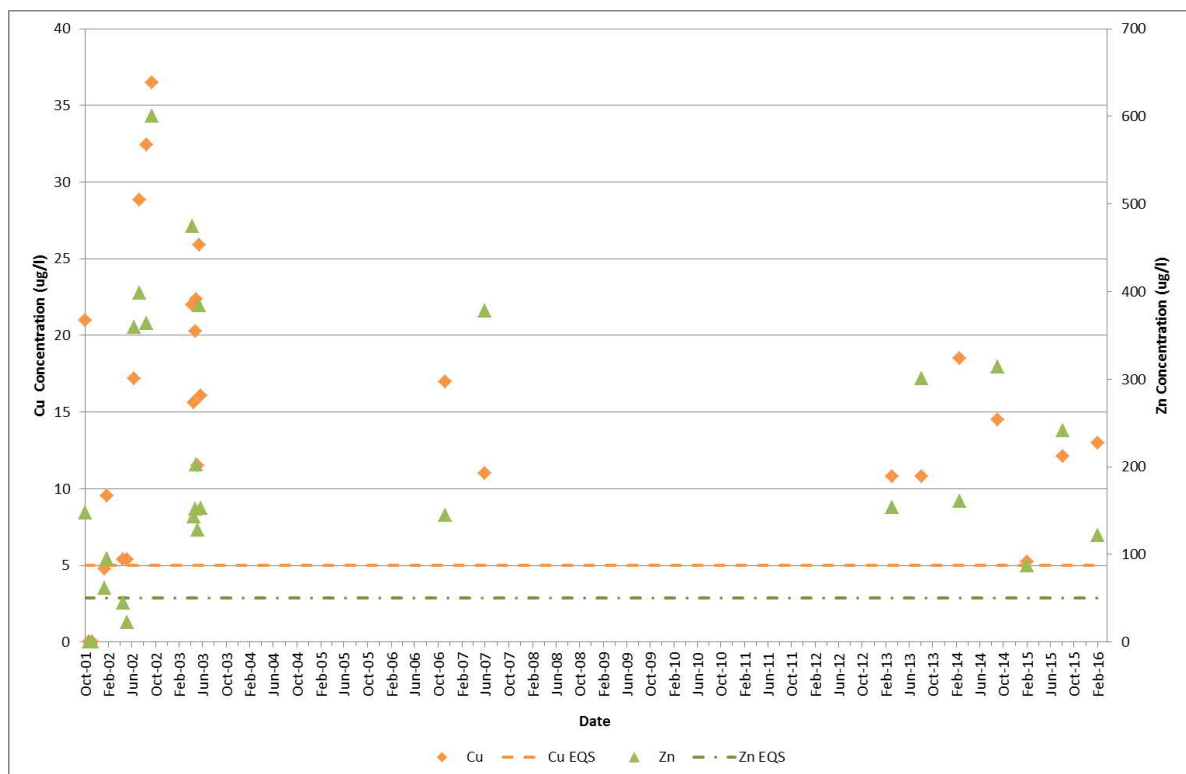


Figure 7 Concentration trends for dissolved copper and zinc at Avoca Bridge compared with the environmental quality objective (EQS) (Oct 2001 to Feb 2016)

The Mann-Kendall test was performed on the surface water sampling locations to assess statistical trends in the water quality data. The Mann-Kendall test is a non-parametric test that is well suited to employ in water quality data analysis. The Mann-Kendall test was performed for dissolved copper, zinc and iron.

The Mann-Kendall test results in the identification of a trend (if one exists) and the probability of that trend being real. Table 15 shows the possible outcomes of the Mann-Kendall trend analysis as applied to the water quality data.

Table 15 Reporting the Mann-Kendall Results

Trend	P value	Trend reported as
Decreasing	$0 \leq p < 0.05$	Decreasing
	$0.05 \leq p < 0.1$	Likely Decreasing
	$p \geq 0.1$	No Trend
Increasing	$0 \leq p < 0.05$	Increasing
	$0.05 \leq p < 0.1$	Likely Increasing
	$p \geq 0.1$	No Trend
No Trend	$p = 1$	No Trend

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 values and a maximum of 50% of the sample set is reported as non-detect.

Trend analyses were conducted for all data since October 2001 because data were available for all of the sample locations from that date onwards. Analyses on data since June 2007 were also carried out to determine if there were any trends in more recent data, which also eliminated the high results in 2001/2002. The Mann-Kendall test results for both time periods are presented in Table 16 and facilitate general observations about trends in the water quality of the two main adit discharges and the downstream location of Avoca Bridge.

Table 16 Mann-Kendall Trend Analysis of data for Deep Adit, Road Adit and Avoca Bridge

Sample location	Parameter	October 2001 to February 2016			June 2007 to February 2016		
		P value	S value	Trend	P value	S value	Trend
Deep Adit	Copper	0	-282	Decreasing	0.0762	-17	Likely Decreasing
	Zinc	N/A	N/A	Not Calculated	0.2371	-9	No Trend
	Iron	0.0001	156	Increasing	0.3603	5	No Trend
Road Adit	Copper	0.0244	-53	Decreasing	0.1257	12	No Trend
	Zinc	0.0002	-93	Decreasing	0.1257	-12	No Trend
	Iron	0.0050	-53	Decreasing	0.0589	-16	Likely Decreasing
Avoca Bridge	Copper	0.2274	-33	No Trend	0.4015	3	No Trend
	Zinc	0.2956	24	No Trend	0.1328	-10	No Trend

Notes:

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

Not calculated: insufficient statistical evidence of a significant trend

The confidence coefficient is 0.95

The results of the Mann-Kendall analysis for October 2001 to February 2016 show that dissolved copper concentrations are decreasing in the Deep Adit and there is no trend for dissolved zinc. Dissolved iron however is increasing in the Deep Adit. Dissolved copper, dissolved zinc and

dissolved iron were decreasing in the Road Adit. These trends can also be inferred from Figure 5 and 6.

The results of the Mann-Kendall analysis for June 2007 to February 2016 show that dissolved copper is likely decreasing in the Deep Adit and dissolved iron is likely decreasing in the Road Adit. No other trends exist for this time period in the adit discharges.

Figure 7 displays the results for dissolved copper and zinc in the Avoca River at Avoca Bridge which is downstream of the main Avoca Mining Area, from 2001 to present. No statistically significant trend was present for dissolved zinc or dissolved copper for both the 2001-2016 period and the 2007-2016 period. The ecological assessment criteria (or EQS) are also shown on the graph for reference. Dissolved copper has been above the ecological assessment criteria of 5 µg/l and dissolved zinc above the ecological assessment criteria of 50 µg/l since mid-2002.

5.3.2 Seasonal Trends

Table 17 shows the seasonal variation between the concentrations of dissolved metals and the calculated loads observed between the high flow sampling events in March 2013 (R1), February 2014 (R3), February 2015 (R5) and February 2016 (R7) and the low flow sampling events in August 2013 (R2), September 2014 (R4) and August 2015 (R6). As can be observed from Table 17, the concentrations of dissolved aluminium, copper, iron and zinc were very similar in each sampling event with a few exceptions. Dissolved copper in the Deep Adit was significantly lower in concentration in August 2013, September 2014 and August 2015 compared with the high flow sampling, however it was also low in February 2015 when the flow in the Deep Adit was lower than other winter sampling events. The concentration of dissolved iron at Avoca Bridge is quite variable and dissolved zinc is higher in concentration during the low flow sampling events in August 2013, September 2014 and August 2015.

Table 17 also shows that the calculated loads of dissolved aluminium, copper, iron and zinc were all significantly lower in August 2013, September 2014 and August 2015 due to the low flow conditions. Similar flow conditions measured at the Deep Adit in February 2015 and February 2016 resulted in relatively low calculated loads of dissolved metals.

Table 17 Seasonal Variation of Concentrations and Calculated Loads of Dissolved Metals in the Adits and at Avoca Bridge from 2013-2016

Sample Description	Date Sampled	Flow l/s	Aluminium		Copper		Iron		Zinc	
			µg/l	kg/day	µg/l	kg/day	µg/l	kg/day	µg/l	kg/day
Deep Adit	R1 15/03/2013	29.2	98800	249	770	1.9	88500	223	47300	119
	R2 15/08/2013	13	96700	110	184	0.21	68300	77.4	44900	50.9
	R3 27/02/2014	22.2	71600	138	1500	2.9	55800	107	35500	68.2
	R4 16/09/2014	17.5	80200	121	130	0.2	98100	148	39900	60.3
	R5 12/02/2015	16.7	85600	123	147	0.2	64200	92	36300	52
	R6 17/08/2015	19.5	106000	179	142	0.2	53800	90.6	46800	78.8
	R7 15/02/2016	12.0	84500	87.9	350	0.36	79700	82.9	53800	56
Road Adit	R1 15/03/2013	28.9	14900	37.2	366	0.9	76100	190	9140	22.8
	R2 15/08/2013	15.6	16400	22.1	335	0.45	69500	93.9	7810	10.5
	R3 27/02/2014	56.2	15000	72.8	321	1.6	265000	1290	20100	97.6
	R4 16/09/2014	18	15600	24.3	294	0.46	126000	196	9810	15.3
	R5 12/02/2015	-	12400	-	339	-	75600	-	8350	-

Sample Description	Date Sampled	Flow l/s	Aluminium		Copper		Iron		Zinc	
			µg/l	kg/day	µg/l	kg/day	µg/l	kg/day	µg/l	kg/day
Avoca Bridge	R6 17/08/2015	14.49	13300	16.7	305	0.4	65800	82.4	8290	10.4
	R7 15/02/2016	31.5	12200	33.2	382	1.04	70400	192	8470	23.1
	R1 20/03/2013	12000	162	167	10.8	11.2	153	158	154	159
	R2 20/08/2013	1940*	161	27	10.8	1.81	232	38.9	301	50.5
	R3 04/03/2014	24000	152	315	18.5	38.4	485	1010	161	334
	R4 17/09/2014	3240	93.1	26.1	14.5	4.06	182	51	314	88
	R5 16/02/2015	20096	246	427.1	5.24	9.10	201	349	87	151.6
	R6 18/08/2015	3010	99.1	25.8	12.1	3.2	161	41.9	241	62.7
	R7 16/02/2016	18400	154	245	13	20.7	230	366	122	194

Notes:

*Unrepresentative flows resulted in an underestimate of the sulphate and dissolved metals loadings at Avoca Bridge

Section 6

Groundwater Levels and Groundwater-Surface Water Interaction

6.1 Groundwater Levels

Groundwater levels were measured at the nine wells using a portable electronic water level recorder. Table 18 provides the measured depth to groundwater and calculated groundwater elevations. The groundwater level was also measured at R3-04 which is located in Tigroney West Spoils and completed in the Deep Adit tunnel (adjacent to the 850 Adit discharge channel) and was drilled as part of the Avoca Works Project in October 2014. All groundwater level data are contained in Appendix C of the Data Report. The groundwater elevations varied between 26.53 to 32.88 m Ordnance Datum (OD) in the Avoca Mining Area. These groundwater elevations were between 0.2 to 2 metres higher than the elevations measured in August 2015. The groundwater elevations were consistent with the hydraulic gradient towards the Avoca River. MWSA2 is located downgradient of Shelton Abbey Tailings which is in a different part of the catchment and the groundwater elevation is much lower than that of the West and East Avoca.

Table 18 Measured Groundwater Levels and Calculated Elevation February 2016

Borehole Identifier	Date	Time	Depth to Groundwater (m bTOC)	Depth to Groundwater (m bgs)	Groundwater Elevation (m OD)
MWDA1	16/2/2016	13:10	5.90	5.30	26.89
MWDA2	16/2/2016	13:00	5.88	5.15	26.74
MWET1	16/2/2016	13:30	6.63	6.06	26.755*
MWET2	16/2/2016	13:15	6.53	5.83	26.835*
MWPF1	16/2/2016	11:25	4.06	3.47	27.43
MWSA2	16/2/2016	14:30	6.63	6.35	3.54
GW1/05	28/2/2016	15:50	4.15	3.51	26.65*
GW2/05	28/2/2016	15:50	4.42	3.59	26.53*
SG104	28/2/2016	16:00	25.29	Unknown	32.88*
R3-04	16/2/2016	12:00	9.98	9.31	32.48

Notes:

m is metres

OD is Ordnance Datum

bTOC is below top of casing

bgs is below ground surface

* Monitoring well elevations were based on a GPS survey and therefore may be less accurate

Automatic pressure transducers and loggers have been installed in the six wells owned by the Department. Figure 8 shows the groundwater elevations of the 5 wells located in the Avoca Mining Area from 12 August 2015 to 15 February 2016. Figure 9 shows the groundwater elevation at MWSA2 at Shelton Abbey Tailings Facility from 12 August 2015 to 15 February 2016. Data are omitted for MWET2 for the period 30 December 2015 to 7 January 2016 due to irregular readings. Irregular readings are highlighted in Appendix C (Table C-1) of the corresponding Data Report.

Figure 8 shows that the heads are higher in the shallow alluvium monitoring well MWDA1 with respect to its nested well pair in the deeper alluvium MWDA2 which suggests an apparent downward hydraulic gradient between the pair, which infers that groundwater in the spoils discharges into the alluvial aquifer.

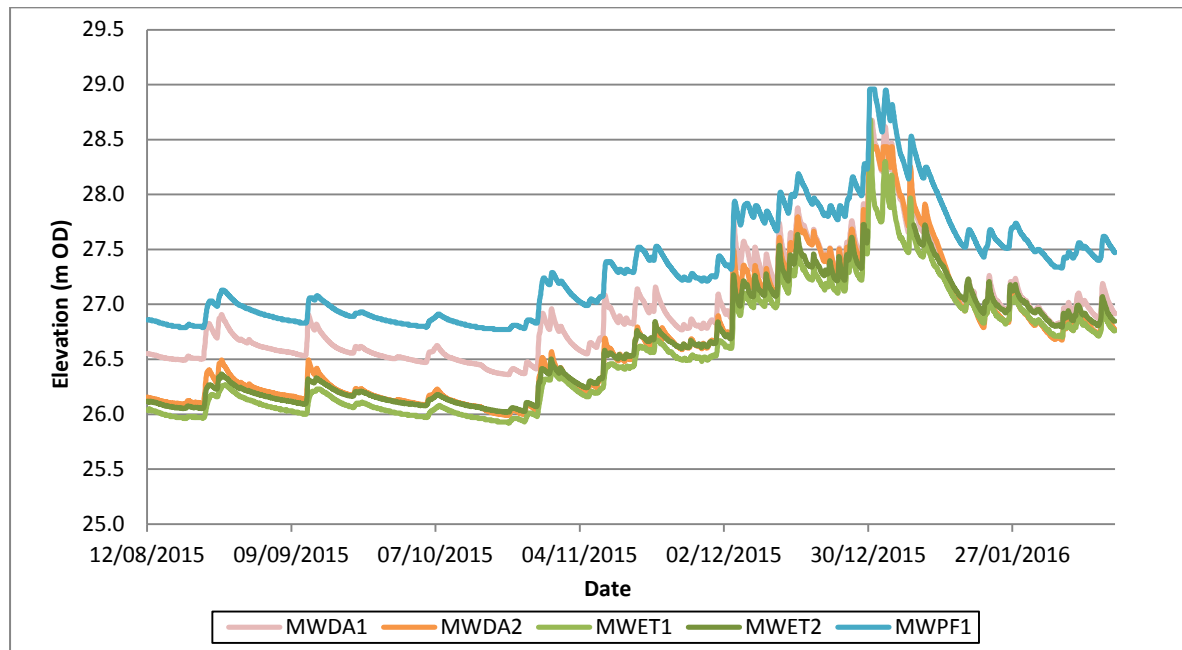


Figure 8 Groundwater Elevations in the Avoca Mining Area from 12 Aug 2015 to 15 Feb 2016

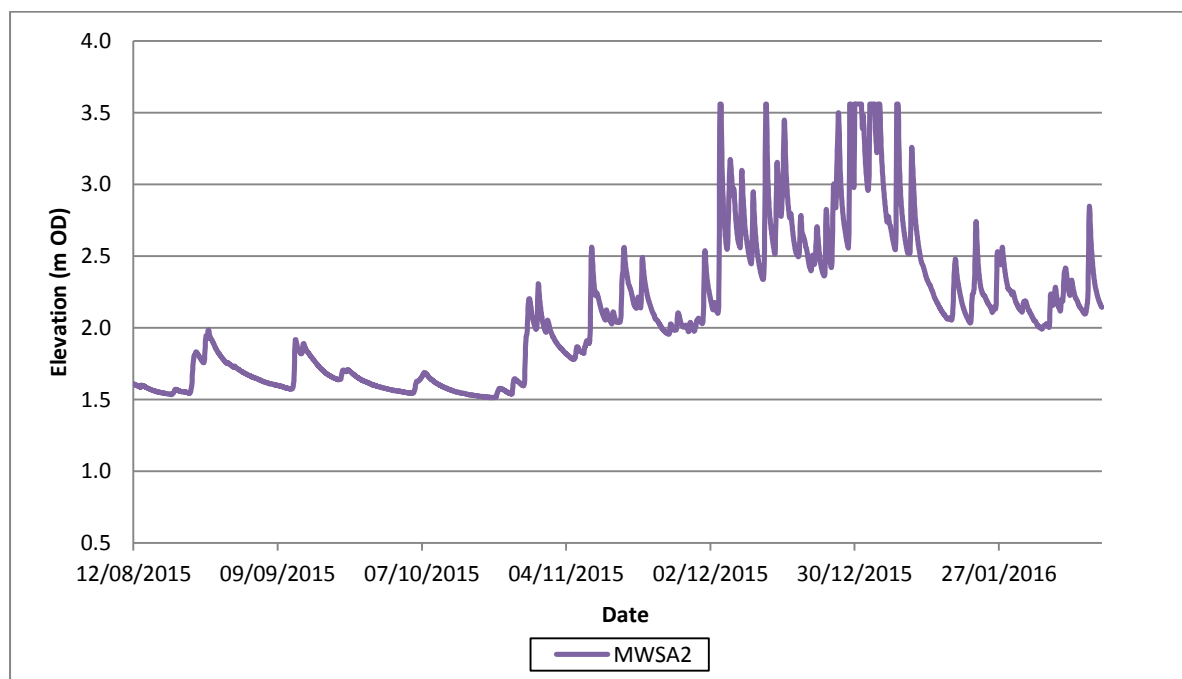


Figure 9 Groundwater Elevation at Shelton Abbey from 12 Aug 2015 to 15 Feb 2016

In contrast to MWDA1 and MWDA2, the head is slightly greater in the deep well MWET2 compared to the shallow monitoring well MWET1. GW1/05 and GW2/05 are located closer to the

western alluvial margin, and approximately 95 m to the south-southeast of the MWET1/ET2 well cluster. Groundwater elevations were similar between the top of bedrock (GW1/05) and the alluvial well GW2/05 at the time of measurement (Table 18).

All data loggers were calibrated and batteries replaced where necessary.

6.2 Surface Water Levels

As described in Section 5.1 Surface Water Flows, there are two EPA stream flow gauges on the Avoca River near the mine site: Whites Bridge GS (EPA station 10044) and the Wicklow County Council Maintenance Yard GS (EPA Station 10045). The measured water elevations from 12 August 2015 to 15 February 2016 for Whites Bridge GS and Wicklow County Council Maintenance Yard GS are reproduced in Figure 10. Data are missing for GS 10045 for several periods of time due to battery issues; the logger has since been replaced. The figure demonstrates that the river appears to respond similarly at both gauging stations.

The distance between the two gauging stations is approximately 470 metres. The measured surface water elevations were used to calculate the average gradient between the two gauges which was 0.006 for the monitoring period. Streambed characteristics and the elevations both influence the flow rates and help define any apparent losses or gains in river flow.

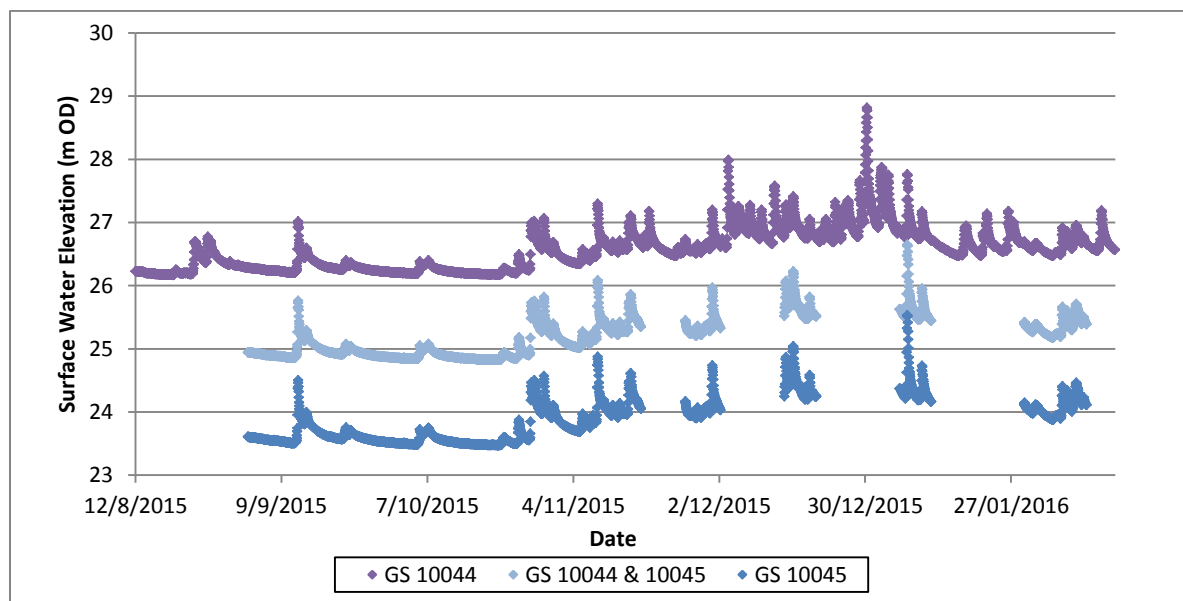


Figure 10 Elevation of the Avoca River at GS 10044 and GS 10045 at the Deep Adit Area from 12 Aug 2015 to 15 Feb 2016

6.3 Groundwater-Surface Water Interaction

Groundwater gradients to the Avoca River were calculated using the estimated groundwater elevations and corresponding river water elevations for the same date and time. The locations of the monitoring wells with respect to the gauging station locations on the Avoca River are shown on Map 3 in [Appendix A](#). The appropriate river gauges were selected as follows:

- For MWDA1, MWDA2, MWPF1 and R3-04 the river water elevation was taken from the EPA gauge located at Whites Bridge GS (GS 10044);

- MWET1, MWET2, GW1/05 and GW2/05 are located approximately equidistance between the two gauges. To take account of the gradient between the two gauges, the river water elevation can be estimated using both the Whites Bridge GS (GS 10044) and the Wicklow County Council Maintenance Yard GS (GS 10045) by selecting a midpoint water level. Note that water level data was unavailable for GS 10045 for several periods including 16 February and 28 February due to battery failure and therefore the river water elevation could not be estimated for these time periods. Using the available data, the estimated surface water elevations for the emergency tailing area for the period 12 August 2015 to 15 February 2016 are displayed on Figure 10 (GS 10044 & GS 10045);
- For SG104 the water elevation from Wicklow Maintenance Yard County Council (GS 10045) was unavailable; and
- The river water level at MWSA2 was unable to be determined because there are no gauges available at a nearby location.

Table 19 summarises resulting hydraulic gradient data between the monitoring well clusters and the Avoca River during the monitoring event, and shows an estimated gradient from the wells to the river during the monitoring event in February 2016. These values are similar to previous rounds in both direction and magnitude with an estimated mean gradient of 0.009, 0.005 and 0.022 for MWDA1, MWDA2 and MWPF1 respectively. R3-04 had a significantly greater gradient of 0.17. Readings at R3-04 are likely capturing the water level within the Deep Adit channel rather than groundwater level.

Table 19 Calculated Groundwater Gradients for February 2016

Borehole Identifier	Date	Time	Groundwater Elevation (m OD)	Water Elevation at Perpendicular Stream Point (m OD)	Distance to Perpendicular Stream Point (m)	Gradient
MWDA1	16/2/2016	13:10	26.89	26.54	40	0.009
MWDA2	16/2/2016	13:00	26.74	26.54	40	0.005
MWET1	16/2/2016	13:30	26.76*	ND	44	ND
MWET2	16/2/2016	13:15	26.84*	ND	72	ND
MWPF1	16/2/2016	11:25	27.43	26.54	72	0.022
MWSA2	16/2/2016	14:30	3.54	ND	74	ND
GW1/05	28/2/2016	15:50	26.65*	ND	74	ND
GW2/05	28/2/2016	15:50	26.53*	ND	142	ND
SG104	28/2/2016	16:00	32.88*	Not available	45	Not available
R3-04	16/2/2016	12:00	32.48	26.54	160	0.17

* Monitoring Well elevations were based on a GPS survey and therefore may be less accurate
 ND No water level data available from station 10045 for this time period due to battery failure

The hydraulic communication between the river and groundwater is of primary importance in reviewing potential contaminant loads to the river from diffuse groundwater flow. Where a positive hydraulic gradient from the alluvial aquifer to the river is present (i.e. the head in the aquifer is higher than in the river), the Avoca River is a net gaining river.

Hourly water level data for both gauges on the Avoca River: Whites Bridge GS (EPA station 10044) and the Wicklow County Council Maintenance Yard GS (EPA Station 10045) were obtained from the EPA for the monitoring period. Groundwater elevation data were plotted against the recorded elevations of the Avoca River as shown in Figure 11 for the Deep Adit area and Figure 13 for the emergency tailings area. Both figures demonstrate that there is a direct relationship between the river stage and the groundwater levels in both areas. Rises in river levels are accompanied by rises in groundwater levels.

Monthly rainfall totals were above their monthly Long Term Average (LTA) during all three months of winter (December, January and February) (Met Eireann, 2016a). Figure 11 shows that in the recorded data several significant hydrological (rainfall) events occurred throughout the monitoring period, particularly from November to December which resulted in groundwater levels rising. For example groundwater levels rose by approximately 1.2 metres between 28 and 30 December 2015. This peak was in response to river levels which rose by up to 2 metres during the same event. Sustained high groundwater levels were recorded in December due to the occurrence of numerous high rainfall events. The majority of stations reported their wettest December on record (Met Eireann, 2016b). Average groundwater levels in the Deep Adit area in December 2015 were approximately 0.8 metres higher than in December 2014 and December 2013.

Figure 12 and Figure 14 show the calculated gradient to the Avoca River at the deep adit area (MWDA1, MWDA2) and the emergency tailings area (MWET1, MWET2) from 12 August 2015 to 16 February 2016 based on hourly elevation data. Both figures show that as river stages change hydraulic gradients to or from the river also change. Gradients are predominantly positive which suggests that the Avoca River is a net gaining river from the alluvium in both areas during the monitoring period. The implication is that the spoil and the alluvial areas on both sides of the river contribute contaminant load to the river.

However, Figure 12 shows that a negative gradient occurs in the Deep Adit area during periods of high flow, particularly when there was a rapid rise in water level. Between 28 and 30 December a significant hydrological (rainfall) event resulted in groundwater levels rising in MWDA1 and MWDA2 by approximately 1.2 metres. A negative gradient can be observed during this period between the river and MWDA2, as shown in Figure 12. During the 28 to 30 December event the river water level also rose (approximately 1.2 metres) but more rapidly which resulted in water moving into the monitoring well area, apparent from the rise in groundwater levels. It is likely the river water moved into an unsaturated zone, which could result in mobilising new metals if they were not exposed before. Also, this zone of fluctuation may under repeated oxidizing reducing conditions result in the precipitation and mobilization of metals.

As illustrated in Figure 12 a negative gradient existed for the period 16 to 30 October 2015 in MWDA2. This was in response to a rapid rise in river water level following a sustained period of low flow ($<5 \text{ m}^3/\text{s}$). MWDA2 which is located in the deeper alluvium appears to respond less to the river than MWDA1 and may be more seasonally influenced (e.g. aquifer storage). A positive gradient existed for approximately 80% of the monitoring period for MWDA2 with a minimum gradient of minus 0.021 and an average gradient of 0.005.

For MWET1 and MWET2 only positive gradients were observed during the monitoring period with a minimum gradient of 0.003 (MWET1) and a maximum of 0.029 (MWET2). Note that the elevations are based on the GPS survey of the boreholes and the river water elevations were

estimated using both the Whites Bridge GS elevation and the Wicklow County Council Maintenance Yard gauges because they are located equidistance between the gauges.

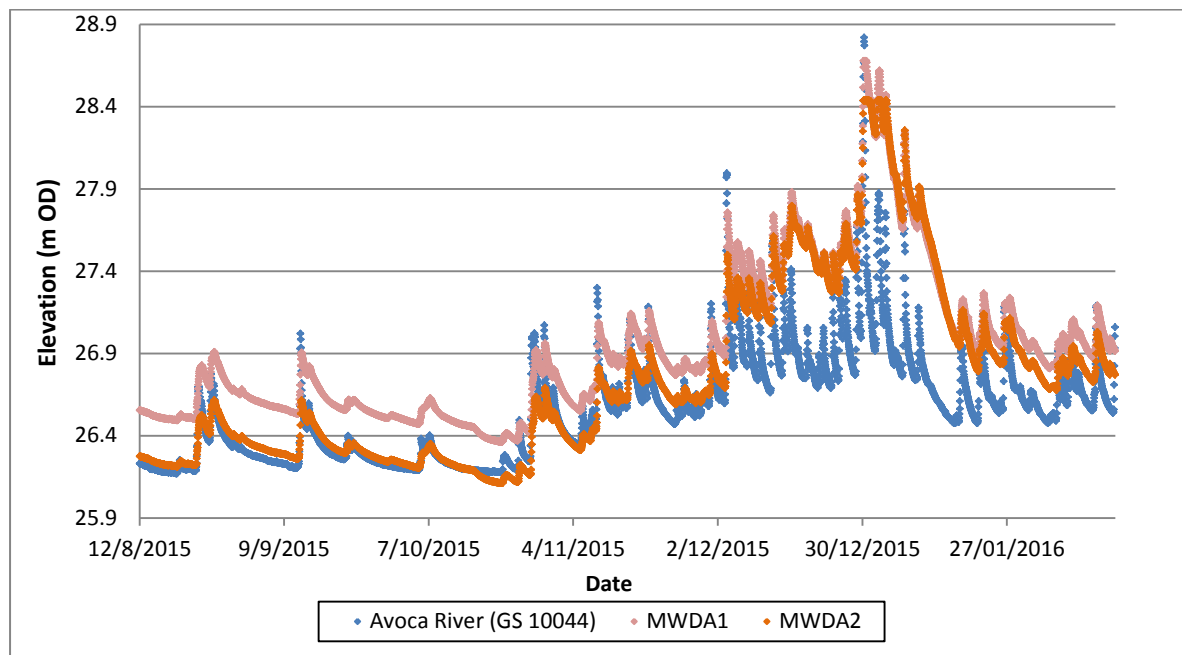


Figure 11 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044) at the Deep Adit Area from 12 Aug 2015 to 16 Feb 2016

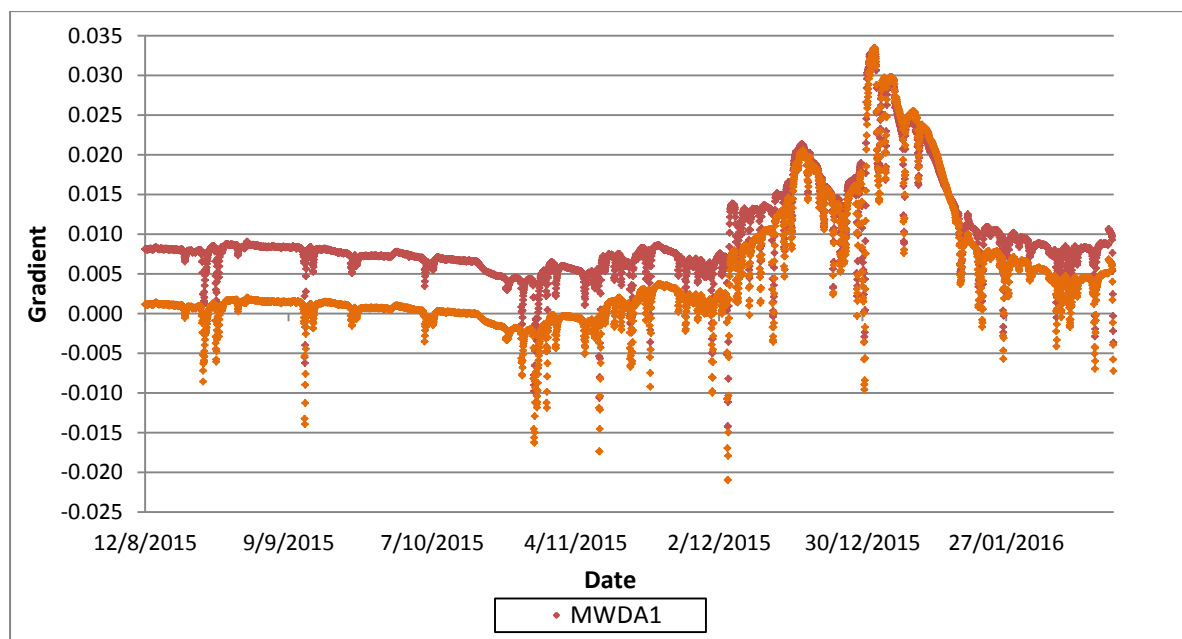


Figure 12 Calculated Groundwater Gradient to the Avoca River at the Deep Adit Area from 12 Aug 2015 to 16 Feb 2016

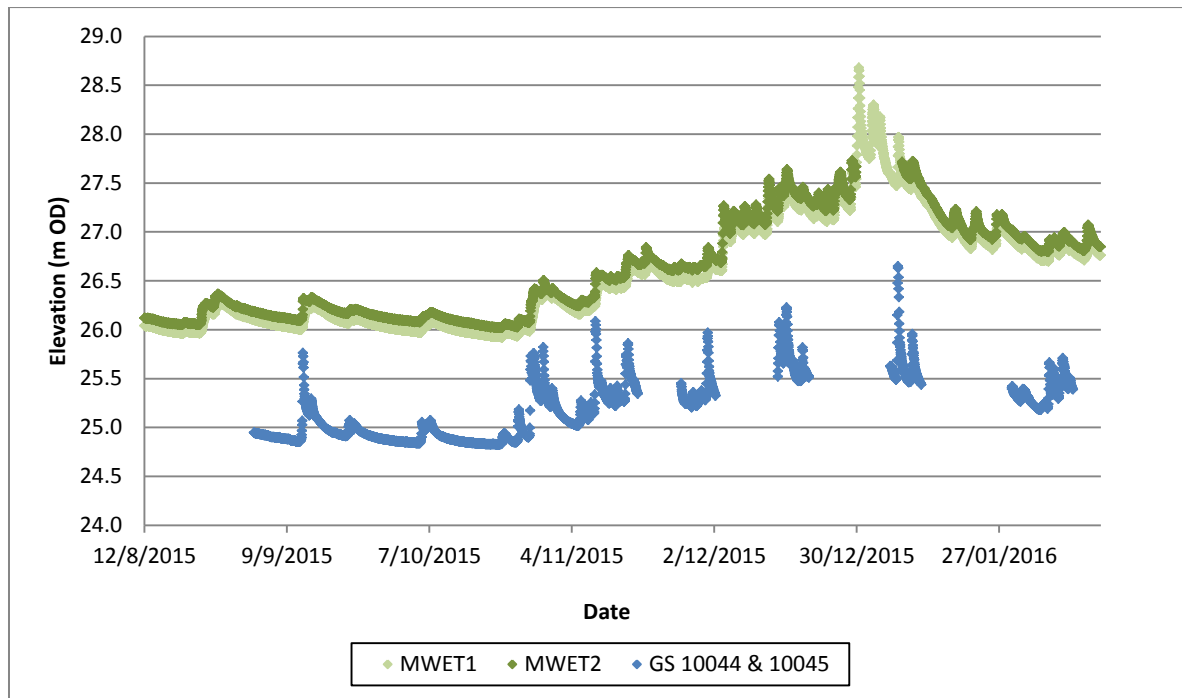


Figure 13 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044 & 10045) at the Emergency Tailings Area from 12 August 2015 to 16 February 2016

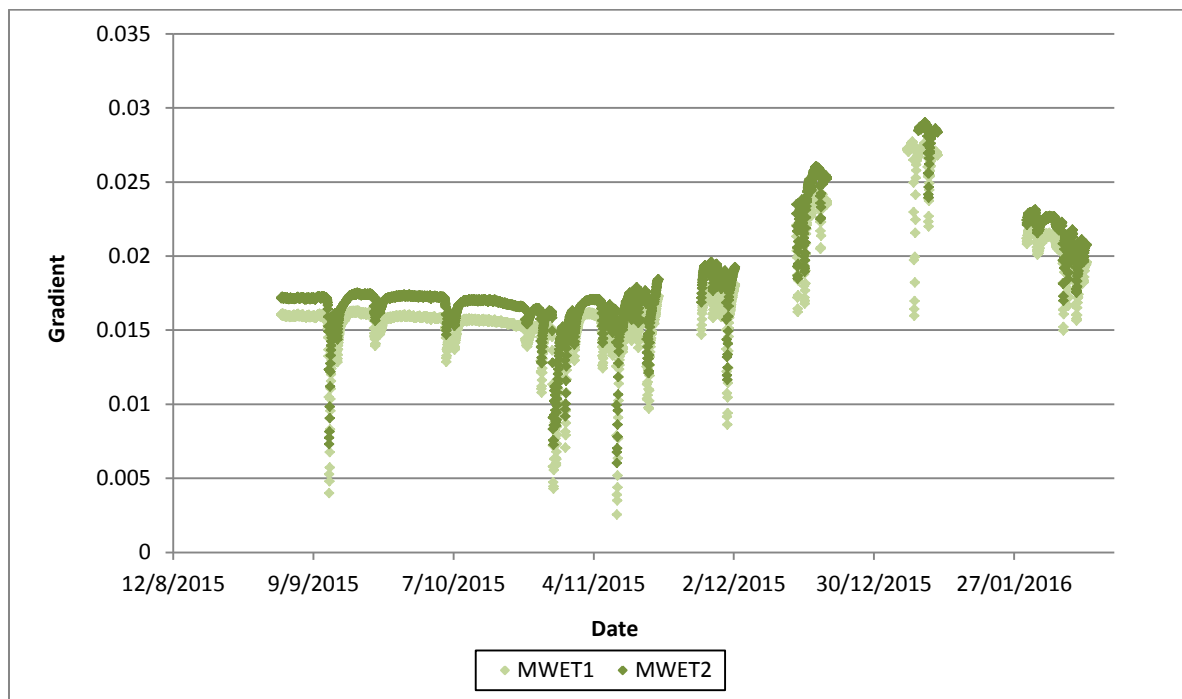


Figure 14 Calculated Groundwater Gradient to the Avoca River at the Emergency Tailings Area from 12 August 2015 to 16 February 2016

6.4 Summary of Diffuse Loading

Overall it has been shown that the Avoca River and its interaction with groundwater is very dynamic. In the Avoca mining area diffuse flow discharges to the Avoca River from a combination of sources including groundwater, ditch infiltration and infiltration on spoil piles.

A significant increase in dissolved metal loads was observed between upstream of the mining area (Site T1) and downstream of the mining area (Avoca Bridge). As illustrated in Figure 4, dissolved iron load increased from 58.6 to 366 kg/day, dissolved zinc load increased from 31.6 to 194 kg/day, dissolved aluminium load increased from 94.3 to 245 kg/day and dissolved copper load increased from 0.66 to 20.7 kg/day.

The increase in dissolved metal loads is primarily due to the 850 Adit, Deep Adit and Road Adit discharges. However, it can be inferred from the findings of previous monitoring rounds and the calculated groundwater gradients (see Section 6.3) that diffuse contamination is also a significant source of dissolved metals to the Avoca River. Note that the Vale View and Sulphur Brook tributaries were not sampled due to very low levels of dissolved metals recorded in previous sampling rounds.

The groundwater gradients are predominantly positive which suggests that the Avoca River is a net gaining river from the alluvium in the Deep Adit area and the Emergency Tailings area during the monitoring period. Very high concentrations of dissolved metals were recorded in the groundwater at the Deep Adit and Emergency Tailings area in R1 (March 2013) to R6 (August, 2015). The implication is that the spoil and the alluvial areas on both sides of the river contribute contaminant load to the river.

A comprehensive review of diffuse contamination will be undertaken in August 2016 facilitated by a full sampling schedule and a tracer study on the Avoca River.

6.5 Surface Water Flow Data at the EPA Gauging Stations

In order to examine whether the Avoca River was a losing or gaining river between Whites Bridge GS and Wicklow County Council Maintenance Yard GS (see Map 3 in [Appendix A](#) for locations) the flow records were examined for the monitoring period.

Discharge measurements in open channel cross-sections are all subject to some level of error. It is not possible to predict the error but an indication can be taken from the deviation plots. The deviation plots compare the measured flow against the rating curve flow. The deviation plots were obtained from the EPA for the Whites Bridge GS and the Wicklow County Council Maintenance Yard GS. The total number of gauging's at Whites Bridge GS was 26 and the difference between the measured flow and the flow rating curve ranged from 0.010 to 1.22 m³/s (or 0.1 to 6.7 %). The total number of gauging's at Council Yard GS was 20 and the difference between the measured flow and the flow rating curve ranged from 0.010 to 0.418 m³/s (or 0.4 to 12.7 %).

The mean daily flow at the two stations were similar during the monitoring period with the percentage difference ranging from 0 to 12 % which is likely to be within the margin of error determined from the deviation plots. The average percentage difference between the two stations over the monitoring period was 4.5 %. Therefore it is not possible to draw any conclusions using the gauge data at this time as to whether the stretch of river between the two gauges is a gaining

or a losing river. In the future when the rating curve is improved and the margin of error is reduced it may be possible to make a determination.

Section 7

Summary and Recommendations

7.1 Summary of Findings

Nine surface water locations were sampled and analysed in February 2016 with flows measured at each location. Water levels were measured at ten groundwater wells. 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 perform trend and loading evaluations.

A statistical summary of the analytical results for surface water was prepared and results were compared to assessment criteria. Analyses of loading, concentration time trends and groundwater levels were also provided.

The overall conclusions are as follows:

- The Cronebane Shallow Adit was the adit discharge with the highest concentrations of dissolved metals including aluminium, copper, iron and zinc. The Cronebane Shallow Adit and the Ballygahan Adit are of minor importance in terms of metal loads to the Avoca River, because of absence of direct flow to the river and low flow respectively.
- In the Avoca River, dissolved metal concentrations were low in comparison to the adit discharges; however, several exceedances of both the ecological and human health criteria occurred downstream of the mining area at Avoca Bridge, namely for dissolved copper, iron, manganese and zinc. Detections of dissolved metal concentrations were recorded upstream of the mining area at Site T1 but no exceedances occurred.
- There was an apparent slight loss of sulphate, dissolved iron and lead load from the Deep Adit and 850 Adit samples when compared to the Deep Adit confluence sample. The decreases in loads are likely due to the precipitation of iron and other metals along the ditch, the loss of flow which can be attributed to the difficulties in measuring the flows or from infiltration.
- The results of the Mann-Kendall analysis for October 2001 to February 2016 show that dissolved copper concentrations are decreasing and dissolved iron concentrations are increasing in the Deep Adit. There is no trend for dissolved zinc. Dissolved zinc, copper and iron were decreasing in the Road Adit. At Avoca Bridge no statistically significant trend was present for dissolved zinc or dissolved copper for both the 2001-2015 period and the 2007-2015 period.
- As river stages change hydraulic gradients to or from the river also change. Gradients are predominantly positive which suggests that the Avoca River is a net gaining river from the alluvium during the monitoring period. The implication is that the spoil and the alluvial areas either side of the river contribute contaminant load to the river.

7.2 Recommendations for the Monitoring Programme

Overall, the reduced monitoring programme both in terms of parameter analysis and sample locations was adequate in meeting the requirements of the February 2016 sampling event. No amendments to the monitoring programme are recommended at this time. However, as outlined in the Summary Report (Document Ref: 95735/40/DG/25, dated 20 January 2016), a full sampling schedule will be completed in Round 8 in addition to a tracer study on the Avoca River.

Section 8

References

CDM (2008). Feasibility Study for Management and Remediation of the Avoca Mining Site. Report prepared for Department of Communications, Energy and Natural Resources.

CDM Smith (2013). Monitoring Report for the Avoca Mining Area Round 1 2013. June 2013. Document Reference: 95735/ DG 06.

European Communities Drinking Water Regulations, 2007 (S.I. No. 106 of 2007).

European Communities Environmental Objectives (Surface Water) Regulations, 2009 (S.I. 272 of 2009).

Hedberg, Y., Herting, G. and Odnevall Wallinder, I. (2011). Risks of using membrane filtration for trace metal analysis and assessing the dissolved metal fraction of aqueous media. A study on zinc, copper and nickel. Environmental Pollution, 159, 1144-1150.

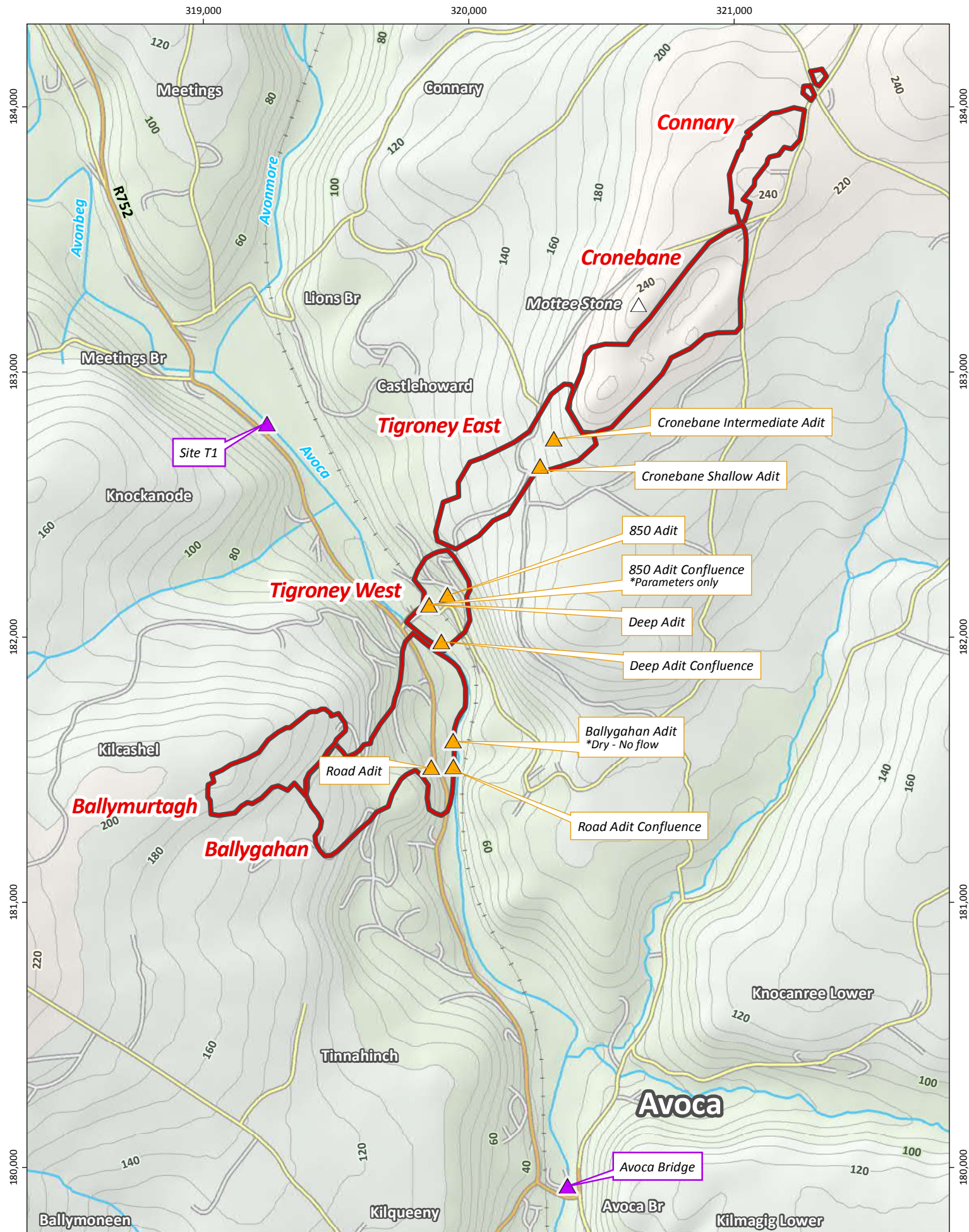
Met Eireann (2016a). Winter Weather Summary. Available from:
<http://www.met.ie/climate/MonthlyWeather>

Met Eireann (2016b). December 2015. Monthly Weather Summary. Available from:
<http://www.met.ie/climate/monthly-weather-reports.asp>

Suter, G.W. II and Tsao, C.L. (1996). Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Appendix A

Figures



Map 1 - Avoca - Main Area

Drawn by: OC Date: 14/04/2016

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\16_MonRptR7\MXD\01_AvocaMon1.mxd

Source: © Ordnance Survey Ireland. All rights reserved. Licence No AR 0095916

CDM Smith

Legend

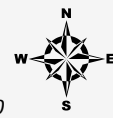
Sampling Locations

- Surface water (Rivers and Streams)
- Surface water (Adit discharges)

*Approximate Locations

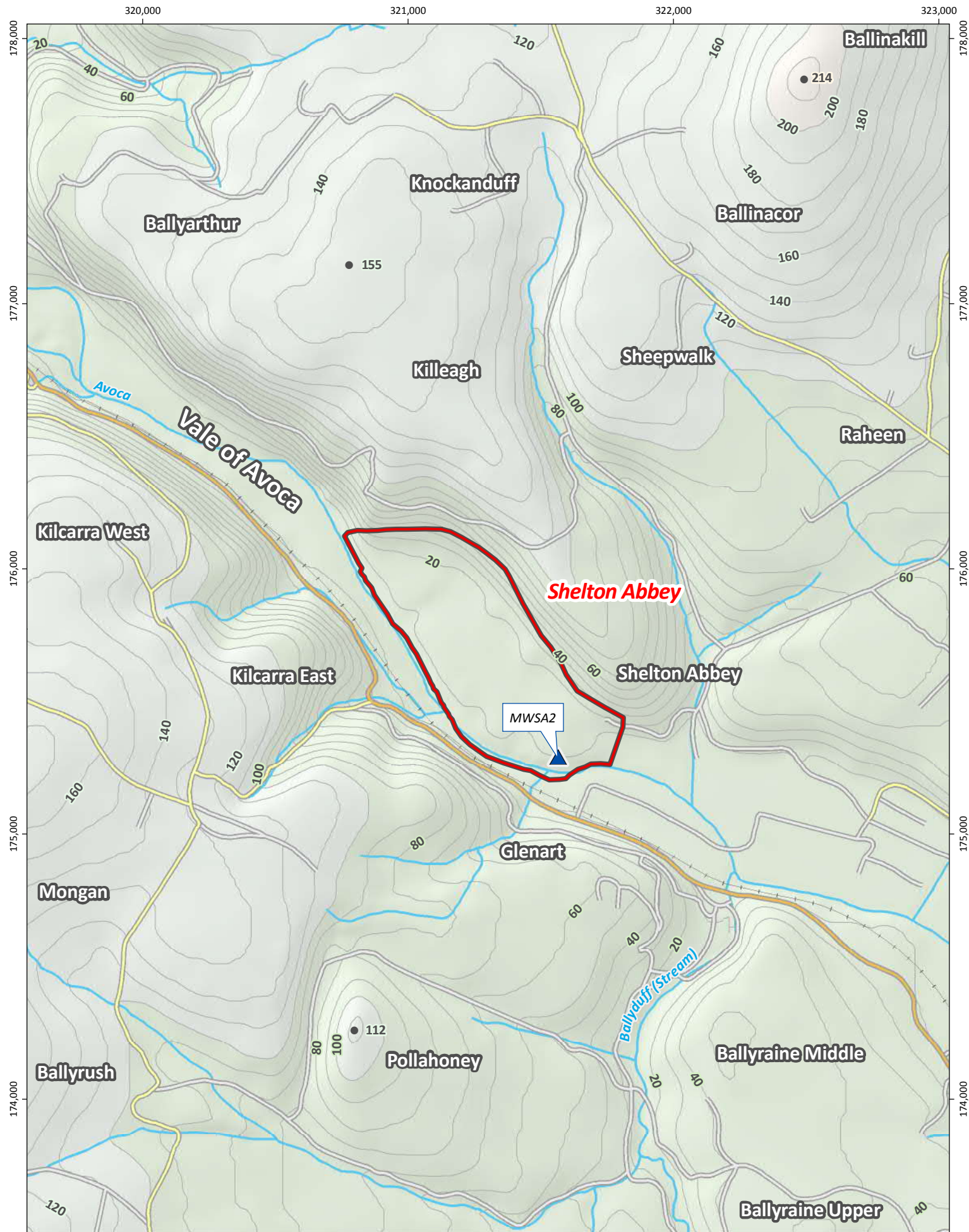
Mines

- Mining Area
- Rivers



Scale is 1:18,000

0 125 250 500 m



Map 2 - Avoca - Shelton Abbey

Drawn by: OC Date: 14/04/2016

Internal Project Reference: Q:\95500-95999\95735\
40 Documents Generated\GIS\02_GIS_Tasks\16_MonRptR7\
MXD\02_AvocaMon2.mxd

Source: © Ordnance Survey Ireland.
All rights reserved. Licence No AR 0095916

**CDM
Smith**

Legend

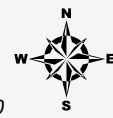
Sampling Locations

▲ Groundwater

Mines

Mining Area

Rivers



Scale is 1:18,000

0 125 250 500 m



Map 3 - Avoca - Main Area - Groundwater and Surface Water

Drawn by: OC Date: 14/04/2016




Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\16_MonRptR7\MXD\03_AvocaMonGW.mxd

Source: © DCENR Lidar Survey (2007)

**CDM
Smith**

Legend

Sampling Locations

-  Surface water (Rivers and Streams)
-  Surface water (Adit discharge)
-  Groundwater*



Borehole R3-04



Rivers



Scale is 1:7,000

0 50 100 m

*Note: Only groundwater levels monitored in February 2016

Appendix B

Analytical Data Tables and Assessment Criteria

Table B-1 Comparison of Groundwater and
Surface Water Results to Assessment Criteria R7

Sample Description			Specific Conductance @ deg.C (field)												
			Ammoniacal Nitrogen as N	Oxygen, dissolved (field)	pH (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)
			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
Units															
Ecological Criteria			0.14	80 to 120*	4.5 to 9	-	-	1,900	-	25	4	0.45	3.4	5.1	5
Human Health Criteria			0.3	-	6.5 to 9.5	2.5	250	200	5	10	-	5	50	-	2000
850 ADIT	Adit	15/02/2016	0.273	80.2	3.11	1.412	772	72500	0.08	1.8	6.1	59.5	1.36	77.9	7670
CRONEBANE INTER ADIT	Adit	15/02/2016	0.384	9.6	3.14	1.368	727	61700	0.3	8.92	4.92	84.2	1.98	78.8	6450
CRONEBANE SHALLOW ADIT	Adit	15/02/2016	0.695	52.8	2.97	2.990	2290	261000	3.04	35.4	7.01	253	7.73	198	11300
DEEP ADIT	Adit	15/02/2016	0.291	25.8	3.58	1.450	955	84500	7.13	0.06	9.89	113	0.11	88.1	350
DEEP ADIT CONFLUENCE	Adit	15/02/2016	0.258	83.8	3.21	1.433	850	88800	0.08	1.23	5.77	56.1	1.11	75.7	5360
ROAD ADIT	Adit	15/02/2016	6.56	31.5	4.36	1.572	922	12200	2.65	0.6	16.1	16.5	1.1	87.3	382
ROAD ADIT CONFLUENCE	Adit	15/02/2016	6.47	74.5	4.39	1.562	913	12300	3.16	0.6	16	17.2	1.1	89	385
SITE T1	River	16/02/2016	1	83.7	6.16	0.068	1	60.8	0.364	0.319	5.25	0.05	0.291	0.129	0.425
AVOCA BRIDGE	River	16/02/2016	1	84.3	6.99**	0.076	9.2	154	0.43	0.319	4.76	0.415	0.344	0.635	13

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

- Not analysed or no assessment criteria

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

** Laboratory result

Table B-1 Comparison of Groundwater and
Surface Water Results to Assessment Criteria R7

Sample Description	Type	Date Sampled	Iron (diss.filt)	Lead (diss.filt)	Manganese (diss.filt)	Molybdenum (diss.filt)	Nickel (diss.filt)	Vanadium (diss.filt)	Zinc (diss.filt)
			µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Ecological Criteria			-	7.2	1100	-	20	-	50
Human Health Criteria			200	10	50	-	20	-	-
850 ADIT	Adit	15/02/2016	35300	809	2510	0.12	37.8	0.241	29000
CRONEBANE INTER ADIT	Adit	15/02/2016	69200	957	2180	0.278	50.2	1.04	31100
CRONEBANE SHALLOW ADIT	Adit	15/02/2016	108000	746	6820	1.2	110	1.2	79300
DEEP ADIT	Adit	15/02/2016	79700	1390	3200	7.85	30.7	1.2	53800
DEEP ADIT CONFLUENCE	Adit	15/02/2016	51800	992	3460	0.12	31.1	0.12	45600
ROAD ADIT	Adit	15/02/2016	70400	309	8050	1.2	44.6	1.2	8470
ROAD ADIT CONFLUENCE	Adit	15/02/2016	68000	305	8100	2.79	44	1.2	8340
SITE T1	River	16/02/2016	37.8	2.45	20.4	0.12	0.829	0.12	20.4
AVOCA BRIDGE	River	16/02/2016	230	3.21	50.1	0.12	0.97	0.12	122

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

- Not analysed or no assessment criteria

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

** Laboratory result



**CDM
Smith**
cdmsmith.com