

Department of Communications,
Climate Action and Environment



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

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

Final



**CDM
Smith**



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1	P Barrett	R O'Carroll	R L Olsen	Nov 2016

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Section 1

Introduction

1.1 Objectives and Scope

The Department of Communications, Climate Action and Environment (the Department) appointed CDM Smith Ireland Ltd (CDM Smith) to undertake a programme of environmental monitoring at the closed mine sites of Silvermines and Avoca for a three year period, 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 August 2016. This report should be read alongside the Avoca Data Report (Document Ref: 95735/40/DG28, dated October 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 and August 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 August 2016, no flow was discharging from the 850 Adit and a temporary gate had been installed. Engineering works were ongoing at the Tigroney West spoils area in August 2016.

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 council 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 August 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 in August 2016. Minor discharges from the seeps on the cliff bank were observed from a downstream location.

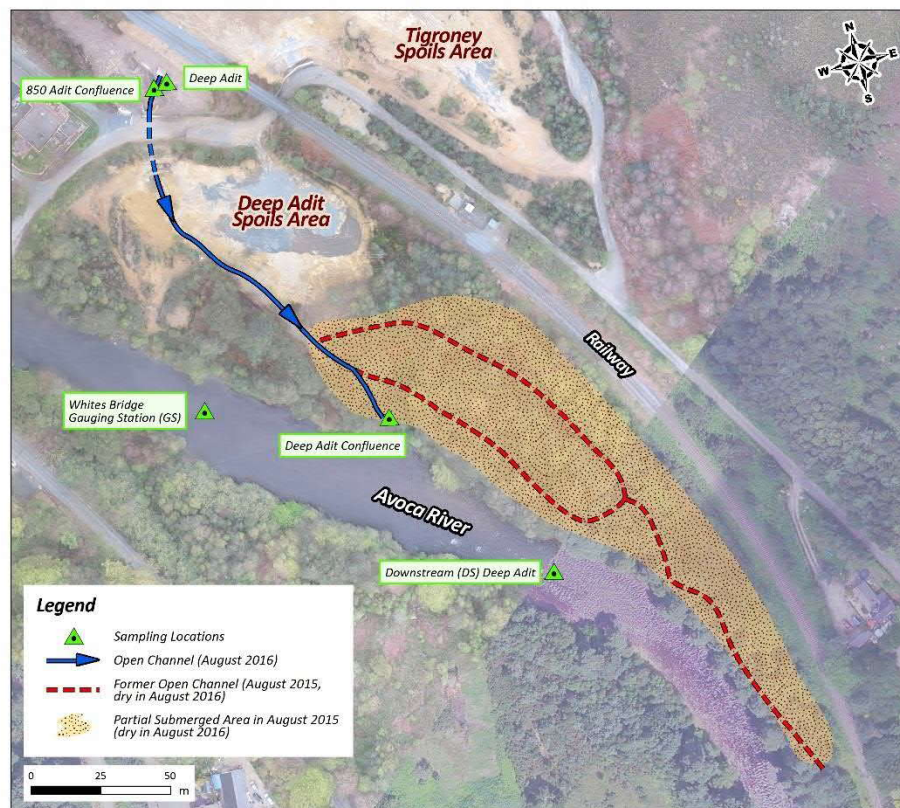


Figure 1 Location of the Deep Adit Confluence Discharge (August 2016)

Section 2

Methodology

2.1 Field Sampling Methods

2.1.1 Groundwater Sampling

Eight groundwater monitoring wells were sampled on 29 and 30 August 2016. No sample was collected from one additional well (SG104) because the well was dry. Additionally, a sample was collected of a drinking water spring (FS-1) located east of Tigroney West spoils area. Details of groundwater monitoring locations are listed in Table 1 and illustrated on Map 2 and 3 in [Appendix A](#).

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

- 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).

The Wicklow County Council monitoring wells follow:

- Three of the wells were installed for Ballymurtagh Landfill monitoring purposes (GW1/05, GW2/05 and SG104), which are located downgradient of the landfill (in West Avoca) and one located at the toe of the landfill (SG104).

Additional monitoring well:

- R3-04 is located on the Tigroney West spoils and was installed in October 2014 as part of the Avoca Works project.

Table 1 Location of Avoca Groundwater Monitoring Points

Sample ID	Sample Type	Easting	Northing	Water Level	Field Parameters	Sample for Lab Analysis	Owner	Depth (m-bgl)	Screen Interval (m bgl)
MWDA1	Borehole	319877	182043	Yes	Yes	Yes	Dept.	12	9.0 – 12
MWDA2	Borehole	319879	182039	Yes	Yes	Yes	Dept.	24.9	21.9 – 24.9
MWET1	Borehole	319916	181778	Yes	Yes	Yes	Dept.	10.9	7.8 – 10.6
MWET2	Borehole	319917	181781	Yes	Yes	Yes	Dept.	21	17 – 20
MWPF1	Borehole	319678	182296	Yes	Yes	Yes	Dept.	10	4.7 – 7.7
MWSA2	Borehole	321566	175292	Yes	Yes	Yes	Dept.	12.6	8.0 – 11

Sample ID	Sample Type	Easting	Northing	Water Level	Field Parameters	Sample for Lab Analysis	Owner	Depth (m-bgl)	Screen Interval (m bgl)
GW1/05	Borehole	319880	181673	Yes	Yes	Yes	WCC	31	25.0 – 31
GW2/05	Borehole	319880	181673	Yes	Yes	Yes	WCC	10	4.0 – 10
SG104	Borehole	319806	181523	Yes	Yes	Yes	WCC	26.8	-
R3-04	Borehole	319879	182171	Yes	No	No	Dept.	16.1	-
FS-1	Spring	320005	182009	-	Yes	Yes	-	-	-

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

Water quality indicator parameters were monitored in the field during low-flow purging using a flow-through cell to minimise oxidation by the atmosphere. Water quality indicator parameters include temperature, pH, ORP, conductivity and dissolved oxygen (DO). Purging continued until the field parameters had stabilised. The results were recorded approximately every five minutes during the purging process on the Groundwater Purging and Sampling Form. Field sheets are contained in Appendix H and physico-chemical field data are summarised in Appendix A of the Data Report.

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

The exceptions to the low-flow sampling procedure were for GW2/05 where sufficient water was not present in the well and GW1/05 where a blockage exists in the well which obstructs access. The samples were collected using single use bailers, after greater than three volumes of the well had been purged (calculated as $\pi r^2 h$ – where r is the inner casing radius and h is the height of the water column) and the field parameters had stabilised.

Groundwater levels were measured at the nine wells using a portable electronic water level recorder. Groundwater levels were also measured at R3-04. Automatic groundwater recorders have been placed in six wells and the data were downloaded. Groundwater level data are discussed in Section 6 and the data are contained in Appendix C of the Data Report.

2.1.2 Surface Water Sampling

Twenty surface water locations were sampled between 30 August and 1 September 2016 as listed in Table 2 and shown on Map 1 and 2 in [Appendix A](#). Four sampling locations on the Avoca River (US Whites Bridge, DS Millrace, US Ballygahan Adit and DS Ballygahan Adit) were added to the monitoring programme to provide greater detail of the dissolved metal loads in the Avoca River. No sample could be collected from Ballygahan Adit or the 850 Adit because they were dry at the time of sampling.

Surface water sampling was conducted consistent with the Surface Water Sampling Procedure (SOP 1-1) as detailed in the Monitoring Plan.

The predetermined surface water sampling locations were located in the field using a GPS. Photographs were taken of the surface water sampling locations (Appendix D of the Data Report). The sample location was approached from downstream so that the underlying sediments are not disturbed. Samples were grab samples collected from a well-mixed portion of the water stream where possible. For monitoring locations on the Avoca River, samples were collected as composite samples across the River, whereby a volume of water was collected along a transect across the river in proportion to the river flow. Water was collected from approximately 6 to 10 locations (depending on the width of the channel) along the transect. At Shelton Abbey, a grab sample from the bank was collected using an extendable rod because the river is not wadable at this location.

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	Flow Meter	Yes
Upstream (US) of Whites Bridge*	Avoca River Location (between Site T1 and Whites Br.)	319584	182389	Equal to flow recorded at Whites Bridge GS	Yes
Whites Bridge	Avoca River Location (at Whites Br.)	319773	182066	Equal to flow recorded at Whites Bridge GS	Yes
Whites Bridge Gauging Station GS (10044)	Avoca River Location (90m downstream of Whites Br.)	319843	182015	Automatic recorder - Whites Bridge GS (Data from EPA)	Yes
Downstream (DS) Deep Adit	Avoca River Location (Downstream of Deep Adit confluence on the Avoca River)	319951	181922	Equal to flow recorded at Whites Bridge GS	Yes
Downstream (DS) of Millrace*	Avoca River location (Downstream of contaminated Millrace area)	320016	181796	Equal to flow recorded at Whites Bridge GS (less Deep Adit discharge)	Yes
Upstream (US) of Ballygahan Adit*	Avoca River Location (Upstream of Ballygahan Adit discharge)	319936	181633	Equal to flow recorded at Wicklow County Council Maintenance Yard GS (less Road Adit discharge)	Yes
Downstream of Ballygahan Adit*	Avoca River Location (Downstream of Ballygahan Adit discharge)	319961	181595	Equal to flow recorded at Wicklow County Council Maintenance Yard GS (less Road Adit discharge)	Yes
Upstream (US) of Road Adit	Avoca River Location (Upstream of Road Adit Discharge on the Avoca River)	319942	181532	Equal to flow recorded at Wicklow County Council Maintenance Yard GS	Yes

Site Name	Sample Site Description	Easting	Northing	Flow Measurement Method	Sample collected?
Wicklow Co. Co. Maintenance Yard Gauging Station GS	Avoca River Location	319939	181445	Automatic Recorder - Wicklow County Council Maintenance Yard GS (Data from EPA)	Yes
Site T5	Avoca River Location (Abandoned Coal Yard)	319972	181114	Flow Meter	Yes
Avoca Bridge	Avoca River (Upstream of Avoca Bridge)	320372	179932	Float method	Yes
Upstream (US) of Shelton Abbey	Avoca River Location	320847	175947	Equal to measured flow downstream of Shelton Abbey	Yes
Downstream (DS) of Shelton Abbey	Avoca River Location	321939	175213	Float Method used at bridge to fertiliser plant. No flow measured for this location. Float method results from IFI bridge	Yes
850 Adit	Adit Discharge (at portal)	319919	182161	No Flow	No
850 Adit Confluence	Adit Discharge (before entering Deep Adit Discharge)	319845	182122	No Flow	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
Cronebane Shallow Adit	Adit Discharge	320268	182646	Flume	Yes
Ballygahan Adit	Adit Discharge	319940	181610	No Flow	No

* New sampling location

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 10 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, data were obtained from the EPA for the existing automatic recorders at Whites Bridge GS (EPA station 10044) and Wicklow County Council Maintenance Yard GS (EPA Station 10045) and projected to seven locations. 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 from a bridge at regular intervals (approximately 8 locations). The float was released into the channel upstream from the beginning of the section and measured the amount of time it takes the “float” to travel the marked section. This was repeated at least three times and the average time calculated.

2.1.3 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):

- Groundwater:
 - One duplicate groundwater sample was collected; and
 - One decontamination blank was collected by pumping deionised (DI) water through the groundwater pump after decontamination.
- Surface Water:
 - Two duplicate surface water samples; and
 - One decontamination blank was collected by pouring DI water over the surface water sampling equipment after decontamination.
- Two certified standard reference materials (SRMs) 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 samples are 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
AVGD01.8	GW Duplicate	Duplicate of MWSA2
AVDB01.8	GW Decontamination blank	DI water (Lennox Lab Supplies: Batch No: 602-5965) Pumped through groundwater pump after final decon at site MWSA2
AVSD01.8	SW Duplicate	Duplicate of US Road Adit
AVSD02.8	SW Duplicate	Duplicate of Cronebane Intermediate Adit
AVDB02.8	SW Decontamination blank	DI water (Lennox Lab Supplies: Batch No: 602-5965) poured over SW composite sample bottle after final decon at Cronebane Intermediate Adit.
AVSR01.8	Standard Reference Material	Water ERA “Trace Metals” Lot #P252-740A
AVSR02.8	Standard Reference Material	Water ERA “Trace Metals” Lot #P252-740A
WB01.8	Filtration blank	Deionised water filtered onsite (Lennox Lab Suppliers. Batch No: 602-5965)
WB02.8	Water blank	Deionised water (Lennox Lab Suppliers. Batch No: 602-5965)

2.2 Sample Handling

One waterproof label for each sample container collected was completed with an indelible, waterproof, marking pen. The label contained the location, Sample ID code and date 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 (both surface water and groundwater) samples were dispatched from its distribution centre in Dublin and analysed at its facility in North Wales. ALcontrol is accredited by the United Kingdom Accreditation Service (UKAS) in accordance with ISO/IEC 17025:2005 and has also obtained a Certification of Approval by Lloyd’s Register Quality Assurance for Environmental Management System Standard ISO 14001:2004. For groundwater and surface water, analyses were performed for the following parameters: pH, ammoniacal nitrogen as N, sulphate and dissolved metals including Al, Sb, As, Ba, Cd, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, V and Zn.

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

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

Section 3

Data Quality and Usability Evaluation

3.1 Introduction

Laboratory data quality and usability were assessed using data quality indicators (DQIs). Data “usability” means that the data are 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
 D₁ = First sample value
 D₂ = 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: Duplicate groundwater and surface water samples were created in the field and submitted blind to the laboratory (see Table 3 for sample IDs). The results are used to evaluate the combined reproducibility of both the laboratory analyses and field sampling;
- Decontamination Blanks: After the sampling equipment was cleaned, DI water was poured over or pumped through the sampling equipment and collected for laboratory analysis (see Table 3 for sample IDs). Analyses of these samples were used to evaluate the adequacy of the sampling equipment cleaning or decontamination procedure;
- Standard Reference Material (SRM): Two certified water SRMs were sent blind to the laboratory (Sample IDs AVSR01.8 and AVSR02.8) to evaluate laboratory accuracy. The certified SRM was supplied by ERA Certified Reference Materials and was Lot #P252-740A (Metals). The Certificate of Analysis is provided in Appendix G of the Data Report. The use of a blind or unknown SRM is the only method to independently verify the laboratory accuracy.
- One water blank was collected of the DI water during the sampling event. An additional filtration blank using DI water was collected in order to try to quantify any contamination caused by the filtration procedure.

3.2 Results of Field QA/QC Samples

3.2.1 Duplicates

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

All of RPD values were below 50 % and the RPDs for the key parameters ranged from 1.1 to 2.5 % for aluminium, 0 to 4.7% for copper 0.4 to 3.7% for manganese and 0.5 to 4.9 % for zinc which was very good. 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)	MWSA2	AVGDO 1.8	% RPD	US Road Adit	AVSD0 1.8	% RPD	Crone-bane Inter. Adit	AVSD0 2.8	% RPD
Aluminium	<2.9	60100	58700	2.4	158	162	-2.5	36500	36100	1.1
Antimony	<0.1	1.11	<0.96*	14.5	<0.16	<0.16	0	<0.96*	<0.96*	0
Arsenic	<0.1	27.7	26.2	5.6	0.53	0.685	-25.5	13.2	13.7	-3.7
Barium	<0.0	12.4	12.8	-3.2	4.69	4.68	0.2	9.16	8.98	2.0
Cadmium	<0.1	2.26	2.37	-4.8	0.449	0.445	0.9	88.5	91.2	-3.0
Chromium	<0.2	7.78	8.24	-5.7	<1.2*	<1.2*	0	<7.2*	<7.2*	0
Cobalt	<0.0	165	164	0.6	0.704	0.724	-2.8	62	65.4	-5.3
Copper	<0.8	153	153	0.0	13.5	13.4	0.7	560	587	-4.7
Iron	<19	94.8	93.5	1.4	174	174	0.0	77.1	70.1	9.5
Lead	<0.0	30.7	30.8	-0.3	3.58	3.49	2.5	1190	1210	-1.7
Manganese	<0.0	24200	24100	0.4	35.4	34.1	3.7	2040	2090	-2.4
Molybdenu	<0.2	<3.72*	<3.72*	0	<0.62*	<0.62*	0	<3.72*	<3.72*	0
Nickel	<0.1	108	110	-1.8	0.813	0.923	-12.7	36.9	36.3	1.6
Vanadium	<0.2	<7.8*	<7.8*	0	<1.3*	<1.3*	0	<7.8*	<7.8*	0
Zinc	<0.4	3840	3860	-0.5	189	180	4.9	24200	24900	-2.9

Notes:

Bold indicates an exceedance in the Duplicate RPD acceptance criteria

*The LOD was raised due to a dilution that was carried out on the sample.

3.2.2 Decontamination Blanks

Two decontamination blanks were created by pumping DI water through or pouring water over the sampling equipment after decontamination and sent to ALcontrol for analysis. Table 5 provides the results of the 15 metals for the two decontamination blank samples, the DI water blank and filtration blank samples and the associated laboratory method blank samples.

The majority of reported concentrations were below the limits of detection. Most metals were analysed by ICP-MS to achieve the lowest possible detection limits. The limits of detection ranged from 0.02 to 2.9 µg/l except for iron with a detection limit of 19 µg/l.

Detections were observed for eight dissolved metals ranging from 0.037 to 73.1 µg/l except for one result of 95.5 µg/l for aluminium. Three of the metals (aluminium, copper and zinc) detected

in the decontamination blanks were also detected in the DI water filtration blank (WB01.8). Relatively low concentrations of dissolved chromium, iron, lead, molybdenum and nickel were also found in the decontamination blanks but not the DI water blanks.

The levels of detections in the DI water filtration blank were significantly greater than those found in the decontamination blank. The concentrations recorded in the DI filtration blank sample (aluminium at 95.5 µg/l, copper at 12.3 µg/l, manganese at 5.94 µg/l and zinc at 34.4 µg/l) were checked and confirmed by ALcontrol. The laboratory advised that such cases may be caused by hotspots in the sample.

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

In total there were ten detections of dissolved metals in the decontamination blanks. Three of the parameters which were detected in the decontamination blanks but not detected in the DI water blank were greater than ten times the detection limit; In AVDB01.8, chromium (2.96 µg/l) and nickel (2.75 µg/l) and in AVDB02.8, lead (0.262 µg/l). None of the reported values which were detected in both the DI water blank and the decontamination blank were greater than ten times the detection limit. All of the detections including chromium, nickel and lead were less than the assessment criteria outlined in Section 4; therefore, these low concentrations in the blanks do not affect interpretation of results. Overall, the decontamination procedures employed in the field were adequate.

To assess the level of cross contamination between samples in the field, the concentrations in the decontamination blanks were compared with the concentration in the preceding environmental samples. In AVDB01.8, chromium (2.96 µg/l) was 38% of the preceding sample, nickel (2.75 µg/l) was 2.5%, copper (2.34 µg/l) was 1.5%, zinc (1.57 µg/l) was 0.04% and iron (73.1 µg/l) was 0.1%. In AVDB02.8, lead (0.262 µg/l) was 0.02% of the preceding sample, aluminium (4.72 µg/l) was 0.01% and iron (37.4 µg/l) was 0.04%. The concentration of chromium in the blank sample was below the ecological health assessment criteria of 3.4 µg/l and significantly below the human health assessment criteria of 50 µg/l. However, the detection of chromium in the blank sample may indicate cross contamination and therefore concentrations of chromium in the groundwater samples should be used with caution.

The results from the laboratory instrumentation blank were obtained from ALcontrol to determine if any contamination occurred within the laboratory (Table 5). It was noted dissolved molybdenum was detected in the method blank (1.24 µg/l) for Sample Batch 160825-107 and was similar to the concentration in the decontamination blank sample (0.697 µg/l).

Overall, the decontamination procedures were adequate and blank samples do not indicate any cross-contamination in the field and therefore all the results are considered acceptable and can be used for their intended purposes. One exception is for chromium which was detected in the groundwater decontaminated blank sample at 38% of the concentration in the preceding sample.

Therefore, it is recommended that concentrations of dissolved chromium in the groundwater samples are used with caution.

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

Dissolved Metal	LOD (µg/l)	Filtration Blank WB01.8 (µg/l)	Water Blank WB02.8 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank AVDB01.8 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank AVDB02.8 (µg/l)	Laboratory Method Blank (µg/l)
Sample batch:		160902-24			160903-17		160904-11	
Aluminium	<2.9	95.5	<2	<2	<2	<2	4.72	<2
Antimony	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16
Arsenic	<0.12	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51	<0.51
Barium	<0.03	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cadmium	<0.1	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Chromium	<0.22	<1.2	<1.2	<1.2	2.96	<1.2	<1.2	<1.2
Cobalt	<0.06	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15
Copper	<0.85	12.3	<0.85	<0.85	2.34	<0.85	<0.85	<0.85
Iron	<19	<19	<19	<19	73.1	<19	37.4	<19
Lead	<0.02	<0.1	<0.1	<0.1	0.107	<0.1	0.262	<0.1
Manganese	<0.04	5.94	<0.76	<0.76	<0.76	<0.76	<0.76	<0.76
Molybdenum	<0.24	<0.62	<0.62	1.2	0.697	1.24	<0.62	1.14
Nickel	<0.15	<0.44	<0.44	<0.44	2.75	<0.44	<0.44	<0.44
Vanadium	<0.24	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Zinc	<0.41	34.4	<1.3	<1.3	1.57	<1.3	<1.3	<1.3

Notes:

Bold indicates a detection

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

Italics indicates a detection in the lab method blank that was also detected in a field water or decontamination blank in the same batch

3.2.3 Standard Reference Materials

As previously discussed, two certified water SRMs were sent blind to the laboratory (Sample IDs AVSR01.8 and AVSR02.8) to evaluate laboratory accuracy. The ALcontrol laboratory reports are provided in Appendix F of the Data Report. Table 6 summarises the SRM results and provides the calculated %R values for the 15 requested metals.

Reported values for the majority of the metals were within the acceptable ranges. Dissolved aluminium, antimony, chromium, cobalt, copper, lead, manganese, molybdenum, nickel, vanadium and zinc are in excellent agreement with the certified value (%R ranged from 89 to 107 %).

One of the reported values for dissolved arsenic (86 %), barium (85 %), cadmium (82 %) and iron (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 is not affected.

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

Dissolved Metal	Certified Value (µg/l)	Acceptance Limits		AVSR01.8 (µg/l)	% R	AVSR02.8 (µg/l)	% R
		Lower (%)	Upper (%)				
Aluminium	1370	88	114	1400	102	1380	101
Antimony	665	87	111	630	95	632	95
Arsenic	647	87	111	574	89	556	86
Barium	1150	91	109	1060	92	980	85
Cadmium	221	89	106	204	92	181	82
Chromium	783	91	109	778	99	772	99
Cobalt	919	93	111	948	103	941	102
Copper	390	91	109	399	102	398	102
Iron	1900	90	111	2030	107	1690	89
Lead	1380	90	110	1420	103	1390	101
Manganese	499	92	109	500	100	492	99
Molybdenum	467	90	109	459	98	463	99
Nickel	625	91	109	632	101	619	99
Vanadium	597	91	107	575	96	609	102
Zinc	637	91	110	633	99	625	98

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 taken 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 AQCs.

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

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 34.1%. 71% of samples had calculated %RPD values of less than 20%. Field pH is more representative of actual conditions and is used for interpretive purposes. Recordings of pH in the field are typically lower than the laboratory due to carbon dioxide degassing during transport or within the laboratory itself. Overall, the %RPDs between the field and laboratory data are considered satisfactory.

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

Sample Description	pH Lab	pH Field	% RPD
	pH Units		
Cronebane Inter. Adit	3.1	3.36	8.0
Cronebane Shallow Adit	2.85	2.58	-9.9
Deep Adit	3.39	3.52	3.8
Deep Adit Conf.	3.19	3.84	18.5
Road Adit	4.04	3.79	-6.4
Road Adit Confluence	3.92	3.84	-2.1
Site T1	7.1	5.96	-17.5
US Whites Bridge	7.14	6.26	-13.1
Whites Bridge	7.04	6.52	-7.7
Whites Bridge (GS)	7.05	6.51	-8.0
DS Millrace	6.74	5.74	-16.0
DS Deep Adit	6.18	6.29	1.8
US Ballygahan Adit	6.91	6.04	-13.4
US Road Adit	6.88	5.58	-20.9
DS Ballygahan Adit	6.93	5.64	-20.5
Wicklow Co.Co. Main. Yard GS	6.68	5.6	-17.6

Sample Description	pH Lab	pH Field	% RPD
	pH Units		
Site T5	6.95	5.63	-21.0
Avoca Bridge	6.84	6.05	-12.3
US Shelton Abbey	7.31	5.6	-26.5
DS Shelton Abbey	7.29	5.83	-22.3
FS-1*	7.34	5.2	-34.1

Notes:

Bold indicates an exceedance in acceptance limits

Section 4

Results and Evaluations

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

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

4.1 Statistical Summary of Analytical Results

4.1.1 Groundwater Sample Results

Table 8 provides a summary of the reported dissolved concentrations of the nine groundwater samples (8 boreholes, 1 spring). Included in the table 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.

Table 8 Summary of Dissolved Metal Concentrations in Groundwater (Boreholes and Spring Discharge)

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2	9	8	1 (6*)	107,000	45,400	41,400
Antimony	<0.16	9	1	0.08	1.11	-	-
Arsenic	<0.51	9	7	0.255	27.7	6.95	8.2
Barium	<0.2	9	9	2.16	12.8	6.96	3.66
Cadmium	<0.08	9	9	0.238	81.8	25.8	31.4
Chromium	<1.2	9	5	0.6	24.4	8.02	8.04
Cobalt	<0.15	9	8	0.075	206	114	75.7
Copper	<0.85	9	7	0.425 (2.55*)	15,200	4,680	5,460
Iron	<19	9	9	21.6	127,000	52,300	55,100
Lead	<0.1	9	8	0.202	30.8	5.88	9.79
Manganese	<0.76	9	9	0.909	29,300	9,780	10,300
Molybdenum	<0.62	9	0	0.31	0.31 (1.86*)	-	-
Nickel	<0.44	9	8	0.22	110	53.1	42.3
Vanadium	<1.3	9	0	0.65	0.65 (3.9*)	-	-
Zinc	<1.3	9	9	33.6	54,800	14,600	19,800

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 the majority of groundwater (borehole) samples. The shallow well MWPF1 located upgradient of the Deep Adit area, near the eastern margin of the alluvial sediments had the lowest concentrations of dissolved metals. However, MWET2 had the lowest concentration of dissolved aluminium (<12 µg/l), copper (<5.1 µg/l) and zinc (45.8 µg/l). MWET1 had the highest concentrations of aluminium (107,000 µg/l) and iron (127,000 µg/l). MWDA1 had the highest

concentrations of copper (15,200 µg/l) and cadmium (81.8 µg/l). MWDA2 had the highest concentration of zinc (54,800 µg/l). Dissolved arsenic was only detected in MWSA2 which with a recorded value of 27.7 µg/l. The concentrations of dissolved metals were very low at FS-1 (drinking water spring) with 7 detections reported.

4.1.2 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 9 provides a summary of the reported results of the six adit discharge samples and Table 10 provides a summary of the dissolved metals of the 14 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 9 Summary of Dissolved Metal Concentrations in Adit Discharges

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2	6	6	10,900	403,000	104,000	150,000
Antimony	<0.16	6	0	0.08 (0.48*)	0.08 (0.88*)	-	-
Arsenic	<0.51	6	6	13.7	49.9	25.4	15.7
Barium	<0.2	6	6	6.78	16.1	11.4	3.77
Cadmium	<0.08	6	6	12.1	317	99.2	113
Chromium	<1.2	6	2	0.6 (3.6*)	38.8	-	-
Cobalt	<0.15	6	6	65.4	296	119	88.5
Copper	<0.85	6	6	85.2	5,480	1,130	2,140
Iron	<19	6	6	51,500	174,000	80,800	46,500
Lead	<0.1	6	6	345	1,730	1,030	584
Manganese	<0.76	6	6	2,090	9,310	4,880	2,480
Molybdenum	<0.62	6	0	0.31 (1.86*)	0.31 (3.41*)	-	-
Nickel	<0.44	6	6	32	154	56.2	48.1
Vanadium	<1.3	6	0	0.65 (3.9*)	0.65 (7.15*)	-	-
Zinc	<1.3	6	6	6,300	145,000	43,600	51,900

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.

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 (403,000 µg/l), copper (5,480 µg/l), iron (174,000 µg/l), manganese (9,310 µg/l) and zinc (145,000 µg/l). Significant concentrations of arsenic were recorded at all sampling locations ranging from 13.7 µg/l at Cronebane Intermediate Adit to 49.9 µg/l at Cronebane Shallow Adit. No detections were recorded for antimony, molybdenum and vanadium. No samples were collected from the 850 Adit and Ballygahan Adit because they were not discharging water in August 2016.

Avoca River

Table 10 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)	SDEV
Aluminium	<2	14	14	48.7	191	121	45.7
Antimony	<0.16	14	3	0.08	1.26	0.18	-
Arsenic	<0.51	14	9	0.255	0.743	0.49	0.19
Barium	<0.2	14	14	4.5	5.31	4.87	0.24
Cadmium	<0.08	14	11	0.04	1.4	0.41	0.35
Chromium	<1.2	14	0	0.6	0.6	-	-
Cobalt	<0.15	14	11	0.075	1.64	0.67	0.49
Copper	<0.85	14	14	0.98	14.5	8.82	4.65
Iron	<19	14	14	59.4	703	222	195
Lead	<0.1	14	14	1.26	10.3	3.39	2.43
Manganese	<0.76	14	14	3.48	97	36.9	26.9
Molybdenum	<0.62	14	4	0.31	4.33	0.73	1.08
Nickel	<0.44	14	14	0.498	1.13	0.82	0.2
Vanadium	<1.3	14	0	0.65	0.65	-	-
Zinc	<1.3	14	14	17.9	578	173	149

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.

Dissolved metals were detected upgradient of the mining area at Site T1 with concentrations of aluminium at 50.4 µg/l, copper at 0.98 µg/l, iron at 60.7 µg/l, manganese at 3.48 µg/l and zinc at 18.4 µg/l.

Between Site T1 and US Whites Bridge (365m upstream of the bridge) no significant increases in dissolved metals were recorded. Whites Bridge (at the bridge) is the first sampling location along the Avoca River within the mining area where increases in metals concentrations are observed namely; aluminium (51.3 µg/l), copper (10.8 µg/l) and zinc (17.1 µg/l).

Along the Avoca River the concentrations of dissolved metals were variable; the highest dissolved aluminium was 191 µg/l recorded at US Ballygahan Adit. The highest dissolved copper was 14.5 µg/l recorded at DS Ballygahan Adit. The highest dissolved cadmium (1.4 µg/l) and zinc (578 µg/l) were recorded at DS Deep Adit. Concentrations of dissolved manganese (97 µg/l) and iron (703 µg/l) were highest at WCC Maintenance Yard GS (downstream of the Road Adit discharge).

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

To assess the analytical results of the 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 11. These include standards for physico-chemical conditions

supporting the biological elements general conditions and standards for specific pollutants. In the case of metals, the EQS refers to the dissolved concentration. Compliance with the standards in the surface water regulations is either based on an annual average (AA), a maximum allowable concentration (MAC) or a 95 percentile standard. The MAC or 95 percentile (95%-ile) was selected where possible as the assessment criteria because it is the most appropriate for assessment of one value; however, the AA was used in the absence of the MAC or 95%-ile. To supplement the Irish legislation, screening criteria were selected from Oak Ridge National Laboratory (Suter and Tsao, 1996) for certain metals including aluminium, barium, cobalt, manganese and uranium (Table 11).

For hardness-dependent metals copper, zinc and cadmium, the hardness is taken into account when selecting the appropriate EQS value. The average hardness in the rivers and streams in the 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 11.

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

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

The two main receptors 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 were utilised for screening purposes for groundwater (Table 11 and Table 12).

Table 11 Surface Water and Groundwater Assessment Criteria for Biological Elements

Parameter	Unit	AA	MAC (or 95%ile)	Source	Description
Ammonia as N	mg/l	0.065	0.14	S.I. No. 272 of 2009	Good status
pH	pH units		> 4.5 and < 9.0	S.I. No. 272 of 2009	Within range
Dissolved Oxygen	% Sat		80 to 120	S.I. No. 272 of 2009	Within range. 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	

Parameter	Unit	AA	MAC (or 95%ile)	Source	Description
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 12 Surface Water and Groundwater Assessment Criteria for Drinking Water**

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

4.3 Comparison to Assessment Criteria

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

Table B-2 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 Groundwater Assessment

Monitoring wells

The pH was found to be acidic in the majority of groundwater samples with results ranging from 2.9 to 5.9 (field). All exceeded the acceptable ranges for ecological (4.5 to 9 pH units) and human health (6.5 to 9.5 pH units) criteria, except one location (MWET2) which only exceeded the criteria for human health with a pH of 5.9. The specific conductance ranged from 0.141 to 3.184 mS/cm with the lowest conductivity located at MWPF1 and the highest at MWET2. The specific conductance exceeded the human health criteria (2.5 mS/cm) at MWET2.

Sulphate levels greatly exceeded the criteria for human health of 250 mg/l in all of the monitoring wells with values ranging from 831 to 2,380 mg/l. One exception was at MWPF1 where sulphate was below the human health assessment criteria with a value of 29.7 mg/l. Ammonia exceeded both the ecological (0.14 mg/l) and human health (0.3 mg/l) assessment criteria in three monitoring wells with concentrations ranging from 0.458 to 1.05 mg/l. The ecological assessment criteria of 0.14 mg/l was exceeded in one monitoring well (MWET2) with a concentration of 0.241 mg/l.

The dissolved metal concentrations were elevated in the majority of the monitoring wells with numerous exceedances of ecological, human health criteria or both, particularly for aluminium, cadmium, copper, iron, manganese, nickel and zinc (Table B-2 in [Appendix B](#) includes the full listing). There were seven detections of dissolved arsenic, only MWSA2 with a result of 27.7 µg/l exceeded both the human health criteria (10 µg/l) and ecological assessment criteria (25 µg/l).

The dissolved aluminium and copper concentrations at MWET2 (deep) (<12 and <5.1 µg/l) were significantly lower than at MWET1 (shallow) which had concentrations of 107,000 and 9,970 µg/l, respectively. MWET1 exceeded both the ecological and human health criteria for aluminium (1,900 and 200 µg/l) and copper (5 and 2,000 µg/l). This could be explained by the apparent confined nature of MWET2 (heads in MWET2 are higher than in MWET1) and also because MWET1 is screened directly beneath the Emergency Tailings deposits.

The bedrock monitoring well GW1/05 showed higher dissolved metal concentrations than its nested, shallow alluvial well GW2/05. For example, dissolved copper was 7,180 µg/l in GW1/05 and 6,690 µg/l in GW2/05. Both monitoring wells exceeded the ecological and human health criteria for copper (5 and 2,000 µg/l). In GW1/05 and GW2/05, levels of dissolved aluminium (59,700 and 45,500 µg/l), cadmium (22.3 and 19.5 µg/l), manganese (5,250 and 4,100 µg/l) and nickel (54.1 and 40.1 µg/l) exceeded both the ecological assessment criteria and human health assessment criteria respectively.

The groundwater in the shallow well at the Deep Adit area (MWDA1) showed higher dissolved metal concentrations of aluminium and copper (102,000 and 15,200 µg/l) than at MWDA2 (deep) which had concentrations of 34,200 and 2,840 respectively. However, both wells still exceeded the criteria for ecological and human health for aluminium and copper. Both monitoring wells exceeded the ecological and human health criteria for cadmium (81.8 and 73.8 µg/l), manganese (6,820 and 11,300 µg/l) and nickel (68.1 and 101 µg/l). As well, the human health criteria of 200 µg/l for iron is exceeded in both wells (36,100 and 110,000 µg/l). As discussed, iron is not an important parameter for human health criteria.

The well located upgradient of the Deep Adit area and at the eastern margin of the alluvial aquifer, MWPF1, had significantly lower metal concentrations than the other wells. However, the human health assessment criteria for dissolved aluminium (200 µg/l) was exceeded with a value of 267 µg/l and the ecological assessment criteria for dissolved copper (5 µg/l) and dissolved barium (4 µg/l) was exceeded with a values of 8.78 and 41 µg/l respectively.

Monitoring well SG104 was dry at the time of sampling in August 2016.

Spring

A sample of a spring used for drinking water was collected in August 2016. The spring is located east of the Tigroney West spoils area. Eight of the fifteen dissolved metals analysed were not detected. Aluminium, cadmium, iron, lead, manganese and zinc were detected in low concentrations. Dissolved barium exceeded the ecological assessment criteria (4 µg/l) with a concentration of 9.45 µg/l. Therefore, based on these results the spring is considered safe for drinking water use.

4.3.2 Surface Water Assessment

Adit Discharges

The pH was found to be acidic in all adit discharges with results within the range of 2.58 to 3.84 pH (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 1.073 to 3.646 mS/cm. There was one exceedance of the human health criteria (2.5 mS/cm) at the Cronebane Shallow Adit.

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 in all of the adit discharges with values ranging from 584 to 3,320 mg/l. Ammonia was detected in all of the adit discharges ranging from 0.356 mg/l (Deep Adit) to 9.18 mg/l (Road Adit Conf.). Concentrations of ammonia exceeded the ecological criteria (0.14 mg/l) and the human health criteria (0.3 mg/l) in all of the adit discharge locations.

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-2 in [Appendix B](#) includes the full listing).

Dissolved zinc ranged from 6,300 to 145,000 µg/l which exceeded the ecological assessment criteria of 50 µg/l. Dissolved aluminium ranged from 10,900 to 403,000 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 (2,000 µg/l) criteria in the Cronebane Shallow Adit (5,480 µg/l).

Dissolved cadmium ranged from 12.1 to 317 µg/l which exceeded both the ecological (0.45 µg/l) and human health (5 µg/l) criteria. Dissolved cobalt ranged from 65.4 to 296 µg/l which exceeded the ecological criteria (5.1 µg/l). Dissolved lead ranged from 345 to 1,730 µg/l which exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) criteria. Dissolved nickel ranged from 32 to 154 µg/l which also exceeded both the ecological and human health criteria of 20 µg/l.

Dissolved arsenic was detected in all of the adit discharges, ranging from 13.7 to 49.9 µg/l. Concentrations in the Cronebane Shallow Adit and Deep Adit Confluence exceeded the criteria for human health (10 µg/l) and ecological health (25 µg/l) with a recorded value of 49.9 and 40.4 µg/l respectively. Dissolved chromium was detected and exceeded the ecological assessment criteria of 3.4 µg/l in the Cronebane Shallow Adit (16.5 µg/l) and at the Deep Adit Confluence (38.8 µg/l).

Dissolved iron and manganese were also high in all adit discharges. Iron ranged from 51,500 to 174,000 µg/l, exceeding the human health assessment criteria of 200 µg/l at every location. Manganese ranged from 2,090 to 9,310 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 13 provides a summary of the reported values for river sampling locations in the Avoca Mining area 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 for the majority of rivers and streams ranging from 5.58 to 6.52 pH (field); 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 0.056 to 0.122 mS/cm.

Ammonia exceeded the ecological assessment criteria of 0.14 mg/l at Avoca Bridge (0.243 mg/l) and both the ecological and human health assessment criteria (0.3 mg/l) at DS Millrace (0.304) and Whites Bridge (0.67 µg/l). No exceedances of sulphate were recorded at any of the river sampling locations.

The dissolved metal concentrations in the Avoca River were low in comparison to the groundwater and the adit discharges; however, several exceedances of both ecological and human health criteria occurred. Dissolved copper exceeded the ecological criteria (5 µg/l) at White Bridge and all river locations from DS Deep Adit to the DS Shelton Abbey location, with results ranging from 6.97 to 14.5 µg/l. The highest dissolved copper concentration was recorded at DS Ballygahan Adit. Dissolved zinc exceeded the ecological assessment criteria (50 µg/l) from DS Deep Adit on the Avoca River to DS Shelton Abbey with results ranging from 121 to 578 µg/l. Dissolved aluminium was below the human health criteria of 200 µg/l at all locations.

Dissolved cadmium exceeded the ecological assessment criteria (0.45 µg/l) at five locations including DS Deep Adit, WCC Maintenance Yard GS (downstream of the Road Adit confluence) and Avoca Bridge with results ranging from 0.46 to 1.4 µg/l. Dissolved lead exceeded the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria at DS Deep Adit (10.3 µg/l). No other exceedances in dissolved lead were recorded. As well, dissolved nickel did not exceed the ecological (20 µg/l) and human health (20 µg/l) assessment criteria at any of the river or stream sampling locations.

Dissolved iron exceeded the human health assessment criteria of 200 µg/l at two locations downstream of the Deep Adit confluence and two locations downstream of the Road Adit confluence with concentrations ranging from 254 to 703 µg/l. Dissolved manganese exceeded the criteria for human health (50 µg/l) at three locations which ranged in concentration from 59.3 to 97 µg/l. Note that iron and manganese are not important criteria for human health (see Section 4.2.1).

Table 13 Summary of Reported Values for Rivers and Streams and the Surface Water Assessment Criteria

Sample Description	Date Sampled	pH (field)	Ammoniacal Nitrogen as N	Cadmium (diss.filt)	Copper (diss.filt)	Iron (diss.filt)	Lead (diss.filt)	Manganese (diss.filt)	Zinc (diss.filt)
Units		pH Units	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Ecological Criteria		4.5 to 9	0.14	0.45	5	-	7.2	1100	50
Human Health Criteria		6.5 to 9.5	0.3	5	2000	200	10	50	-
Site T1	31/08/2016	5.96	<0.2	<0.08	0.98	60.7	1.26	3.48	18.4
US Whites Bridge	31/08/2016	6.26	<0.2	<0.08	1.1	63.5	1.28	3.79	17.9
Whites Bridge	31/08/2016	6.52	0.67	0.134	11.9	59.4	1.49	13.7	35
Whites Bridge GS	31/08/2016	6.51	<0.2	<0.08	3.11	64	1.39	6.78	26.6
DS Deep Adit	31/08/2016	6.29	<0.2	1.4	6.97	586	10.3	59.3	578
DS Mill Race	31/08/2016	5.74	0.304	0.683	7.41	304	5.47	38	316
US Ballygahan Adit	31/08/2016	6.04	<0.2	0.388	12.4	179	3.53	29.4	160
DS Ballygahan Adit	31/08/2016	5.64	<0.2	0.417	14.5	171	3.75	32.8	177
US Road Adit	31/08/2016	5.58	<0.2	0.449	13.5	174	3.58	35.4	189
WCC Maintenance Yard	31/08/2016	5.6	<0.2	0.604	14	703	4.8	97	266
Site T5	31/08/2016	5.63	<0.2	0.464	12	254	3.94	44.1	198
Avoca Bridge	31/08/2016	6.05	0.243	0.53	10.9	183	3.16	49.2	194
US Shelton Abbey	30/08/2016	5.6	<0.2	0.268	7.34	123	1.77	30.3	121
DS Shelton Abbey	30/08/2016	5.83	<0.2	0.297	7.37	183	1.68	73.1	124

Notes

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

Metals are dissolved

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 February to 29 August 2016 for Whites Bridge GS is reproduced in Figure 2 and for Wicklow County Council Maintenance Yard GS for the same period in Figure 3. The figures show the measured flows ranged from $>50 \text{ m}^3/\text{s}$ to approximately $1\text{--}2 \text{ m}^3/\text{s}$ during low-flow. The flashy nature of the river shows a rapid response to rainfall. The median flows for this period of approximately $5.69 \text{ m}^3/\text{s}$ at Whites Bridge GS and $6.54 \text{ m}^3/\text{s}$ at Wicklow County Council Maintenance Yard GS are lower than the long term median of approximately $8.5 \text{ m}^3/\text{s}$ and $9.1 \text{ m}^3/\text{s}$ respectively, which reflects the relatively low levels of rainfall during the monitoring period. Flow in early June was particularly low with a baseline flow of $2 \text{ m}^3/\text{s}$ at Whites bridge GS and $1.96 \text{ m}^3/\text{s}$ at Wicklow county Council Maintenance Yard GS which is close to the 95%-ile flow (low flow) of approximately $2 \text{ m}^3/\text{s}$ at both stations.

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 6.4.3 Surface Water Flow Data at the EPA Gauging Stations.

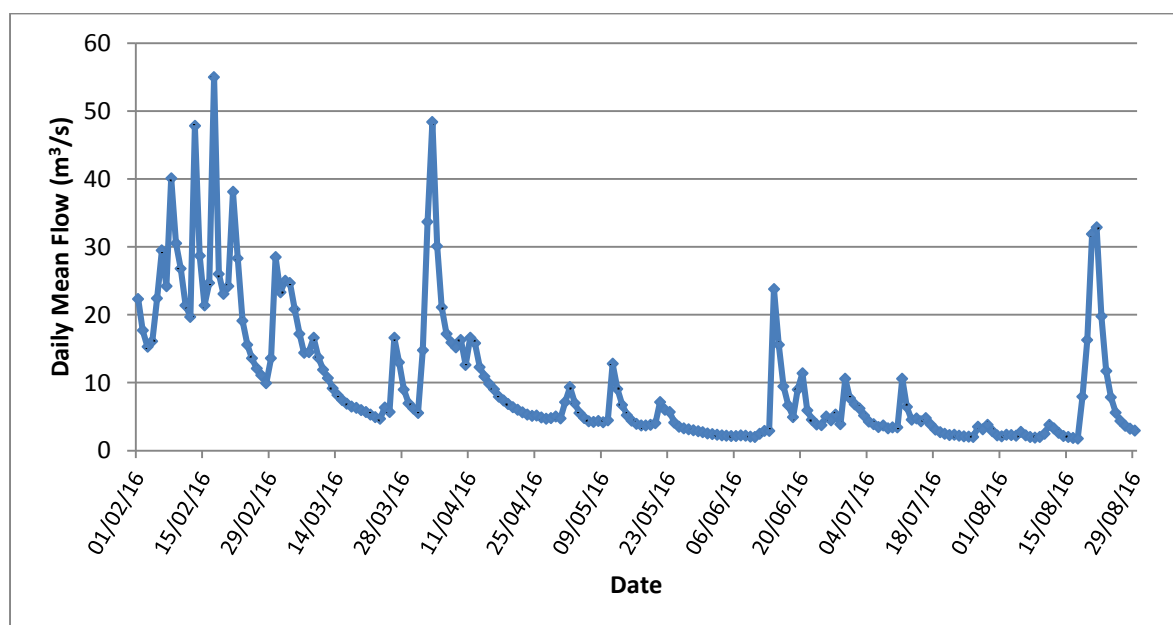


Figure 2 Mean Daily Flow (m^3/s) at Whites Bridge (Station 10044) from 1 Feb to 29 Aug 2016

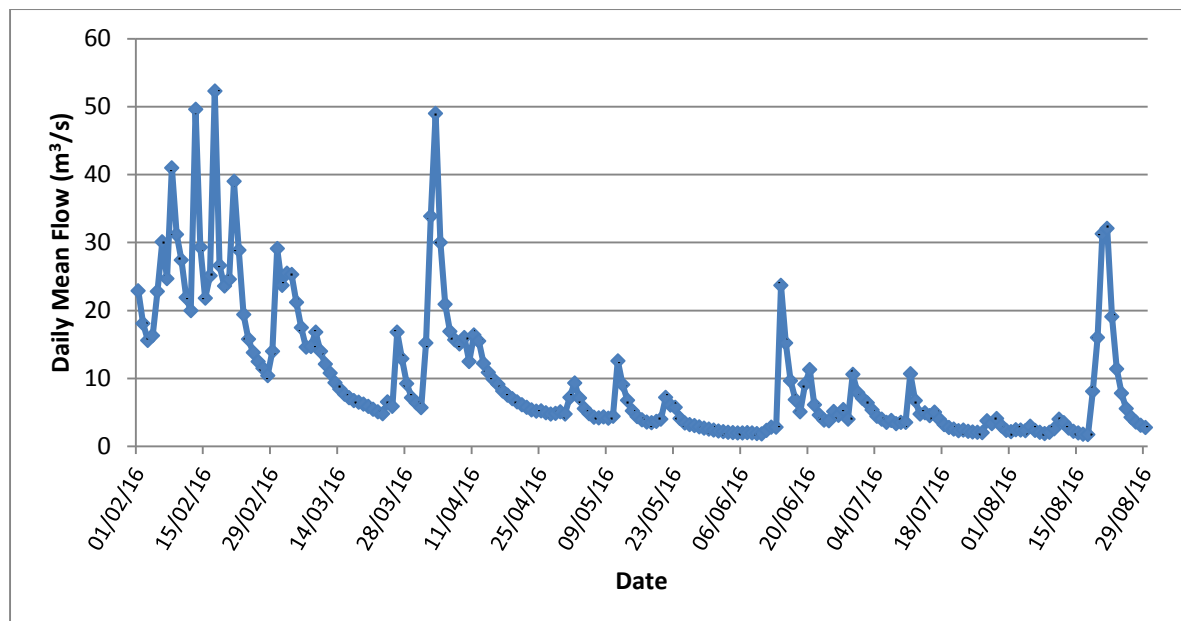


Figure 3 Mean Daily Flow (m³/s) at Wicklow County Council Maintenance Yard (Station 10045) from 1 Feb to 29 Aug 2016

Flow was measured directly in the field using different methodologies depending upon the quantity of flow to be measured and any safety concerns, as described in Section 2.1.2. Table 14 presents a summary of the results from the flows measured in August and September 2016 at the time of sampling. All of the flow measurements on the main river channel were performed on the same day. This 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 10.4 l/s is considered a low flow as past records for the Deep Adit ranged from approximately 10 to 37.5 l/s. The 850 Adit was not discharging water at the time of sampling and therefore no flow was present at the 850 confluence with the Deep Adit. The surface water drainage channel which joins the 850 channel upgradient of the railway tracks was also dry at the time of sampling. The flow was also measured at the Deep Adit Confluence prior to it discharging to the Avoca River and the measured flow was 8.1 l/s which is less than the flow at the Deep Adit portal. Note this location is not ideal for measuring flow because 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 was measured at the Road Adit and the measured flow was 8.34 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 9.5 l/s. The difference in flow is likely due to two different flow measurement methods being employed.

Table 14 Surface Water Flow Value Measured in August and September 2016

Site Name	Flow m ³ /s	Flow l/s	Date	Notes
Avoca Bridge	3.30	3,298	31/08/2016	
DS Ballygahan adit	2.76	2,761	31/08/2016	
DS Deep Adit	2.93	2,930	31/08/2016	
DS Mill Race	2.93	2,930	31/08/2016	
DS Shelton Abbey	7.57	7,567	30/08/2016	
Site T1	2.60	2,600	31/08/2016	
Site T5	2.88	2,882	31/08/2016	
US Ballygahan Adit	2.76	2,761	31/08/2016	
US Road Adit	2.76	2,761	31/08/2016	
US Shelton Abbey	7.57	7,567	30/08/2016	
US Whites Bridge	2.94	2,940	31/08/2016	
WCC Maintenance Yard	2.77	2,770	31/08/2016	
Whites Bridge	2.94	2,940	31/08/2016	
Whites Bridge GS	2.94	2,940	31/08/2016	
Cronebane Inter. Adit	0.003	2.87	01/09/2016	
Cronebane Shallow Adit	0.000	0.09	01/09/2016	
Deep Adit	0.010	10.40	01/09/2016	
Deep Adit Confluence	0.008	8.10	01/09/2016	
Road Adit	0.008	8.34	01/09/2016	
Road Adit Confluence	0.009	9.50	01/09/2016	
850 Adit	-	-	01/09/2016	No Flow
Ballygahan Adit	-	-	01/09/2016	No Flow

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 15 aid with the interpretation of the loading of sulphate and dissolved aluminium, copper, iron, lead and zinc to the Avoca River.

Table 15 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
Avoca Bridge	31/08/2016	3298	6.05	13200	3760	130	37	10.9	3.11	183	52.1	3.16	0.9	194	55.3
DS Ballygahan adit	31/08/2016	2761	5.64	9300	2220	158	37.7	14.5	3.46	171	40.8	3.75	0.89	177	42.2
DS Deep Adit	31/08/2016	2930	6.29	17300	4380	84.6	21.4	6.97	1.76	586	148	10.3	2.61	578	146
DS Mill Race	31/08/2016	2930	5.74	12800	3240	167	42.3	7.41	1.88	304	76.9	5.47	1.38	316	80
DS Shelton Abbey	30/08/2016	7567	5.83	13500	8830	121	79.1	7.37	4.82	183	120	1.68	1.1	124	81.1
Site T1	31/08/2016	2600	5.96	1000	225	50.4	11.3	0.98	0.22	60.7	13.6	1.26	0.28	18.4	4.13
Site T5	31/08/2016	2882	5.63	11700	2910	156	38.8	12	2.99	254	63.2	3.94	0.98	198	49.3
US Ballygahan Adit	31/08/2016	2761	6.04	8400	2000	191	45.6	12.4	2.96	179	42.7	3.53	0.84	160	38.2
US Road Adit	31/08/2016	2761	5.58	9800	2340	162	38.6	13.5	3.22	174	41.5	3.58	0.85	189	45.1
US Shelton Abbey	30/08/2016	7567	5.6	11600	7580	112	73.2	7.34	4.8	123	80.4	1.77	1.16	121	79.1
US Whites Bridge	31/08/2016	2940	6.26	1000	254	48.7	12.4	1.1	0.28	63.5	16.1	1.28	0.33	17.9	4.55
WCC Maintenance Yard	31/08/2016	2770	5.6	18000	4310	151	36.1	14	3.35	703	168	4.8	1.15	266	63.7
Whites Bridge	31/08/2016	2940	6.52	1000	254	100	25.4	11.9	3.02	59.4	15.1	1.49	0.38	35	8.89
Whites Bridge GS	31/08/2016	2940	6.51	1000	254	68.3	17.3	3.11	0.79	64	16.3	1.39	0.35	26.6	6.76
Cronebane Inter. Adit	01/09/2016	3	3.36	584000	145	36500	9.05	587	0.15	77100	19.1	1210	0.3	24900	6.18
Cronebane Shallow Adit	01/09/2016	0.09	2.58	3320000	25.8	403000	3.13	5480	0.04	174000	1.35	992	0.01	145000	1.13
Deep Adit	01/09/2016	10.4	3.52	980000	881	68500	61.6	85.2	0.08	61300	55.1	1530	1.37	34200	30.7
Deep Adit Confluence	01/09/2016	8.1	3.31	934000	654	91100	63.8	107	0.07	63100	44.2	1730	1.21	44700	31.3
Road Adit	01/09/2016	8.34	3.79	879000	633	10900	7.85	244	0.18	51500	37.1	345	0.25	6300	4.54
Road Adit Confluence	01/09/2016	9.5	3.84	864000	709	11000	9.03	252	0.21	57500	47.2	352	0.29	6560	5.38

Loading from Adit Discharges

The Deep Adit had aluminium, copper and zinc loads of 61.6, 0.08 and 30.7 kg/day and the Road Adit had loads of 7.85, 0.18 and 4.54 kg/day, respectively. The Deep Adit had a higher load of sulphate with 881 kg/day and dissolved iron with 55.1 kg/day and the Road Adit had 633 kg/day sulphate and 37.1 kg/day of iron. No loading results are available for the 850 Adit because there was no flow at the time of sampling.

To determine if there was any apparent loss of sulphate or metals loading along the Deep Adit channel, the flow and loading results were evaluated between the portal and confluence samples (Table 15). 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 portal. A slight decrease in loads was recorded for sulphate (881 kg/day to 654 kg/day), iron (55.1 kg/day to 44.2 kg/day), copper (0.08 to 0.07 kg/day) and lead (1.37 kg/day to 1.21 kg/day). Additionally, a slight increase in zinc load (30.7 to 31.3 kg/day) was recorded between both sampling locations. The variances in dissolved metal loads between the portal and confluence samples is likely primarily due to the difficulties in conducting accurate flow measurements at the Deep Adit Confluence. The decrease in flow and dissolved metal loads may also be attributed to infiltration along the Deep Adit channel.

The Cronebane Intermediate Adit had dissolved metal loads of 9.05 kg/day for aluminium, 19.1 kg/day iron and 6.18 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 3.13 kg/day for aluminium, 0.04 kg/day for copper and 1.13 kg/day for zinc. Ballygahan Adit was dry at the time of sampling.

Avoca River Loadings

Background Loadings

Background loads upstream of the Avoca Mining Area of metals were present which is evident from the calculated loads at Site T1. The dissolved metal loads at Site T1 were 11.3 kg/day for aluminium, 0.22 kg/day for copper, 13.6 kg/day for iron, 0.28 kg/day for lead and 4.13 kg/day for zinc. Figure 4 and Figure 5 graphically show the calculated loads of dissolved aluminium, iron, zinc and copper respectively at each location along the Avoca River from Site T1 upstream of the mining area to Avoca Bridge (see also Map 1 and 3 in [Appendix A](#)). Composite samples were taken at all sites along the Avoca River.

Whites Bridge

At sampling location US Whites Bridge which is located approximately 365m upstream of the bridge, there is a negligible increase in dissolved metal loads compared to Site T1. Further downstream at Whites Bridge there is a significant increase with loads of dissolved aluminium at 25.4 kg/day, iron at 15.1 kg/day, zinc at 8.89 kg/day and copper at 3.02 kg/day. There was a decrease in dissolved aluminium (17.3 kg/day), copper (0.79 kg/day) and zinc (6.76 kg/day) loads, 90 metres downstream at Whites Bridge GS.

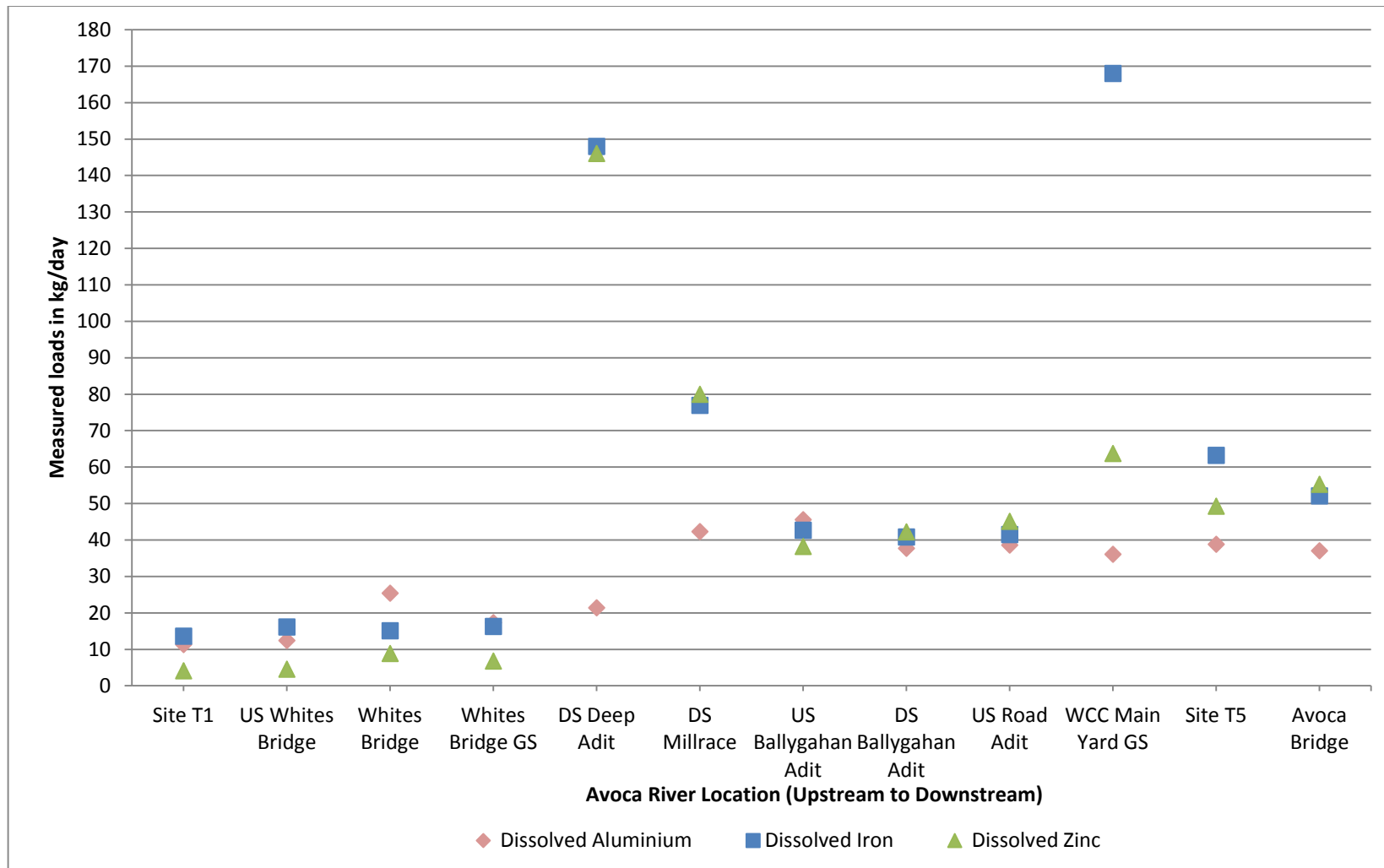


Figure 4 Calculated Loads of Dissolved Aluminium, Iron and Zinc (kg/day) in the Avoca River in August 2016

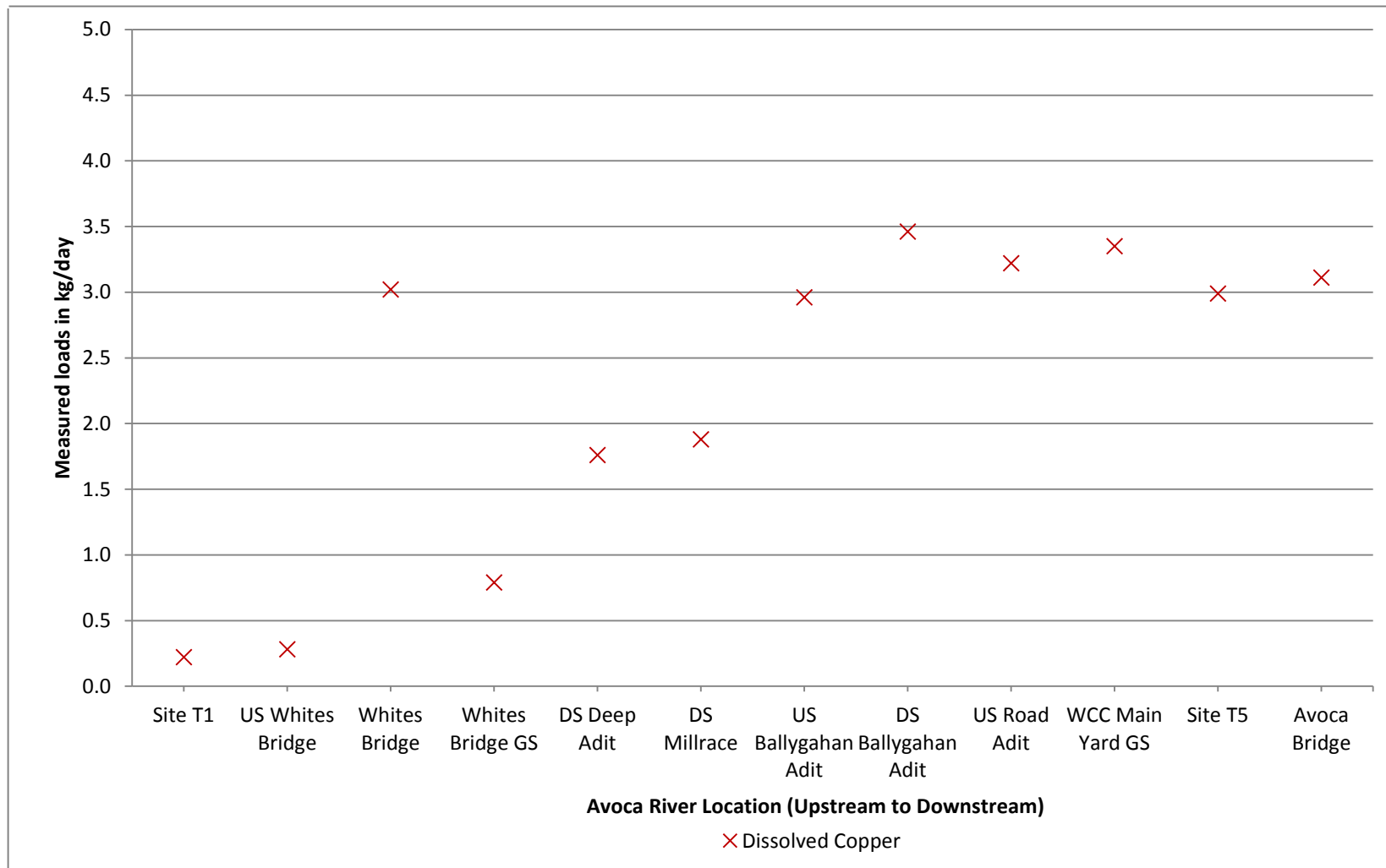


Figure 5 Calculated Loads of Dissolved Copper (kg/day) in the Avoca River in August 2016

Deep Adit Discharge and Contaminated Millrace Area

The DS Deep Adit location on the Avoca River is downstream of the Deep Adit discharge (Deep Adit Confluence sample) and a significant section of the contaminated Millrace area. Therefore, the calculated loads at DS Deep Adit assesses the impact of the Deep Adit discharge and the level of diffuse flow and groundwater contribution from the contaminated Millrace area and Deep Adit spoils. As indicated in Figure 4 and Figure 5, a significant increase in loads occurs at DS Deep Adit compared to the upstream sampling location (Whites Bridge GS) with increases in aluminium (4.1 kg/day), copper (0.97 kg/day), iron (131 kg/day), lead (2.26 kg/day) and zinc (139 kg/day).

Taking into account the calculated dissolved metal loads at the Deep Adit Confluence the loading results at DS Deep Adit would be expected to be lower for copper (0.87 kg/day), iron (71.4 kg/day), lead (1.72 kg/day) and zinc (37.5 kg/day). The additional dissolved metal load indicates that the West Avoca Spoils that the contamination of the alluvial material in the Millrace area are a secondary source of diffuse load to the Avoca River. Note that the contaminated Millrace area located parallel to the Avoca River extended further downstream than the DS Deep Adit sampling location and therefore an additional sampling location was introduced (DS Millrace). Dissolved metal loads at the DS Millrace sampling location increased for aluminium (20.9 kg/day) and copper (0.12 kg/day). Loads of iron, lead, and zinc decreased by 71.1, 1.23 and 66 kg/day respectively which is likely due to additional mixing of the Deep Adit discharge within the River and/or precipitation of the dissolved metals along the river channel.

Ballygahan Adit and Seeps

In order to assess the groundwater seeps which, discharge to the River in close proximity to the Ballygahan Adit (dry at the time of sampling), two additional sampling locations were added to the monitoring programme; US Ballygahan Adit and DS Ballygahan Adit. Slight increases were calculated for the following dissolved metals; copper (2.96 to 3.46 kg/day), lead (0.84 to 0.89 kg/day) and zinc (38.2 to 42.2 kg/day).

Road Adit Discharge

The Road Adit is the primary discharge from East Avoca. Upstream of the Road Adit Confluence (US Road Adit), dissolved metal loads were calculated as follows; aluminium (38.6 kg/day), copper (3.22 kg/day), iron (41.5 kg/day), lead (0.85 kg/day) and zinc (45.1 kg/day).

The Wicklow County Council Maintenance Yard GS sampling location is located downstream of the Road Adit discharge since October 2014. Taking into account the loadings at US Road Adit and at the Road Adit Confluence the loads would be expected to be 47.6 kg/day for aluminium, 88.7 kg/day for iron and 50.5 kg/day for zinc. However, the loadings were determined slightly higher at Wicklow County Council Maintenance Yard GS for iron (168 kg/day) and for zinc (63.7 kg/day). The calculated loads for aluminium were lower at 36.1 kg/day. The increase in loads at Wicklow County Council Maintenance Yard GS can be attributed to the Road Adit which discharges to the Avoca River approximately 65m upstream. Although a composite sample was taken at this location it's likely that the Road Adit discharge was not fully mixed with the Avoca River and therefore an overestimation of iron and zinc loads at this location is possible.

Site T5 is located further downstream where the Road Adit discharge is mixed better with the Avoca River, which is evident as the measured loads were similar to what would be expected with 63.2 kg/day for iron and 49.3 kg/day for zinc. The measured load for aluminium was 38.8 kg/day which was similar to the measured load at Wicklow County Council Maintenance Yard GS.

Shelton Abbey TMF

There was an apparent increase in dissolved metal loads from upstream of Shelton Abbey TMF (US Shelton Abbey) to downstream of the TMF (DS Shelton Abbey) for the following dissolved metals; aluminium (73.2 to 79.1 kg/day), iron (80.4 to 120 kg/day) and zinc (79.1 to 81.1 kg/day). The calculated loads for dissolved copper and lead were similar at the upstream and downstream locations of Shelton Abbey.

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 for selected parameters including dissolved copper, zinc and iron. The trends are shown graphically in Figure 6 (Deep Adit from October 2001 to September 2016), Figure 7 (Deep Adit from October 2001 to September 2016, excluding high values recorded in November 2001), Figure 8 (Road Adit from October 2001 to September 2016) and Figure 9 (Avoca River at Avoca Bridge from October 2001 to August 2016).

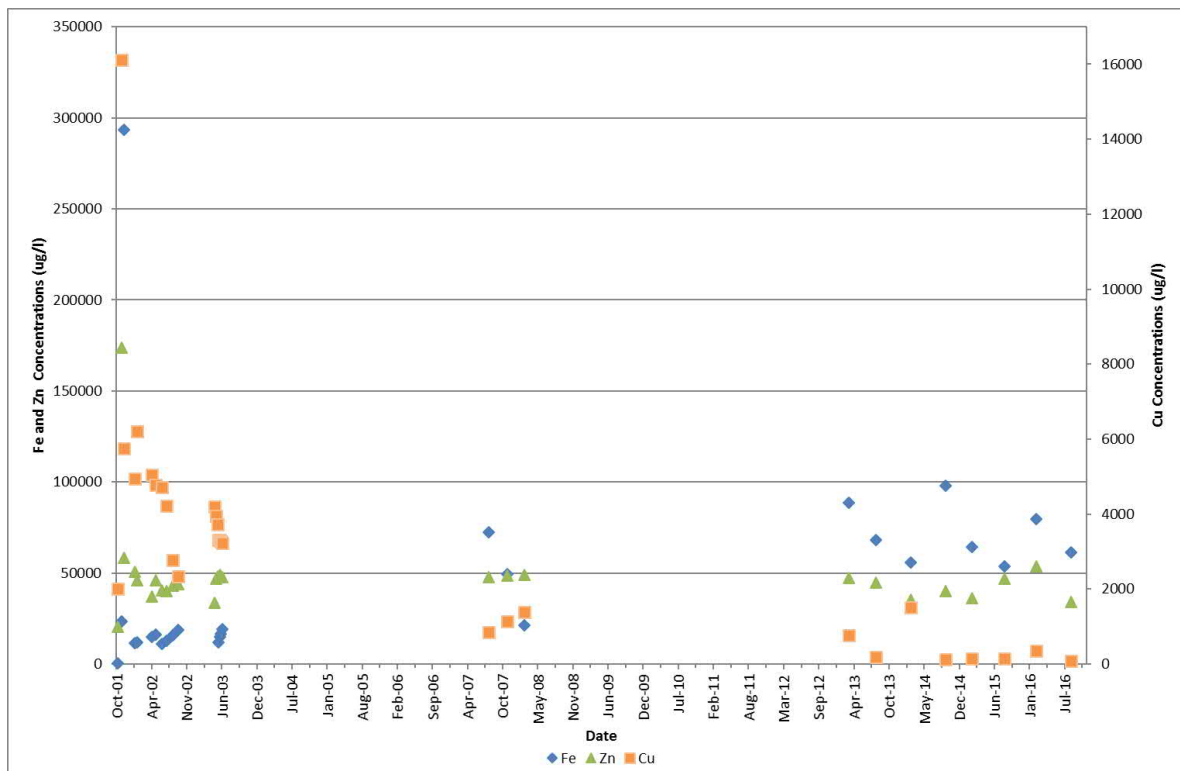


Figure 6 Concentration trends for dissolved copper, zinc and iron within the Deep Adit Discharge (Oct 2001 to Sept 2016)

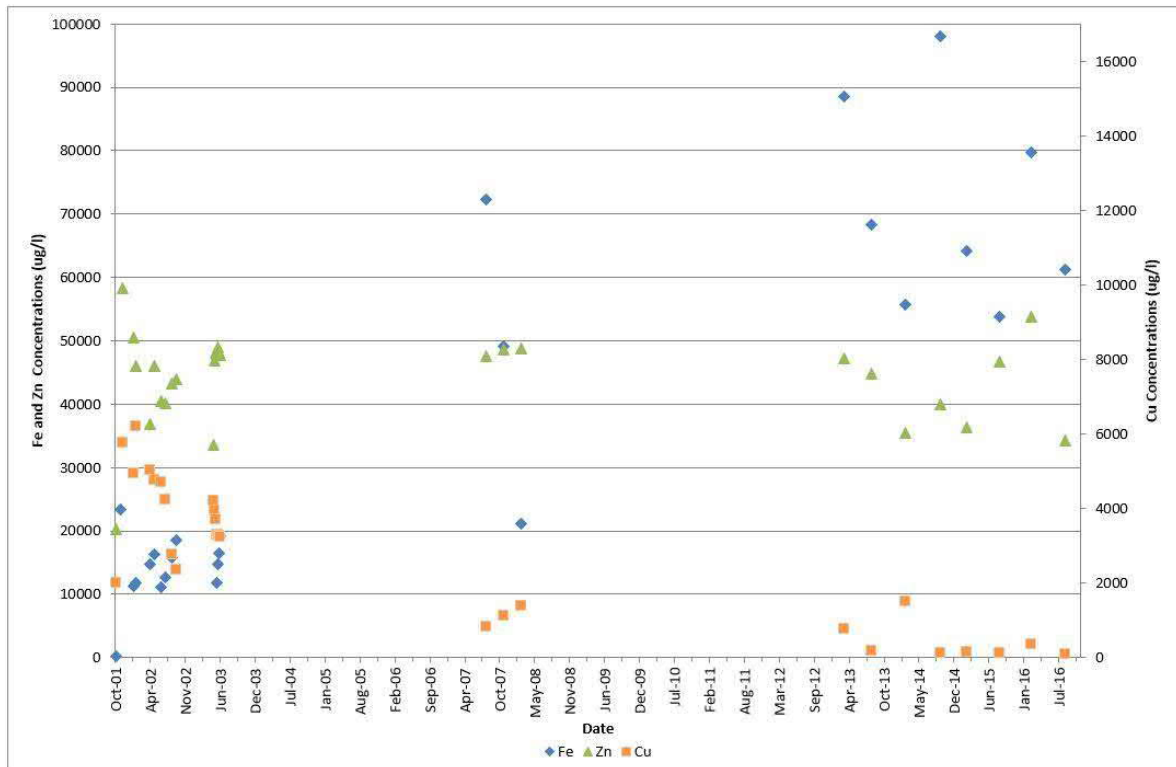
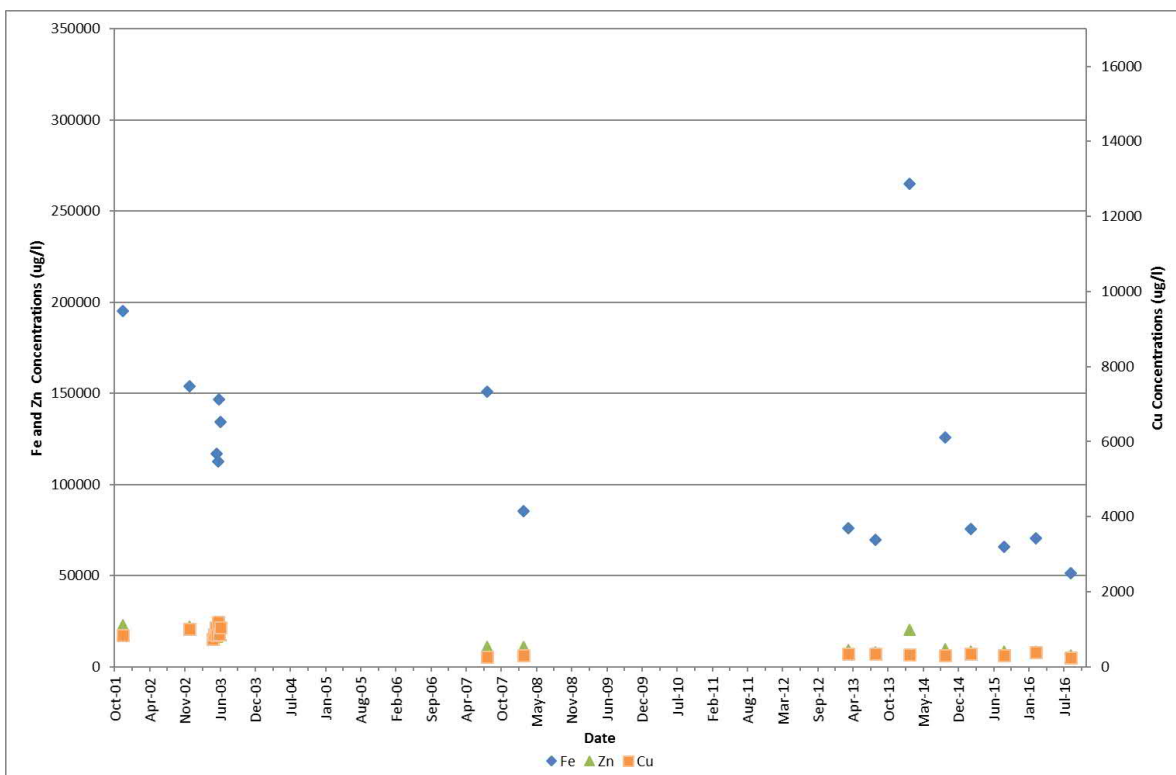


Figure 7 Concentration trends for dissolved copper, zinc and iron within the Deep Adit Discharge (Oct 2001 to Sept 2016), excluding high values recorded in November 2001



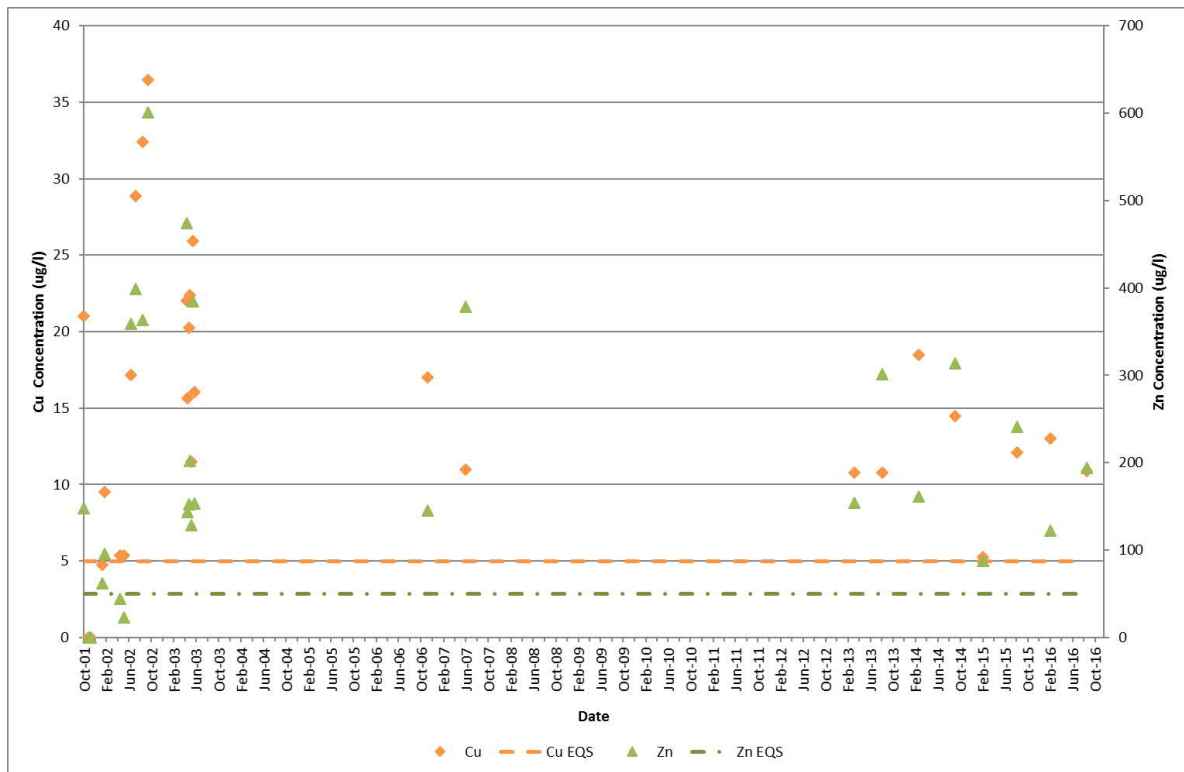


Figure 9 Concentration trends for dissolved copper and zinc at Avoca Bridge compared with the environmental quality objective (EQS) (Oct 2001 to Aug 2016)

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 use 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 16 shows the possible outcomes of the Mann-Kendall trend analysis as applied to the water quality data.

Table 16 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 value 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 17 and facilitate general observations about trends in the water quality of the two main adit discharges and the downstream location of Avoca Bridge.

Table 17 Mann-Kendall Trend Analysis of data for Deep Adit, Road Adit and Avoca Bridge

Sample location	Parameter	October 2001 to September 2016			June 2007 to September 2016		
		P value	S value	Trend	P value	S value	Trend
Deep Adit	Copper	0	-310	Decreasing	0.0215	-27	Decreasing
	Zinc	0.3331	-24	No Trend	0.0806	-19	Likely Decreasing
	Iron	0.0001	167	Increasing	0.4381	3	No Trend
Road Adit	Copper	0.0072	-71	Decreasing	0.4290	3	No Trend
	Zinc	0.0001	-111	Decreasing	0.0368	-21	Decreasing
	Iron	0.0013	-68	Decreasing	0.0159	-25	Decreasing
Avoca Bridge	Copper	0.1716	-44	No Trend	0.5	1	No Trend
	Zinc	0.2833	27	No Trend	0.1740	-10	No Trend

Notes:

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

The confidence coefficient is 0.95.

The results of the Mann-Kendall analysis for October 2001 to September 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 6, Figure 7 and **Figure 8**.

The results of the Mann-Kendall analysis for June 2007 to September 2016, show that dissolved copper is decreasing and dissolved zinc is likely decreasing in the Deep Adit. In the Road Adit, dissolved zinc and iron are decreasing.

Figure 9 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 18 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), August 2015 (R6) and August/September 2016 (R8). As can be observed from Table 18, 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, August 2015 and September 2016 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, August 2015 and August 2016. Seasonal differences in dissolved copper concentrations are less pronounced with values ranging from 10.8 to 14.5 kg/day in low flow conditions and from 5.24 to 18.5 kg/day during winter sampling events. Table 18 also shows that the calculated loads of dissolved aluminium, copper, iron and zinc were typically lower during low flow conditions in August 2013, September 2014, August 2015 and August 2016, compared to the loads calculated during high flow conditions. Flow was particularly low in September 2016 (R8) and consequently, dissolved metal loads at the Deep Adit and the Road Adit were significantly lower than the previous low flow sampling rounds. Similar flow conditions measured at the Deep Adit in February 2015 and February 2016 resulted in relatively low calculated loads of dissolved metals.

Table 18 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
	R8 01/09/2016	10.4	68500	61.6	85.2	0.08	61300	55.1	34200	30.7
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	-
	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
	R8 01/09/2016	8.34	10900	7.85	244	0.18	51500	37.1	6300	4.54
Avoca Bridge	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
	R8 31/08/2016	3298	130	37	10.9	3.11	183	52.1	194	55.3

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 19 provides the measured depth to groundwater and calculated groundwater elevations. The groundwater level was also measured at R3-04 which is located in the Tigroney West spoils area (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 25.43 to 32.53 m Ordnance Datum (OD) in the Avoca Mining Area. These groundwater elevations were between 0.35 to 1.1 metres lower than the elevations measured in February 2016. 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 19 Measured Groundwater Levels and Calculated Elevation August 2016

Borehole Identifier	Date	Time	Depth to Groundwater (m bTOC)	Depth to Groundwater (m bgs)	Groundwater Elevation (m OD)
MWDA1	29/8/2016	10:50	6.40	5.80	26.39
MWDA2	29/8/2016	10:45	6.48	5.75	26.14
MWET1	30/8/2016	9:05	7.46	6.89	25.93
MWET2	30/8/2016	9:10	7.41	6.71	25.96*
MWPF1	29/8/2016	9:30	4.67	4.08	26.82*
MWSA2	30/8/2016	12:00	8.64	8.36	1.53*
GW1/05	29/8/2016	13:20	5.37	4.73	25.43*
GW2/05	29/8/2016	14:15	5.52	5.52	25.43*
SG104	29/8/2016	15:00	25.64	Unknown	32.53
R3-04	30/8/2016	16:45	10.17	9.5	32.29

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 10 shows the groundwater elevations of the five wells located in the Avoca Mining Area from 16 February to 28 August 2016. Figure 11 shows the groundwater elevation at MWSA2 at Shelton Abbey Tailings Facility between 16 February and 28 August 2016.

Figure 10 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.

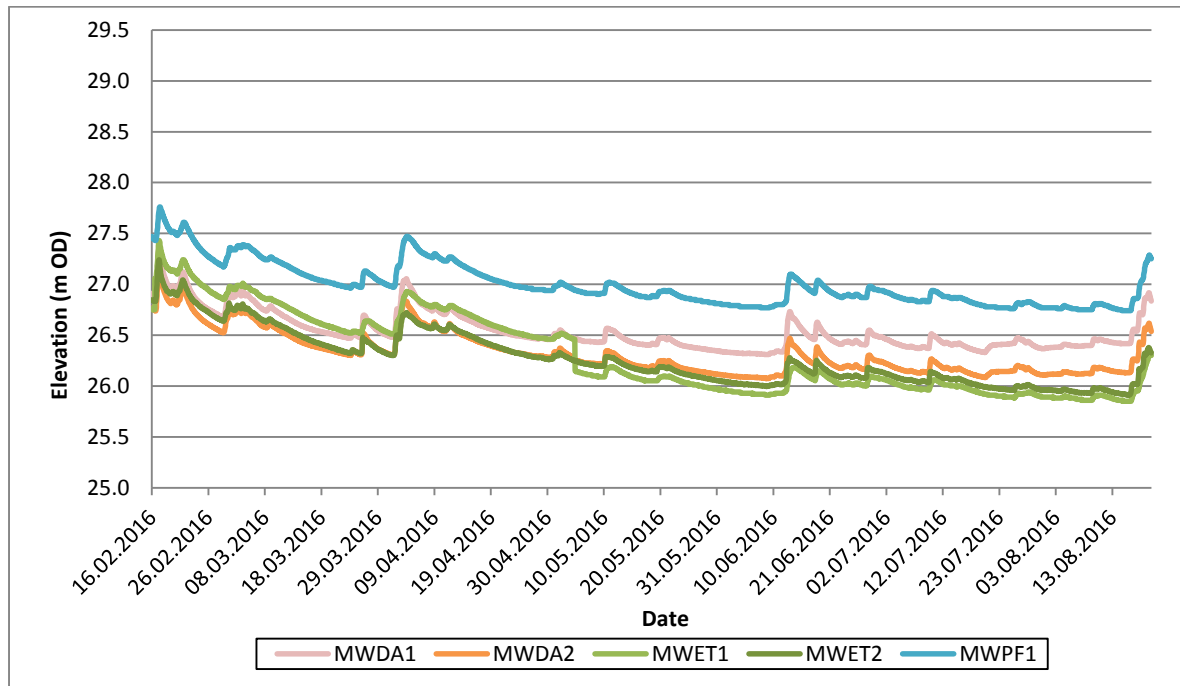


Figure 10 Groundwater Elevations in the Avoca Mining Area from 16 Feb to 28 Aug 2016

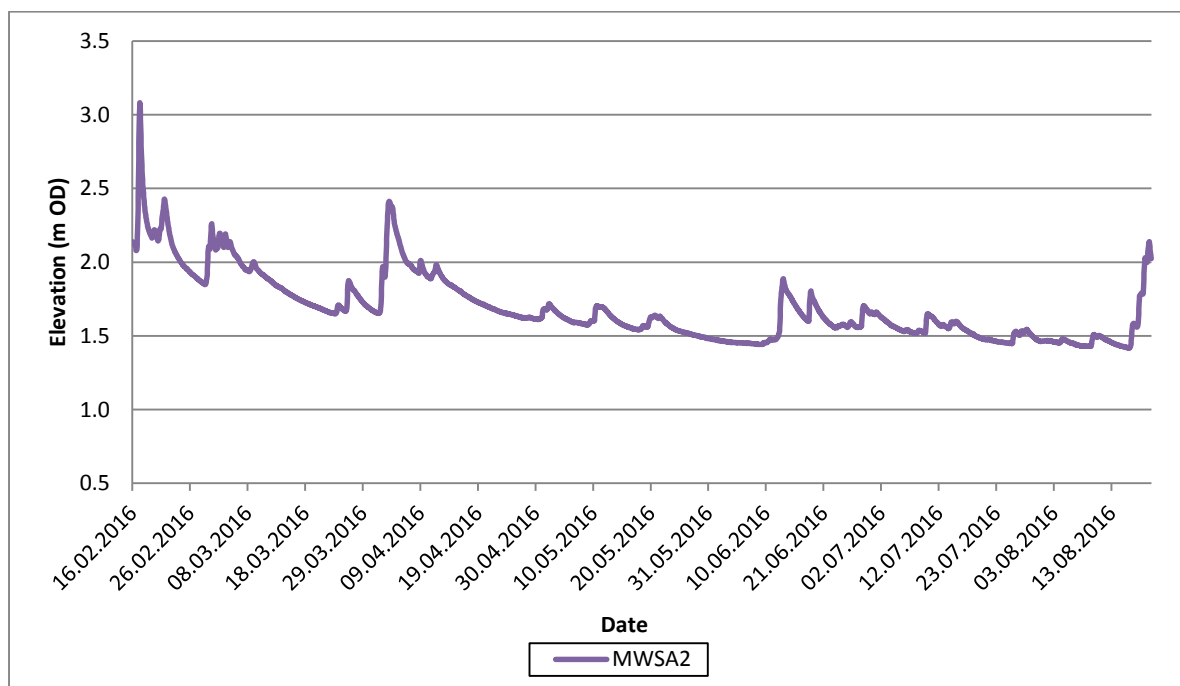


Figure 11 Groundwater Elevation at Shelton Abbey from 16 Feb to 28 Aug 2016

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 the same in both the alluvial well (GW2/05) and top of bedrock well (GW1/05) at this location (Table 19) in August 2016.

All data loggers were checked and calibrated in August 2016. In addition, batteries were 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 16 February to 28 August 2016 for Whites Bridge GS and Wicklow County Council Maintenance Yard GS are reproduced in Figure 12. Additionally, the calculated elevations of the Avoca River at the mid-point between the two automatic flow gauges are shown in Figure 12. 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.

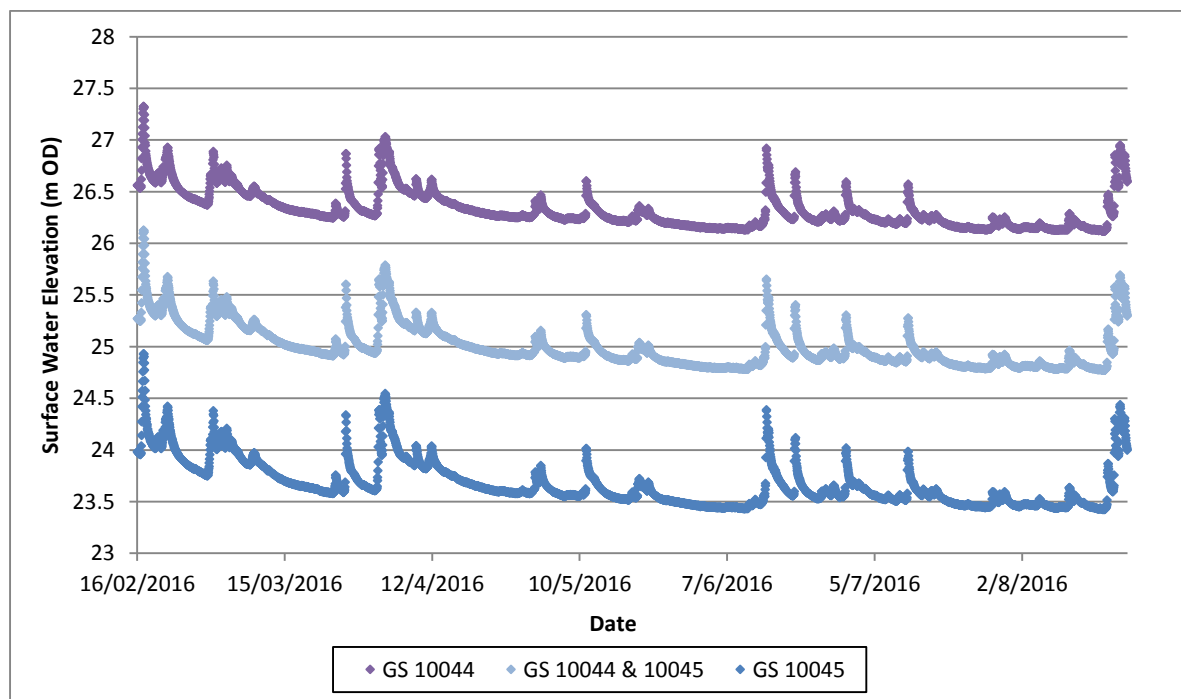


Figure 12 Elevation of the Avoca River at GS 10044 and GS 10045 at the Deep Adit Area from 16 February to 28 August 2016

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 and MWPF1 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. The estimated surface water elevations for the emergency tailing area for the period 16 February to 28 August 2016 are displayed on Figure 12 (GS 10044 & GS 10045);
- For SG104 the water elevation from Wicklow Maintenance Yard County Council (GS 10045) was used; and
- The river water level at MWSA2 was unable to be determined because there are no gauges available at a nearby location.

Table 20 summarises resulting hydraulic gradient data between the monitoring well clusters and the Avoca River during the sampling event, and shows an estimated gradient from the wells to the river at the time of sample collection in August 2016. These values are similar to previous rounds in both direction and magnitude with an estimated mean gradient of 0.005, -0.001 and 0.009 for MWDA1, MWDA2 and MWPF1 respectively. R3-04 had a significantly greater gradient of 0.17. Measurements at R3-04 are likely capturing the water level within the Deep Adit tunnel rather than groundwater level.

Table 20 Calculated Groundwater Gradients for August 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	29/8/2016	10:50	26.39	26.18	40	0.005
MWDA2	29/8/2016	10:45	26.14	26.18	40	-0.001
MWET1	30/8/2016	9:05	25.93*	24.84**	72	0.015
MWET2	30/8/2016	9:10	25.96*	24.84**	72	0.015
MWPF1	29/8/2016	9:30	26.82	26.18	44	0.009
MWSA2	30/8/2016	12:00	1.53	Not available	45	Not available
GW1/05	29/8/2016	13:20	25.43*	24.84**	74	0.008
GW2/05	29/8/2016	14:15	25.43*	24.84**	74	0.008
SG104	29/8/2016	15:00	32.53	23.49	142	0.064
R3-04	30/8/2016	16:45	32.29	26.18	160	0.038

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

** Estimated elevations based on two surface water gauges

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 13 for the deep adit area and Figure 15 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.

Both figures show that in the recorded data several significant hydrological (rainfall) events occurred in March, April, June and August 2016 which resulted in groundwater levels rising. For example, groundwater levels rose by approximately 0.5 metres between 1 and 4 April 2016. This peak was in response to river levels which rose by up to 0.8 metres during the same event. Groundwater levels gradually decrease in the deep adit area and the emergency tailings area for the majority of April and May and remain relatively constant during the summer months (June, July and August). The hydraulic response to rainfall and river stage is more muted in MWET1 than in MWET2, which is possibly due to the fact that the two wells are separated by a fine silt/clay layer at approximately 16 meters' depth, which could act as a confining layer to MWET2. Note that the datalogger in MWET1 was calibrated on 5 May 2016 and water level readings prior to this point should be used with caution.

Figure 14 and Figure 16 show the calculated gradient to the Avoca River at the deep adit area (MWDA1, MWDA2) and the emergency tailings area (MWET1, MWET2) from 16 February to 28 August 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 13 and Figure 14 show that a negative gradient occurs during periods of high flow, particularly when there was a rapid rise in water level. On 14 June 2016 a significant hydrological (rainfall) event resulted in groundwater levels rising in MWDA1 and MWDA2 by approximately 0.4 metres. A negative gradient of up to -0.017 can be observed during this period between the river and MWDA2, as shown in Figure 14. From mid-June to the end of July negative gradients predominantly exist for MWDA2. The minimum gradient for MWDA2 was -0.017 while the average was 0.0004. For MWDA1 which is the shallower well, a positive gradient existed for over 95% of the monitoring period. The findings indicate that shallow groundwater in the deep adit area is likely discharging to the Avoca River for the majority of the monitoring period.

For MWET1 and MWET2 only positive gradients were observed during the monitoring period with a minimum gradient of 0.004 (MWET1) and a maximum of 0.026 (MWET1). 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. Note the calculated gradients for MWET1 prior to datalogger calibration on 5 May 2016 should be used with caution.

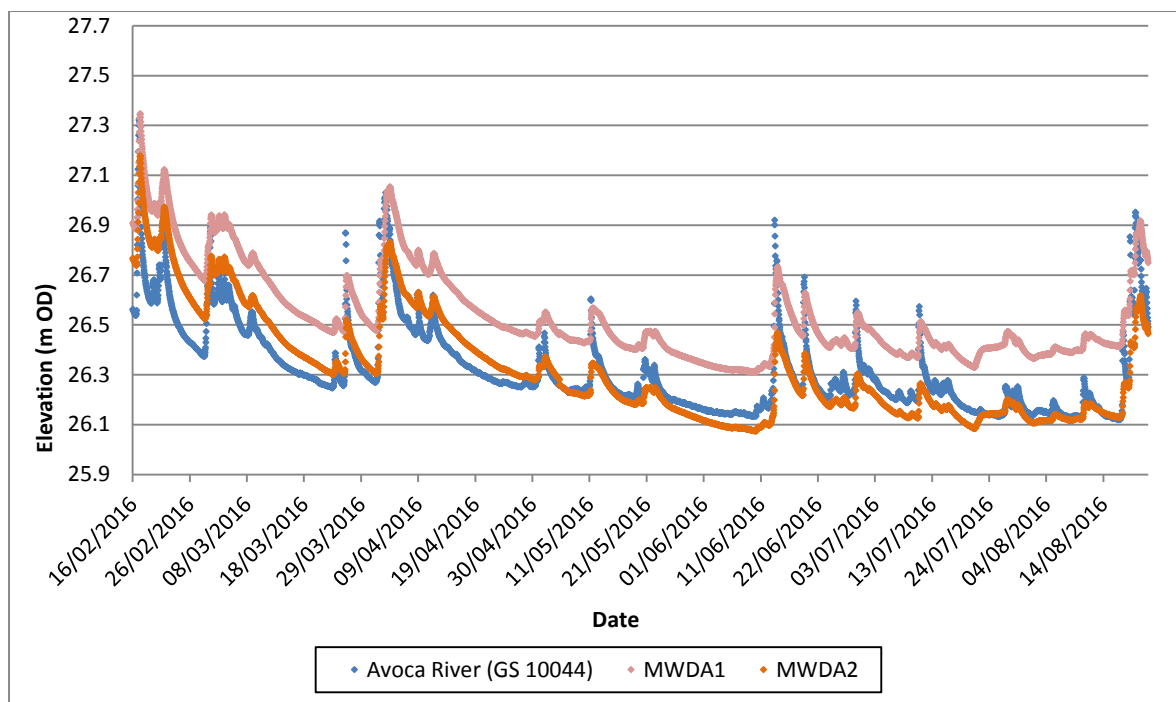


Figure 13 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044) at the Deep Adit Area from 16 February to 28 August 2016

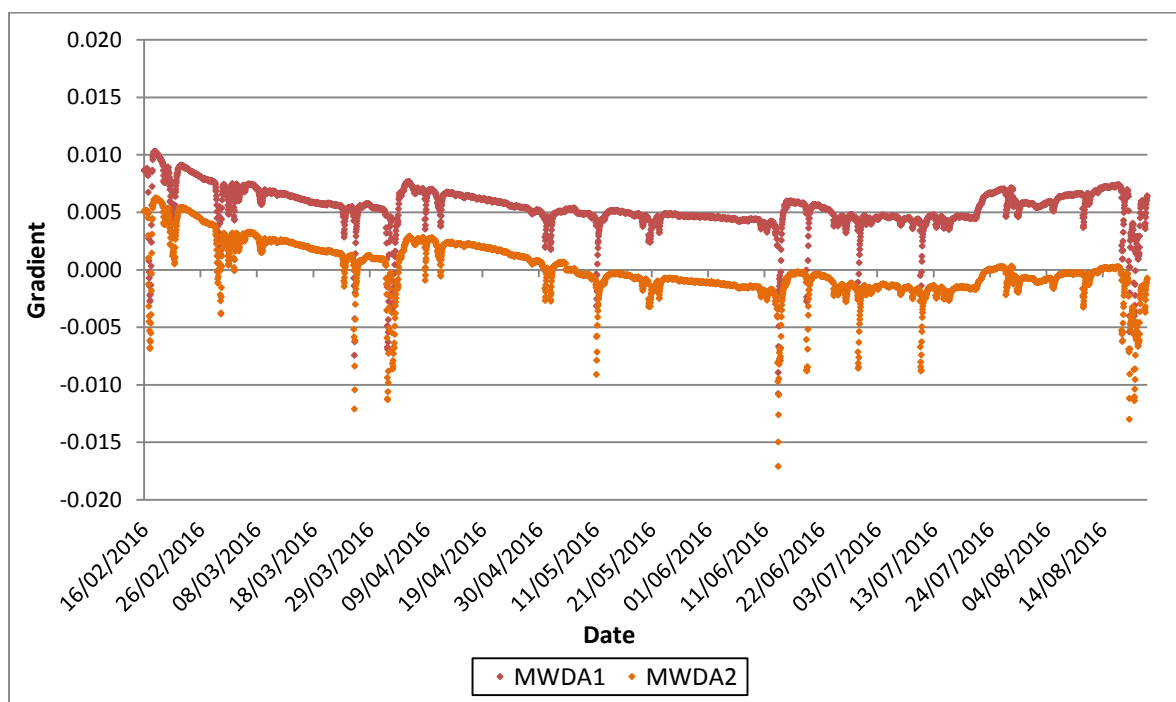


Figure 14 Calculated Groundwater Gradient to the Avoca River at the Deep Adit Area from 16 February to 28 August 2016

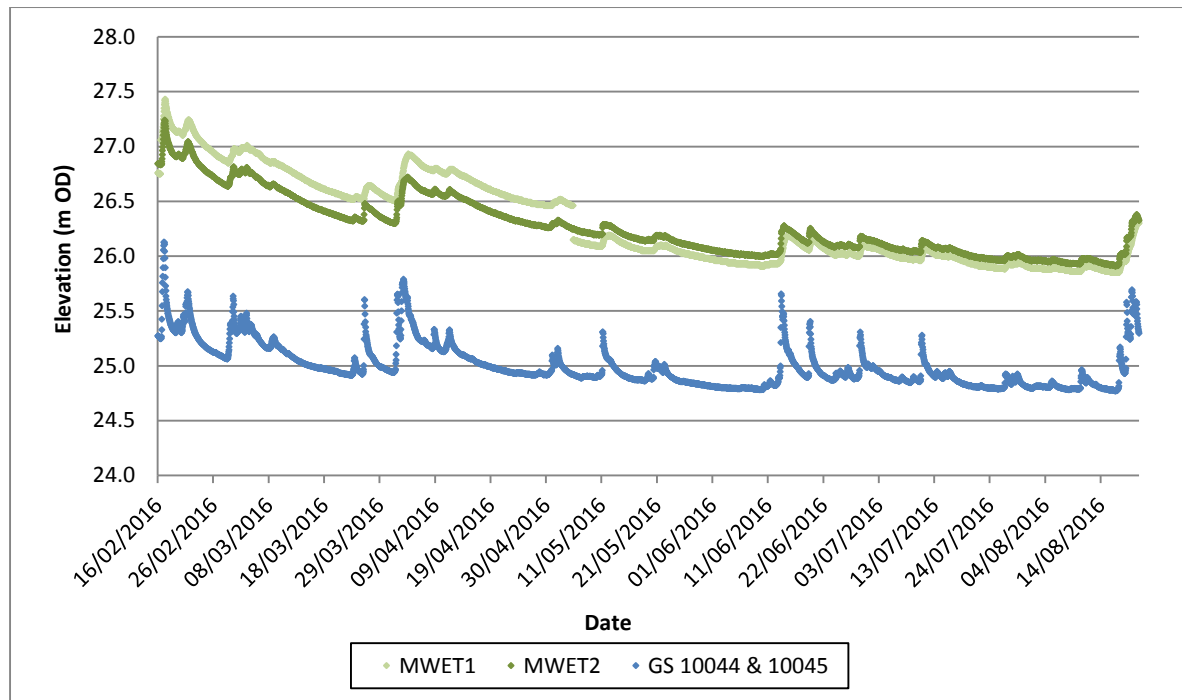


Figure 15 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044 & 10045) at the Emergency Tailings Area from 16 February to 28 August 2016

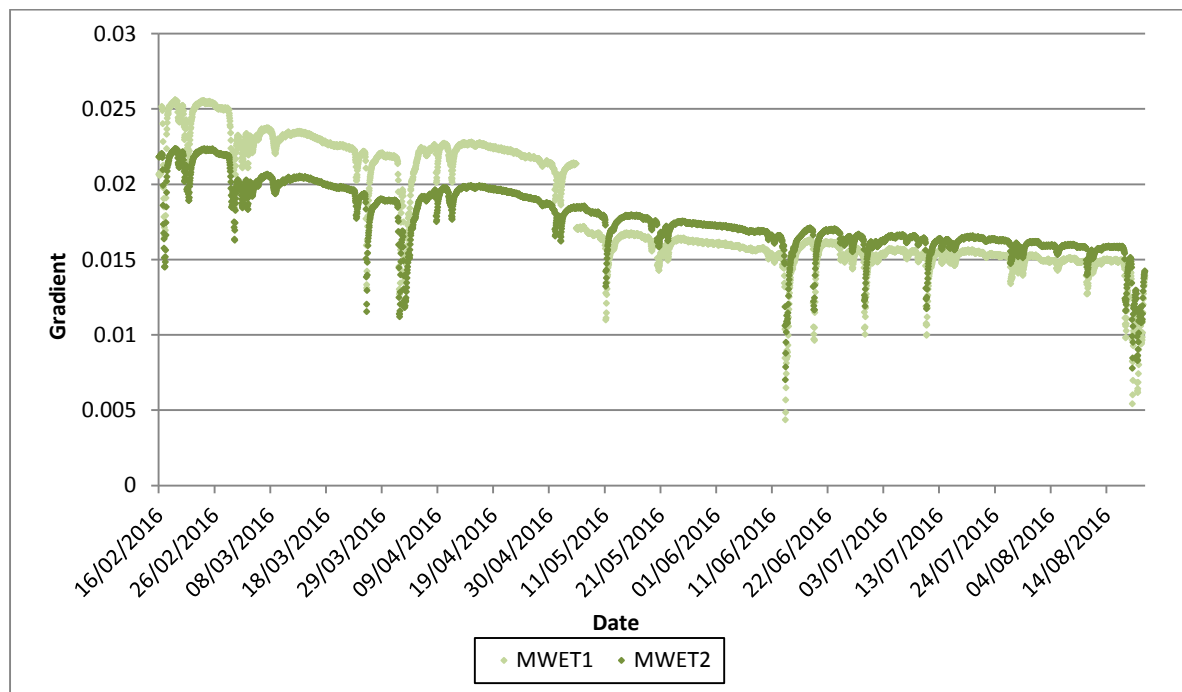


Figure 16 Calculated Groundwater Gradient to the Avoca River at the Emergency Tailings Area from 16 February to 29 August 2016

6.4 Summary of Diffuse Loading

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. In this section a summary of the evidence of diffuse loading to the Avoca River is provided from three sources, as follows:

- Point source and diffuse loading analysis;
- Groundwater gradients; and
- Surface water flow data at the EPA Gauging Stations.

6.4.1 Point Source and Diffuse Loading

The analysis of loading to the Avoca River is discussed in Section 5.2.2, Loading Results and Discussion, and can be summarised as follows using the zinc loading as an example:

- Between Site T1 to US Whites Bridge, there is a slight increase in zinc load from 4.13 to 4.6 kg/day. Between US Whites Bridge and Whites Bridge, zinc load increased from 4.55 to 8.89 kg/day which is a 95 % increase. The only surface water input in this segment is from Vale View which was dry at the time of sampling. Historically, the Vale View tributary has discharged very low zinc loads to the Avoca River. This indicates that the increase in loading is primarily due to diffuse load;
- Between Whites Bridge and Whites Bridge GS, zinc load decreases from 8.89 kg/day to 6.76 kg/day which is a decrease of 23%. The apparent decrease in zinc load may be due to the different methods employed to collect composite samples at each location. The stream bed depth at Whites Bridge makes it difficult to collect a full composite sample, representative of the river at that point. At Whites Bridge GS, the river is significantly shallower and a composite sample was collected across the full width of the River.
- Between Whites Bridge GS and DS Deep Adit on the Avoca River, the zinc load increases significantly from 6.76 to 146 kg/day which is greater than a twenty-fold increase. The Deep Adit (confluence sample) contributed 31.3 kg/day of the load. The calculations indicated that there is a significant level of diffuse flow entering the river from the Deep Adit spoils and/or the contaminated Millrace area which is contributing to the zinc load of the River. Between DS Deep Adit and DS Millrace there is a 45% decrease in zinc load which is likely due to better mixing of the Deep Adit Discharge within the Avoca River and metal precipitation on the river bed. Note that the DS Deep Adit location is positioned downgradient of the primary contamination observed in the Millrace area. An additional section of contamination exists downgradient which is captured by the DS Millrace sampling location;
- Between DS Millrace and US Ballygahan Adit on the Avoca River, zinc loads decrease from 80 to 38.2 kg/day which is likely due to further mixing of both the Deep Adit discharge and the diffuse zinc load input from the contaminated Millrace area;
- Between US Ballygahan Adit and DS Ballygahan Adit there is a 10% increase in zinc load from 38.2 to 42.2. This is likely due to the groundwater seeps located in close proximity to Ballygahan Adit which were observed in August 2016. The Adit was dry at the time of sampling in August 2016;

- Between DS Ballygahan Adit and US Road Adit there is a further 7% increase in dissolved zinc load from 42.2 to 45.1 kg/day. This increase may be due to additional diffuse zinc load inputs from West Avoca. However, further data are required to confirm this trend;
- Between US Road Adit and Wicklow County Council Maintenance Yard GS, the zinc load increases from 45.1 to 63.7 kg/day which is a 41% increase. The Road Adit (confluence sample) contributed 5.38 kg/day of the load. This further highlights the variability in dissolved metal concentrations along the Avoca River as it is unlikely that significant diffuse loading to the River occurs along this short stretch (approximately 85m); and
- Between Wicklow County Council Maintenance Yard GS and Site T5, zinc load decreased from 63.7 to 49.3 kg/day which is a similar to the expected load downstream of the Road Adit confluence.

6.4.2 Groundwater Gradients

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. The implication is that the spoil and the alluvial areas on both sides of the river contribute contaminant load to the river. However, negative gradients existed for the deeper groundwater well (MWDA2) in the deep adit area for a prolonged period in June and July. The implication is that deeper groundwater in the deep adit area does not discharge directly to the Avoca River during and after periods of sustained low flow.

6.4.3 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 derived 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 10 % which is likely to be within the margin of error determined from the deviation plots. 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.

6.4.4 Diffuse Loading Conclusion

Overall the interaction between the Avoca River and groundwater is very dynamic. The quantity of diffuse loading varies along each river stretch with the greatest evidence of diffuse loading just above Whites Bridge and between Whites Bridge GS and DS Deep Adit.

The groundwater gradients are predominantly positive which also 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. The implication is that the spoil and the alluvial areas on both sides of the river contribute contaminant load to the river.

This is particularly evident in the measured zinc load results from the August 2016 sampling event, in the stretches of river between US Whites Bridge and Whites Bridge and between Whites Bridge GS and DS Deep Adit, where the diffuse load is the primary source of zinc loading to the Avoca River. Dissolved zinc exceeded the ecological assessment criteria (50 µg/l) on the Avoca River from DS Deep Adit to Downstream Shelton Abbey with results ranging from 121 to 578 µg/l.

Section 7

Summary and Recommendations

7.1 Summary of Findings

Eight groundwater monitoring wells were sampled and analysed in August 2016 and water levels were measured. Twenty surface water locations were sampled and analysed in August and September 2016 with flows measured at 10 of the locations. The field QA/QC sample results were reviewed for accuracy and precision. The laboratory QC/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 groundwater and 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 dissolved metal concentrations were elevated in the majority of the monitoring wells and adit discharges with numerous exceedances of ecological criteria, human health criteria or both, particularly for dissolved aluminium, cadmium, copper, iron, manganese, nickel and zinc. Sulphate levels greatly exceeded the criteria for human health in the majority of monitoring wells.
- The shallow well MWPF1 located upgradient of the Deep Adit area, near the eastern margin of the alluvial sediments had the lowest concentration of dissolved metals. The highest concentrations of dissolved aluminium, iron and manganese were recorded in the wells located in the Emergency Tailings area (MWET1 and MWET2). The highest concentrations of cadmium and zinc were record in the Deep Adit wells (MWDA1 and MWDA2).
- The Cronebane Shallow Adit was the adit discharge with the highest concentrations of dissolved metals including aluminium, cadmium, iron, manganese, nickel and zinc. The Cronebane Shallow Adit is of minor importance in terms of metals loads to the Avoca River, because of absence of direct flow to the river and low concentrations and/ or flows.
- In the Avoca River and tributaries, dissolved metal concentrations were low in comparison to the groundwater and the adit discharges; however, multiple exceedances of both the ecological and human health criteria occurred, namely for dissolved cadmium, copper, manganese and zinc. Dissolved copper exceeded the ecological criteria (5 µg/l) at White Bridge and all river locations from DS Deep Adit to the Downstream Shelton Abbey location, with results ranging from 6.97 to 14.5 µg/l. Similarly, dissolved zinc exceeded the ecological assessment criteria (50 µg/l) at all river locations from DS Deep Adit to the Downstream Shelton Abbey location with results ranging from 121 to 578 µg/l. Dissolved cadmium exceeded the ecological assessment criteria of 0.45 µg/l at the monitoring point located downstream of both the Deep Adit discharge and the Road Adit discharge. The highest value for dissolved iron was recorded at 703 µg/l at Wicklow County Council Maintenance Yard GS located downstream of the Road Adit discharge on the Avoca River.

- The Deep Adit and Road Adit had significant dissolved metal loads which were discharging to the Avoca River. The Deep Adit had aluminium, copper and zinc loads of 61.6, 0.08 and 30.7 kg/day and the Road Adit had loads of 7.85, 0.18 and 4.54 kg/day, respectively.
- The results of the Mann-Kendall analysis for October 2001 to September 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. At Avoca Bridge no statistically significant trend was present for dissolved zinc or dissolved copper for both the 2001-2016 period and the 2007-2016 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. This is especially evident in the measured zinc load results, in the stretches of river between US Whites Bridge and Whites Bridge and between White Bridge GS and DS Deep Adit where the diffuse load accounts for 49% and 74% respectively.

7.2 Recommendations for the Monitoring Programme

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

Section 8

References

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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).

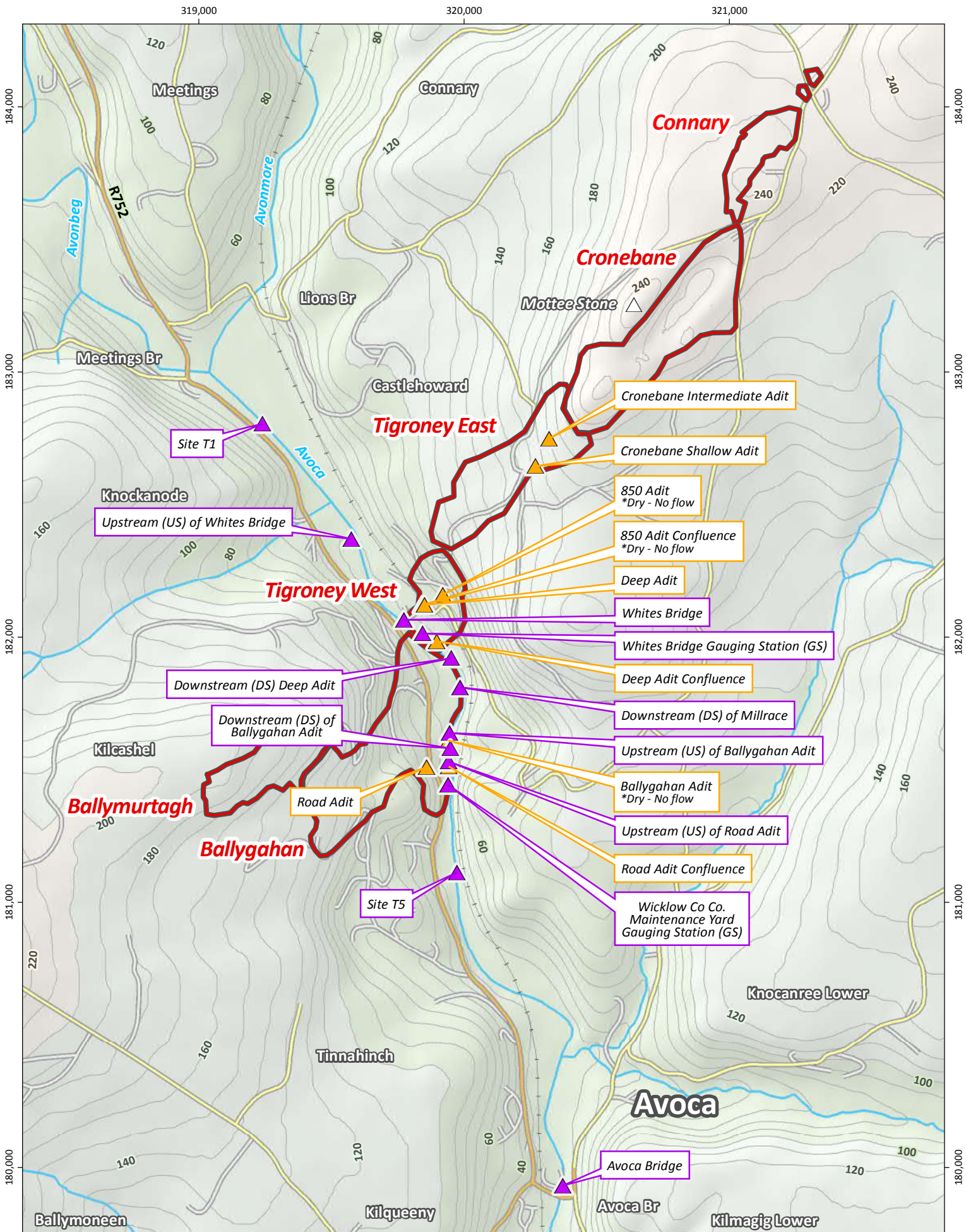
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Suter, G.W. II and Tsao, C.L. (1996). Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Appendix A

Figures



Map 1 - Avoca - Main Area

Drawn by: OC Date: 07/11/2016

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\MXD\01_AvocaMon1.mxd

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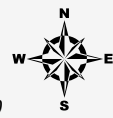
Legend

Sampling Locations

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

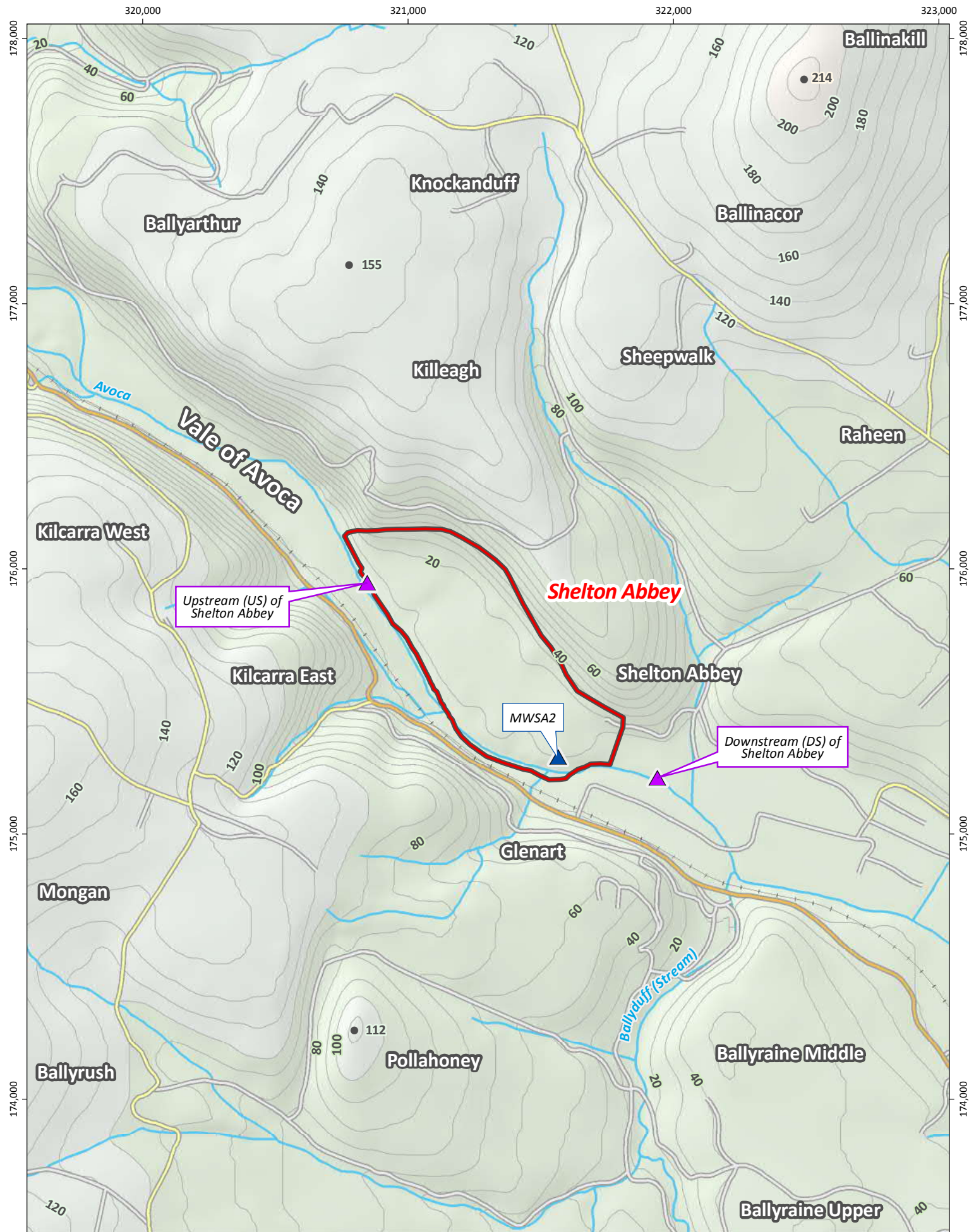
Mines

- Mining Area
- Rivers



Scale is 1:18,000

0 125 250 500 m



Map 2 - Avoca - Shelton Abbey

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40 Documents Generated\GIS\02_GIS_Tasks\18_MonRptR8\
MXD\02_AvocaMon2.mxd

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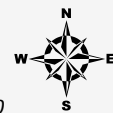
Legend

Sampling Locations

- ▲ Surface Water
- ▲ Groundwater

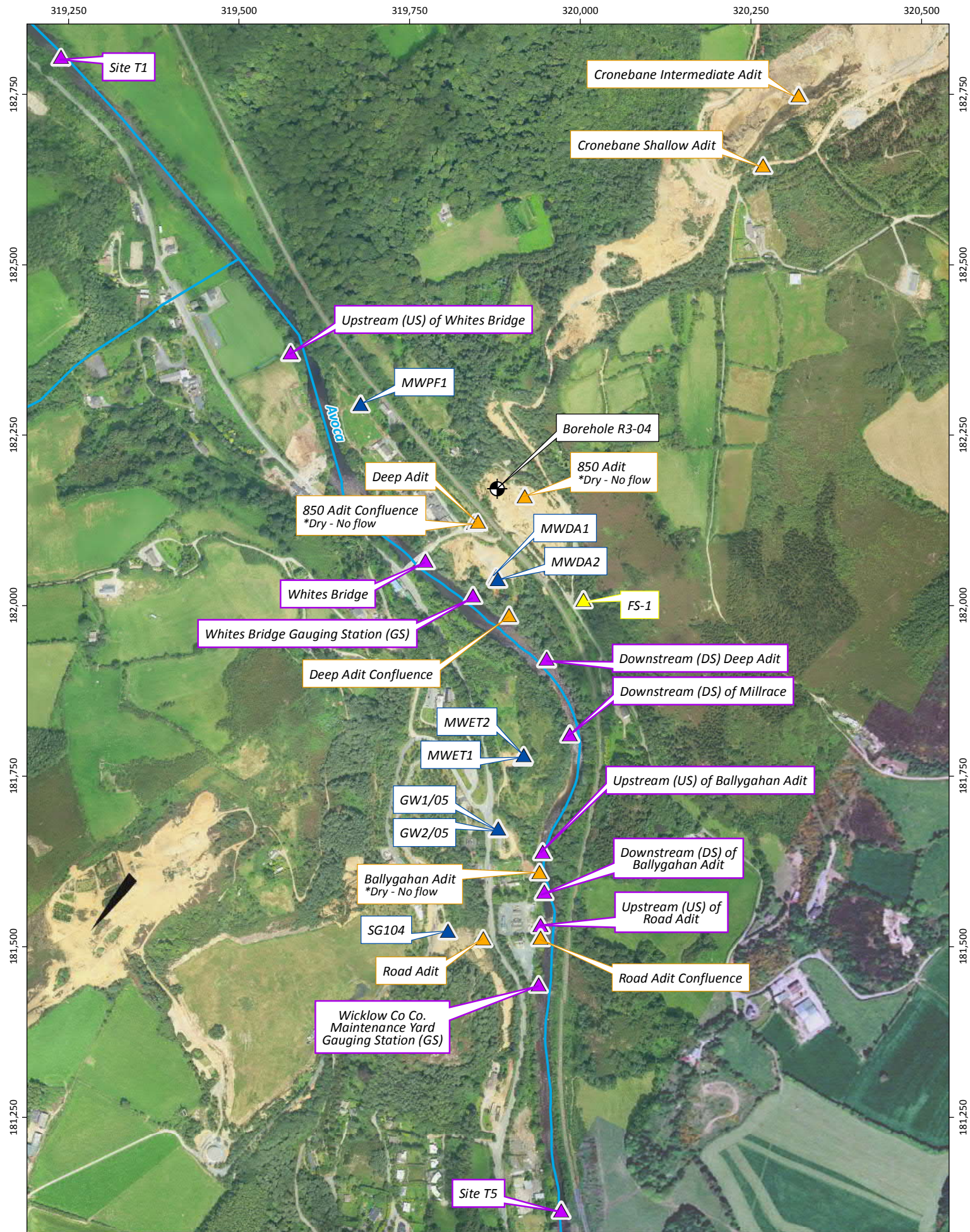
Mines

- ⬮ Mining Area
- Rivers



Scale is 1:18,000

0 125 250 500 m



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

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MXD\03_AvocaMonSWGWMxd

Source: © DCENR Lidar Survey (2007)

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Smith**

Legend

Sampling Locations

- ▲ Surface water (Adit discharge)
- ▲ Surface water (Rivers and Streams)
- ▲ Groundwater (Borehole)
- ▲ Groundwater (Spring)



Borehole R3-04



Rivers



Scale is 1:7,000

0 50 100
m

Appendix B

Analytical Data Tables and Assessment Criteria

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

Sample Description	Type	Date Sampled	Specific													
			Ammoniacal Nitrogen as N	Oxygen, dissolved (field)	Conductance @ deg.C (field)		Sulphate	Aluminium (diss.filt)	Antimony (diss.filt)	Arsenic (diss.filt)	Barium (diss.filt)	Cadmium (diss.filt)	Chromium (diss.filt)	Cobalt (diss.filt)	Copper (diss.filt)	Iron (diss.filt)
			mg/l	% Sat	pH (field)	pH Units	mS/cm	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Units			mg/l	% Sat	pH Units	mS/cm	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
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	200
MWDA1	GW	29/08/2016	0.458	3.9	2.9	1.946	1310	102000	0.48	7.67	3.1	81.8	24.4	129	15200	36100
MWDA2	GW	29/08/2016	0.1	4.9	3.7	1.565	955	34200	0.48	5.99	6.96	73.8	9.06	206	2840	110000
MWET1	GW	30/08/2016	0.692	6.2	3.2	2.149	1510	107000	0.48	4.91	3.92	29.3	17.6	205	9970	127000
MWET2	GW	30/08/2016	0.241	5.5	5.9	3.184	2380	6	0.48	6.89	10.5	2.53	3.6	108	2.55	102000
MWPF1	GW	29/08/2016	0.1	42.8	4.4	0.141	29.7	267	0.08	0.255	8.78	0.348	1.5	0.536	41	28.2
MWSA2	GW	30/08/2016	1.05	5.6	4.0	2.256	1610	60100	1.11	27.7	12.8	2.37	8.24	165	153	94800
GW1/05	GW	29/08/2016	0.1	51.1	3.4	1.602	1030	59700	0.48	4.41	4.95	22.3	3.6	116	7180	601
GW2/05	GW	29/08/2016	0.1	68.9	3.4	1.379	831	45500	0.48	4.47	2.16	19.5	3.6	93.7	6690	145
AVOCA BRIDGE	River	31/08/2016	0.243	89.5	6.05	0.073	13.2	130	0.217	0.255	4.67	0.53	0.6	0.858	10.9	183
DS BALLYGAHAN ADIT	River	31/08/2016	0.1	99.3	5.64	0.067	9.3	158	0.08	0.255	4.71	0.417	0.6	0.69	14.5	171
DS DEEP ADIT	River	31/08/2016	0.1	76.1	6.29	0.059	17.3	84.6	0.08	0.255	4.75	1.4	0.6	1.53	6.97	586
DS MILL RACE	River	31/08/2016	0.304	96.1	5.74	0.072	12.8	167	0.182	0.255	4.78	0.683	0.6	0.892	7.41	304
DS SHELTON ABBEY	River	30/08/2016	0.1	99.5	5.83	0.083	13.5	121	1.26	0.513	5.31	0.297	0.6	0.779	7.37	183
SITE T1	River	31/08/2016	0.1	95.7	5.96	0.056	1	50.4	0.08	0.678	5.22	0.04	0.6	0.075	0.98	60.7
SITE T5	River	31/08/2016	0.1	95.2	5.63	0.082	11.7	156	0.08	0.617	4.65	0.464	0.6	0.831	12	254
US BALLYGAHAN ADIT	River	31/08/2016	0.1	101.2	6.04	0.065	8.4	191	0.08	0.528	4.5	0.388	0.6	0.595	12.4	179
US ROAD ADIT	River	31/08/2016	0.1	101.8	5.58	0.065	9.8	162	0.08	0.685	4.69	0.449	0.6	0.724	13.5	174
US SHELTON ABBEY	River	30/08/2016	0.1	104.7	5.6	0.079	11.6	112	0.08	0.255	5.18	0.268	0.6	0.48	7.34	123
US WHITES BRIDGE	River	31/08/2016	0.1	92.5	6.26	0.056	1	48.7	0.08	0.584	4.95	0.04	0.6	0.075	1.1	63.5
WCC MAINTENCE YARD	River	31/08/2016	0.1	97.6	5.6	0.122	18	151	0.08	0.531	4.85	0.604	0.6	1.64	14	703
WHITES BRIDGE	River	31/08/2016	0.67	95.9	6.52	0.057	1	100	0.08	0.697	4.93	0.134	0.6	0.196	11.9	59.4
WHITES BRIDGE GS	River	31/08/2016	0.1	78.5	6.51	0.057	1	68.3	0.08	0.743	5.01	0.04	0.6	0.075	3.11	64
CRONEBONE INTER ADIT	Adit	01/09/2016	0.397	16.3	3.36	1.073	584	36500	0.48	13.7	9.16	91.2	3.6	65.4	587	77100
CRONEBONE SHALLOW ADIT	Adit	01/09/2016	0.549	3.07	2.58	3.646	3320	403000	0.88	49.9	11.2	317	16.5	296	5480	174000
DEEP ADIT	Adit	01/09/2016	0.356	27.1	3.52	1.413	980	68500	0.48	14.2	6.78	71.1	3.6	91.9	85.2	61300
DEEP ADIT CONF.	Adit	01/09/2016	0.453	88.3	3.31	1.436	934	91100	0.88	40.4	9.39	90.9	38.8	115	107	63100
ROAD ADIT	Adit	01/09/2016	9.1	36.6	3.79	1.503	879	10900	0.48	16	15.7	12.1	3.6	70.6	244	51500
ROAD ADIT CONF.	Adit	01/09/2016	9.18	82.8	3.84	1.529	864	11000	0.48	18.3	16.1	13	3.6	76	252	57500
FS1	Spring	01/09/2016	0.1	97.6	5.2	0.078	1	14.9	0.08	0.255	9.45	0.238	0.6	0.075	0.425	21.6

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

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

- Not analysed or no assessment criteria

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

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

Sample Description	Type	Date Sampled						
			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
Ecological Criteria			7.2	1100	-	20	-	50
Human Health Criteria			10	50	-	20	-	-
MWDA1	GW	29/08/2016	3.27	6820	1.86	68.1	3.9	42200
MWDA2	GW	29/08/2016	2.62	11300	1.86	103	3.9	54800
MWET1	GW	30/08/2016	8.71	7070	1.86	87.5	3.9	10600
MWET2	GW	30/08/2016	0.766	29300	1.86	12.9	3.9	4520
MWPF1	GW	29/08/2016	0.315	24	0.31	2.08	0.65	45.8
MWSA2	GW	30/08/2016	30.8	24200	1.86	110	3.9	3860
GW1/05	GW	29/08/2016	5.95	5250	1.86	54.1	3.9	8710
GW2/05	GW	29/08/2016	0.3	4100	1.86	40.1	3.9	7070
AVOCA BRIDGE	River	31/08/2016	3.16	49.2	1.37	0.942	0.65	194
DS BALLYGAHAN ADIT	River	31/08/2016	3.75	32.8	0.31	0.768	0.65	177
DS DEEP ADIT	River	31/08/2016	10.3	59.3	0.678	0.94	0.65	578
DS MILL RACE	River	31/08/2016	5.47	38	0.31	0.897	0.65	316
DS SHELTON ABBEY	River	30/08/2016	1.68	73.1	4.33	1.11	0.65	124
SITE T1	River	31/08/2016	1.26	3.48	0.31	0.573	0.65	18.4
SITE T5	River	31/08/2016	3.94	44.1	0.31	0.829	0.65	198
US BALLYGAHAN ADIT	River	31/08/2016	3.53	29.4	0.31	0.888	0.65	160
US ROAD ADIT	River	31/08/2016	3.58	35.4	0.31	0.923	0.65	189
US SHELTON ABBEY	River	30/08/2016	1.77	30.3	0.31	0.866	0.65	121
US WHITES BRIDGE	River	31/08/2016	1.28	3.79	0.31	0.498	0.65	17.9
WCC MAINTENCE YARD	River	31/08/2016	4.8	97	0.711	1.13	0.65	266
WHITES BRIDGE	River	31/08/2016	1.49	13.7	0.31	0.62	0.65	35
WHITES BRIDGE GS	River	31/08/2016	1.39	6.78	0.31	0.531	0.65	26.6
CRONEBONE INTER ADIT	Adit	01/09/2016	1210	2090	1.86	36.9	3.9	24900
CRONEBONE SHALLOW ADIT	Adit	01/09/2016	992	9310	3.41	154	7.15	145000
DEEP ADIT	Adit	01/09/2016	1530	3320	1.86	34.2	3.9	34200
DEEP ADIT CONF.	Adit	01/09/2016	1730	4040	3.41	45.3	7.15	44700
ROAD ADIT	Adit	01/09/2016	345	5170	1.86	32	3.9	6300
ROAD ADIT CONF.	Adit	01/09/2016	352	5350	1.86	34.8	3.9	6560
FS1	Spring	01/09/2016	0.202	0.909	0.31	0.22	0.65	33.6

xx Exceeds Ecological Assessment Criteria

xx Exceeds Human Health Assessment Criteria

xx Exceeds both Ecological and Human Health Criteria

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

- Not analysed or no assessment criteria

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



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