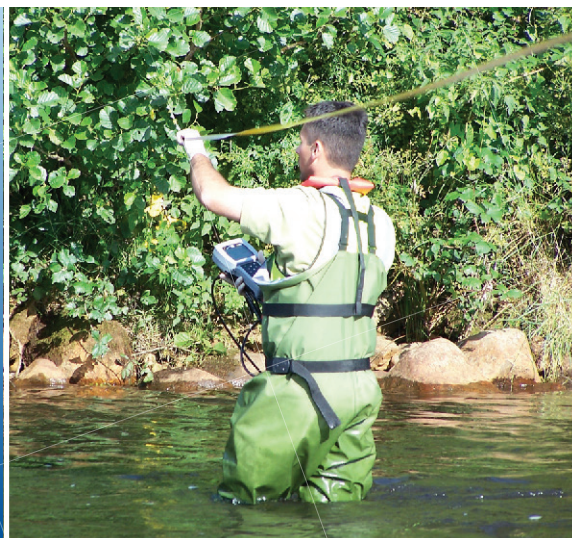


# Department of Communications, Energy & Natural Resources



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

**Avoca Monitoring Report  
- Round 2 (2015)**

Final



# CDM Smith







## Document Control Sheet

<b>Client</b>		Department of Communications, Energy and Natural Resources		
<b>Project</b>		Environmental Monitoring of Former Mining Areas of Silvermines and Avoca		
<b>Project No</b>		95735		
<b>Report</b>		Monitoring Report for the Former Mining Area of Avoca – August 2015		
<b>Document Reference:</b>		95735/40/DG/23		
<b>Version</b>	<b>Author</b>	<b>Checked</b>	<b>Reviewed</b>	<b>Date</b>
1	P Barrett	R O'Carroll	R L Olsen	December 2015

<b>Distribution</b>	<b>Copy No.</b>

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# Section 1

## Introduction

### 1.1 Objectives and Scope

The Department of Communications, Energy and Natural Resources (the Department) appointed CDM Smith Ireland Ltd (CDM Smith) to undertake a programme of environmental monitoring at the closed mine sites of Silvermines and Avoca for a three year period, commencing in 2013.

The scope of the field investigation activities was defined in the *Environmental Monitoring of Former Mining Areas of Silvermines and Avoca Monitoring Plan*, (Document Ref: 95735/40/DG01, dated 26 February 2013) and sampling activities were performed in accordance with the programme and procedures set out therein.

The Monitoring Report for the Avoca Mining Area presents an evaluation of the results of the field investigations carried out in August 2015. This report should be read alongside the Avoca Data Report (Document Ref: 95735/40/DG22, dated September 2015) 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 km<sup>2</sup>. 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 ( $\text{FeS}_2$ ) 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 ( $\text{FeS}_2$ ) accompanied by chalcopyrite ( $\text{CuFeS}_2$ ), sphalerite ( $\text{ZnS}$ ), and galena ( $\text{PbS}$ );
- 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 ( $\text{Cu}_2\text{S}$ ) and covellite ( $\text{CuS}$ ) 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. In September 2014 the adit discharge was mostly diverted into the Millrace through a marshy area to the east of the spoils area. As a result, the Deep Adit discharges both to the Avoca River at its normal discharge point (approximately 170 m from the adit portal) and approximately 20 m downstream of the normal discharge point, through a break in the side of the Millrace. In February 2015 the Deep Adit was not diverted and it was discharging to the Avoca River at its normal discharge point, however there was some ponding of water at the start of the Millrace. In August 2015 the adit discharge was completely diverted through two channels into the Millrace and subsequently seeping into groundwater (see figure 1). No flow was visibly discharging to the Avoca River.

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. 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. A partial sample<sup>1</sup> was taken in August 2015 due to low flow conditions.

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

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<sup>1</sup> Parameter analysis was limited to dissolved metals.

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.

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 the pipe leaking or flow in the adit not captured by the pipe.

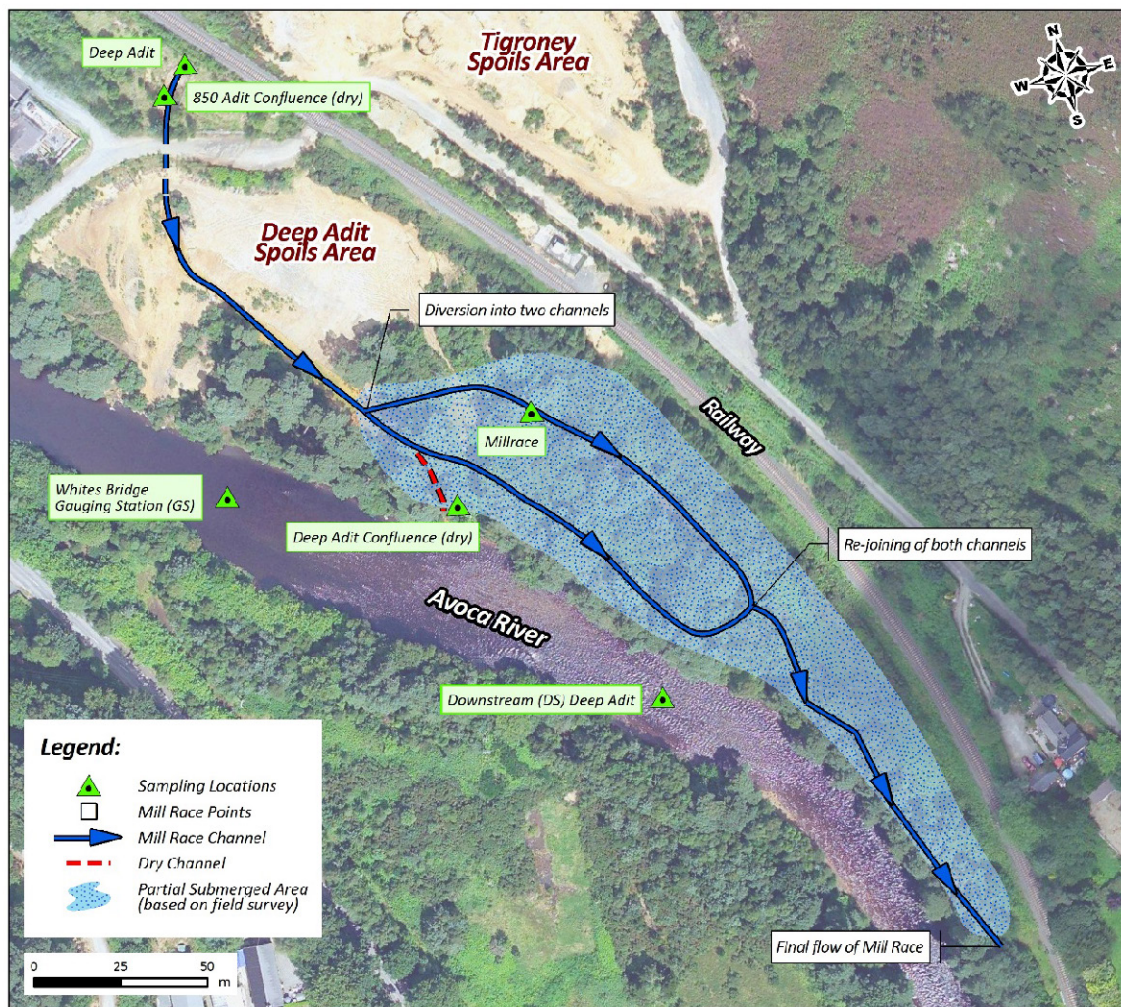


Figure 1 Deep Adit Discharge Diversion to Millrace (August 2015)



## Section 2

# Methodology

## 2.1 Field Sampling Methods

### 2.1.1 Groundwater Sampling

Nine groundwater monitoring wells were sampled on 11, 12 and 13 August 2015 as listed in Table 1 and shown 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).

**Table 1 Location of Avoca Groundwater Monitoring Points**

Borehole Identifier	Easting	Northing	Water Level	Field Parameters	Sample for Lab Analysis	Owner	Depth (m bgl)	Screen Interval (m bgl)
MWDA1	319877	182043	Yes	Yes	Yes	Dept	12	9.0 – 12
MWDA2	319879	182039	Yes	Yes	Yes	Dept	24.9	21.9 – 24.9
MWET1	319916	181778	Yes	Yes	Yes	Dept	10.9	7.8 – 10.6
MWET2	319917	181781	Yes	Yes	Yes	Dept	21	17 – 20
MWPF1	319678	182296	Yes	Yes	Yes	Dept	10	4.7 – 7.7
MWSA2	321566	175292	Yes	Yes	Yes	Dept	12.6	8.0 – 11
GW1/05	319880	181673	Yes	Yes	Yes	WCC	31	25.0 – 31
GW2/05	319880	181673	Yes	Yes	Yes	WCC	10	4.0 – 10
SG104	319806	181523	Yes	Yes	Yes	WCC	26.8	-

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 SG104 and GW2/05 where sufficient water was not present in the wells 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. 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-three surface water locations were sampled between 11 and 19 August 2015, as listed in Table 2 and shown on Map 1 and 2 in [Appendix A](#).

Surface water sampling was conducted consistent with the Surface Water Sampling Procedure (SOP 1-1) as detailed in the Monitoring Plan. No sample could be obtained from Ballygahan Adit because it was not discharging water in August 2015. No sample could be obtained from the Deep Adit confluence because all flow was diverted through the Millrace at the time of sampling.

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 all samples collected on the Avoca River and at Ballinacleish Bridge and Lions Bridge, the sample was collected as a composite sample 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. In the spring sampling events, a grab sample from the bank is collected using an extendable rod because the Avoca River is not wadable during high flows. At Shelton Abbey, the same method was used during high flow 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?
Ballinacleish Bridge	Avoca River Location	317197	185010	Float Method	Yes
Lions Bridge	Avoca River Location	319207	183287	Flow Meter	Yes
Vale View	Tributary of Avoca River	319453	182396	Flow Meter	Yes
Site T1	Avoca River Location (Upstream of Whites Br.)	319239	182805	Flow Meter	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 Automatic recorder - 10044 (data from EPA)	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 (data from EPA)	Yes
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
Sulphur Brook	Tributary of Avoca River	320491	180470	Flow Meter	Yes
850 Adit	Adit Discharge (at portal)	319919	182161	No measurable flow	Partial sample
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	No flow (Diverted into Millrace)	No



Site Name	Sample Site Description	Easting	Northing	Flow Measurement Method	Sample collected?
Millrace	Adit Discharge (Sample taken prior to flow dispersion – see Fig. 1)	319919	182001	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
Spa Adit	Adit Discharge	319637	181747	Bucket and stopwatch	Yes
Cronebane Pit Lake	Pit Lake	320933	183402	n/a	Yes

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 15 locations (see Table 2) using various methods depending upon the quantity of flow to be measured and any safety concerns as detailed in the standard operating procedures in the Monitoring Plan. In addition, flow data was obtained from the EPA for two automatic recorders and projected to four 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.

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

### 2.1.3 Field QA/QC Samples

In accordance with the QA/QC Protocols set out in the Monitoring Plan, the following field QA/QC samples were collected (also see Table 3):

- 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 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
AVGD01.6	GW Duplicate	Duplicate of MWSA2
AVDB01.6	GW Decontamination blank	DI water (Lennox Lab Supplies: Batch No: TE150727W) Pumped through groundwater pump after final decon at site MWSA2
AVSD01.6	SW Duplicate	Duplicate of Deep Adit (portal)
AVSD02.6	SW Duplicate	Duplicate of Avoca Bridge
AVDB02.6	SW Decontamination blank	DI water (Lennox Lab Supplies: Batch No: TE150526W) poured over SW composite sample bottle after final decon at Cronebane Intermediate Adit.
AVSR01.6	Standard Reference Material	Water ERA “Trace Metals” Lot #P240-740A
AVSR02.6	Standard Reference Material	Water ERA “Trace Metals” Lot #P240-740A
WB01.6	Filtration blank	Deionised water filtered onsite (Lennox Lab Suppliers. Batch No: TE150526W)
WB02.6	Water blank	Deionised water (Lennox Lab Suppliers. Batch No: TE150526W)

## 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, conductivity, Total Dissolved Solids, ammoniacal nitrogen as N, potassium, sodium, chloride, fluoride, calcium (total and dissolved), magnesium (total and dissolved), nitrate as NO<sub>3</sub> and nitrite as NO<sub>2</sub>, orthophosphate, sulphate, total alkalinity as CaCO<sub>3</sub>, free cyanide, total and dissolved metals including Al, Sb, Ag, As, Ba, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Tl, Sn, U, V and Zn. Additionally for surface water, acidity, Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD) were analysed.

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

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



## Section 3

# Data Quality and Usability Evaluation

### 3.1 Introduction

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

#### 3.1.1 Accuracy

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

%R is calculated as follows:

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

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

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

#### 3.1.2 Precision

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

RPD is calculated as follows:

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

where: RPD = Relative percent difference  
 D<sub>1</sub> = First sample value  
 D<sub>2</sub> = 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 AVSR01.6 and AVSR02.6) to evaluate laboratory accuracy. The certified SRM was supplied by ERA Certified Reference Materials and was Lot #P240-740A (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 21 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.

The majority of RPD values were below 50 % and the RPDs for the key parameters ranged from 5.6 to 34.9 % for aluminium, 1.7 to 27.4% for manganese and 1.3 to 27.7 % zinc which was good. The RPD's for copper were also good but slightly higher for duplicate pair Deep Adit and AVSD01.6 with an RPD of 59.5%.

Ten % RPDs exceeded 50 % as highlighted in Table 4 and ranged from 50.4 to 147%. Eight of the exceedances were for duplicate pair Deep Adit and AVSD01.6. Some of these differences are likely due to the dilution performed on Deep Adit and the different limits of detection for each sample. Each of these duplicate results were checked and confirmed with ALcontrol. ALcontrol stated that the results were within their duplicate policy margin. 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)	MWSA 2	AVGDO 1.6	% RPD	Deep Adit	AVSD0 1.6	% RPD	Avoca Bridge	AVSD0 2.6	% RPD
Aluminium	<2.9	90,300	85,400	5.6	106,000	74,500	34.9	99.1	93.6	5.7
Antimony	<0.16	<0.16	<0.16	0	<1.6*	<0.16	0	0.626	0.374	<b>50.4</b>
Arsenic	<0.12	13.6	13.2	3.0	2.02	1.25	47.1	0.334	0.28	17.6
Barium	<0.03	8.5	8.22	3.3	7.92	3.73	<b>71.9</b>	5.62	5.41	3.8
Cadmium	<0.1	1.55	1.51	2.6	89.2	34.8	<b>87.7</b>	0.619	0.564	9.3
Chromium	<0.22	7.21	7.12	1.3	4.14	0.63	<b>147.2</b>	0.303	0.271	11.1
Cobalt	<0.06	172	176	-2.3	118	75.5	43.9	1.32	1.29	2.3
Copper	<0.85	114	122	-6.8	142	76.9	<b>59.5</b>	12.1	11.6	4.2
Iron	<19	90,500	95,200	-5.1	53,800	50,300	6.7	158	161	-1.9
Lead	<0.02	28.7	28	2.5	2,490	1,810	31.6	2	1.93	3.6
Manganese	<0.04	36,000	35,400	1.7	4,610	3,500	27.4	85.7	76.6	11.2
Mercury	<0.01	<0.01	<0.01	0	<0.01	<0.01	0	<0.01	<0.01	0
Molybdenum	<0.24	<0.24	<0.24	0	<2.4*	<0.24	0	0.518	0.39	28.2
Nickel	<0.15	119	118	0.8	50.2	27.4	<b>58.8</b>	0.801	0.759	5.4
Selenium	<0.39	1.35	1.44	-6.5	<3.9*	1.83	<b>72.3</b>	<0.39	<0.39	0
Silver	<1.5	<1.5	<1.5	0	<15*	<15*	0	<1.5	<1.5	0
Thallium	<0.96	<0.96	<0.96	0	<9.6*	<0.96	0	<0.96	<0.96	0
Tin	<0.36	<0.36	<0.36	0	<3.6*	0.909	<b>119.4</b>	2.6	1.1	<b>81.1</b>
Uranium	<1.5	7.37	7.03	4.7	<15*	5.47	<b>93.1</b>	<1.5	<1.5	0
Vanadium	<0.24	0.748	0.691	7.9	<2.4*	<0.24	0	<0.24	<0.24	0
Zinc	<0.41	4,870	4,750	2.5	46,800	35,400	27.7	241	238	1.3

Notes:

**Bold** indicates an exceedance in the Duplicate RPD acceptance criteria

NA analyte not determined by the laboratory

\*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 21 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 0.01 to 2.9 µg/l except for iron with a detection limit of 19 µg/l.

Detections were observed for twelve dissolved metals ranging from 0.052 to 41.4 µg/l except for one result of 142 µg/l for iron. Five of the metals (chromium, lead, manganese, nickel and zinc) were also detected in the DI water blank. The levels of detections in the decontamination blanks were similar to those found in the DI water blank with the exception of zinc in AVDB02.6 which was seventeen times greater (10.3 µg/l). Relatively low concentrations of dissolved aluminium, antimony, barium, copper, iron, molybdenum and tin were also found in the decontamination blanks but not the DI water blank.

In total there were nineteen detections of dissolved metals in the decontamination blanks. None 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. Three 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, in AVDB01.6 manganese (2.93 µg/l) and in AVDB02.6 zinc (10.3 µg/l) and manganese (0.699 µg/l). All of the detections including lead, manganese and zinc were significantly less than the assessment criteria outlined in Section 4; therefore, these low concentrations in the blanks do not affect interpretation of results.

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 AVDB01.6 iron (142 µg/l) was 0.2% of the preceding sample and manganese (2.93 µg/l) was 0.008%. In AVDB02.6 manganese (0.699 µg/l) was 12% of the preceding sample and zinc (10.3 µg/l) was 69 %. However the dissolved zinc concentrations in the decontamination blanks were considered to be within acceptable ranges for zinc as it is a common contaminant and has previously been detected in the DI water blank in similar concentrations.

The results from the laboratory instrumentation blank were obtained from ALcontrol to determine if any contamination occurred within the laboratory (Table 5). It was noted dissolved antimony and molybdenum were detected in the method blank and were similar to the concentration in the decontamination blank sample, as follows:

- Two detections of parameters were present in method blank for Sample Batch 150820-115 that occurred in the decontamination blank from the same batch (see Table 5): antimony 0.29 µg/l and molybdenum 0.34 µg/l.

Overall, the decontamination 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.

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

Dissolved Metal	LOD (µg/l)	Filtration Blank WB01.6 (µg/l)	Water Blank WB02.6 (µg/l)	Decon blank AVDB01.6 (µg/l)	Laboratory Method Blank (µg/l)	Decon blank AVDB02.6 (µg/l)	Laboratory Method Blank (µg/l)
<i>Sample batch:</i>		<i>150815-81</i>				<i>150820-115</i>	
Aluminium	<2.9	<2.9	<2.9	<b>8.4</b>	<2.9	<2.9	<2.9
Antimony	<0.16	<b>0.46</b>	<0.16	<0.16	<0.16	<b>0.325</b>	<i>0.29</i>
Arsenic	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12
Barium	<0.03	<b>0.059</b>	<0.03	<b>0.07</b>	<0.03	<b>0.052</b>	<0.03
Cadmium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium	<0.22	<b>0.425</b>	<b>0.445</b>	<b>1.12</b>	<0.22	<b>1.03</b>	<0.22
Cobalt	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Copper	<0.85	<0.85	<0.85	<b>1.43</b>	<0.85	<0.85	<0.85
Iron	<19	<19	<19	<b>142</b>	<19	<b>41.4</b>	<19
Lead	<0.02	0.041	<b>0.021</b>	<b>0.086</b>	NP	<b>0.092</b>	NP
Manganese	<0.04	<b>0.2</b>	<b>0.729</b>	<b>2.93</b>	<0.04	<b>0.699</b>	<0.04
Mercury	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Molybdenum	<0.24	<b>0.383</b>	<0.24	<0.24	<0.24	<b>0.631</b>	<i>0.34</i>
Nickel	<0.15	<0.15	<b>0.273</b>	<b>1.02</b>	<0.15	<b>0.222</b>	<0.15
Selenium	<0.39	<0.39	<0.39	<0.39	<0.39	<0.39	<0.39
Silver	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Thallium	<0.96	<0.96	<0.96	<0.96	<0.96	<0.96	<0.96
Tin	<0.36	<b>1.22</b>	<0.36	<0.36	<0.36	<b>1.62</b>	<0.36
Uranium	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Vanadium	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
Zinc	<0.41	<b>1.13</b>	<b>0.617</b>	<b>2.26</b>	<0.41	<b>10.3</b>	<0.41

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

NP means result was Not Provided by the laboratory.

### 3.2.3 Standard Reference Materials

As previously discussed, two certified water SRMs were sent blind to the laboratory (Sample IDs AVSR01.6 and AVSR02.6) 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 18 requested metals.

Reported values for the majority of the metals were within the acceptable ranges. Dissolved aluminium, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, selenium, thallium and vanadium are in excellent agreement with the certified value (%R ranged from 87 to 104 %).

One of the reported values for dissolved antimony (84 %), nickel (90 %), silver (87 %) and zinc (89 %) were outside the acceptable range, however the corresponding reported values for the second SRM sample were within acceptable ranges and therefore the interpretation of the results are not affected. Both of the reported values for dissolved molybdenum were low at 84 % which fall



outside of the acceptable range. This indicates that there may be bias (low) in the results for molybdenum and any use of these values should be noted with this observation.

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

Dissolved Metal	Certified Value (µg/l)	Acceptance Limits		AVSR01.6 (µg/l)	% R	AVSR02.6 (µg/l)	% R
		Lower (%)	Upper (%)				
Aluminium	1810	87	114	1790	99	1750	97
Antimony	131	87	111	115	88	110	<b>84</b>
Arsenic	304	87	111	269	88	263	87
Barium	372	91	109	373	100	363	98
Cadmium	673	89	106	666	99	648	96
Chromium	483	91	109	466	96	479	99
Cobalt	747	93	111	724	97	753	101
Copper	201	91	109	196	98	196	98
Iron	1930	90	111	1800	93	1760	91
Lead	285	90	110	296	104	294	103
Manganese	1130	92	109	1140	101	1160	103
Molybdenum	140	90	109	118	<b>84</b>	117	<b>84</b>
Nickel	1280	91	109	1150	<b>90</b>	1240	97
Selenium	299	88	111	273	91	269	90
Silver	257	90	110	223	<b>87</b>	237	92
Thallium	567	88	111	578	102	587	104
Vanadium	252	91	107	247	98	258	102
Zinc	769	91	110	715	93	683	<b>89</b>

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 AQC's.

All of the ALcontrol laboratory reports were reviewed to ensure that reported values were ISO17025 certified (where relevant) and for any sample deviations. The sample holding times were exceeded for free cyanide in 23 samples by 2-3 days. Small exceedances are typically considered acceptable from a technical perspective given the conservative nature of holding times.

ALcontrol provided the associated analytical quality control samples (AQC) data. The percentage recovery results for the AQC samples that were analysed with the regular environmental samples were checked against the individual lower control and upper control limits. All AQC samples analysed with the environmental samples were within these upper and lower control limits with the exception of total cyanide in QC 1172 which exceeded the upper limit. However, all of the corresponding environmental results were below the limit of detection which indicates no routine high bias in the results. In addition, several environmental samples were re-analysed to verify the results. The results of method blanks were also assessed as described in Section 3.2.2 above.

## 3.4 Summary of Data Checks

### 3.4.1 Field physico-chemical Versus Laboratory Data

Table 7 summarises the field and laboratory results for pH and conductivity 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 conductivity were less than 31 % which is good. The RPDs between laboratory and field pH were also good at less than 27 %. Lab results for pH are consistently higher than the field readings which is common, particularly for low pH samples, due to carbon dioxide degassing during transport or in the laboratory. The greatest difference between lab and field pH readings was 1.73. The field pH and conductivity are more representative of actual conditions and are used for interpretive purposes. Overall the %RPDs between the field and laboratory data are considered satisfactory.

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

Sample Description	pH	pH	% RPD	Conductivity @ 20deg.C	Specific Cond. @ 25deg.C	% RPD
	Lab	Field		Lab	Field	
	pH Units			mS/cm		
Sulphur Brook	7.35	7	4.9	0.151	0.159	-5.2
DS Shelton Abbey	7.13	6.64	7.1	0.087	0.095	-8.8
US Shelton Abbey	7.25	6.43	12.0	0.087	0.09	-3.4
Deep Adit	3.51	3.34	5.0	1.19	1.306	-9.3
Millrace	3.42	3.23	5.7	1.21	1.329	-9.4
Road Adit	3.94	3.45	13.3	1.44	1.564	-8.3
Road Adit Confluence	3.94	3.57	9.9	1.5	1.56	-3.9
Spa Adit	2.85	2.28	22.2	2.18	2.444	-11.4
Vale View	7.6	6.67	13.0	0.139	0.157	-12.2
Avoca Bridge	7.49	6.08	20.8	0.0887	0.094	-5.8
DS Deep Adit	7.26	6.1	17.4	0.0735	0.07	4.9
Site T5	7.37	5.92	21.8	0.0946	0.107	-12.3
US Road Adit	7.19	5.99	18.2	0.0738	0.087	-16.4
WCC Maintenance Yard GS	7.23	6.19	15.5	0.109	0.08	30.7
Whites Bridge	7.55	6.21	19.5	0.0688	0.075	-8.6
Whites Bridge (GS)	7.39	6.31	15.8	0.069	0.073	-5.6
Ballinacleish Bridge	7.47	5.74	26.2	0.0617	0.061	1.1
Cronebane Inter. Adit	3.03	2.75	9.7	1.11	1.104	0.5
Cronebane Pit Lake	3.21	3	6.8	0.488	0.547	-11.4
Cronebane shallow Adit	2.88	2.29	22.8	2.97	3.269	-9.6
Lions Bridge	6.95	5.79	18.2	0.0766	0.07	9.0
Site T1	7.83	6.27	22.1	0.0734	0.068	7.6
MWDA1	3.08	2.59	17.3	2.06	2.3	-11.0
MWDA2	3.89	3.4	13.4	1.2	1.347	-11.5
GW1/05	3.83	3.47	9.9	1.93	1.722	11.4
GW2/05	3.84	3.46	10.4	1.49	1.469	1.4
MWET 1	3.48	3.18	9.0	1.85	2.201	-17.3
MWET 2	6.28	5.91	6.1	2.64	3.396	-25.0
MWPF 1	5.17	4.35	17.2	0.139	0.154	-10.2
SG104	3.08	2.78	10.2	7.41	7.943	-6.9
MWSA2	3.89	3.88	0.3	2.22	2.447	-9.7

Notes:

**Bold** indicates an exceedance in acceptance limits

### 3.4.2 Internal Consistency Analysis

The analyses were checked for internal consistency using both charge balance and mass balance relationships.

The charge balance was calculated as follows:

$$\frac{(\sum(\text{Cations} \times \text{charge}) - \sum(\text{Anions} \times \text{charge}))}{(\sum(\text{Cations} \times \text{charge}) + \sum(\text{Anions} \times \text{charge}))} \times 100\%$$

where: “cations” refers to the molar concentration of positively charged ions (millimoles/L) and “anions” to the molar concentration of negatively charged ions.

The mass balance was calculated using the following relationship:

$$(\text{TDS-Calc} - \text{TDS-Meas})/\text{TDS-Meas} \times 100\%$$

TDS-Calc was calculated by summing the concentrations of all species in mg/l. Adjustments were made in cases where the species that would be formed upon evaporation (laboratory analytical procedure to yield TDS-Meas) was in a different form than that provided by the laboratory. For instance, the bicarbonate concentration was multiplied by a factor of 0.49 to account for loss of carbon dioxide gas during evaporation.

By evaluating both the mass balance and charge balance, conclusions can be drawn about the accuracy and completeness of the analysis. The possible mass balance and charge balance combinations and the corresponding interpretations are shown in Table 8.

The general acceptance criteria for internal consistency are  $\pm 10\%$  for both the charge balance and the mass balance. The charge balance was generally within acceptable limits, with most values below 10 % which is good, with only 5 samples outside the range. The mass balance, in the majority of cases (bolded values) did not meet these criteria. Most values were less than 30 %; which overall is very good considering the low pH, high TDS and complex nature of the high metal concentrations of many of the samples. The fact that the mass balance values are mostly negative suggests that either one or more parameters were under-reported by the analytical laboratory and/or one or more parameters present within the samples were not analysed (e.g. silica). The charge balance and mass balance result at Whites Bridge GS was omitted due to a very high laboratory reading of sodium (567 mg/l). The recording was checked and confirmed by ALcontrol; however, the result has been rejected because it contradicts the TDS (measured) laboratory result and the SC/TDS relationship. In addition, the result is significantly different than the historical values at this sampling location.

**Table 8 Charge Balance and Mass Balance Results**

Site Description	TDS (Calc) (mg/l)	TDS (Meas) (mg/l)	Cations minus anions	Charge Balance % Diff	Mass Balance % Diff	Conclusion
Avoca Bridge	53	30	-0.1	-3.5	<b>75.5</b>	Too many anions
Ballinacleish Bridge	36	51	0.0	2.4	<b>-29.8</b>	Missing anions
Cronebane Inter. Adit	788	991	0.3	1.4	<b>-20.5</b>	Missing anions
Cronebane Pit Lake	208	262	-0.8	<b>-12.0</b>	<b>-20.5</b>	Missing cations
Cronebane Shallow Adit	3545	4120	-0.9	-0.8	<b>-13.9</b>	Missing cations
Deep Adit	1159	1430	4.1	<b>10.2</b>	<b>-18.9</b>	Missing anions
DS Deep Adit	44	45.3	0.0	1.7	-3.4	Missing anions
DS Shelton Abbey	47	68	0.0	1.7	<b>-30.5</b>	Missing anions
Lions Bridge	40	51	-0.1	-4.6	<b>-20.8</b>	Missing cations
Millrace	1002	1380	-8.3	<b>-30.4</b>	<b>-27.4</b>	Missing cations
Road Adit	1208	1450	-0.9	-2.6	<b>-16.7</b>	Missing cations
Road Adit Conf.	1224	1480	0.1	0.3	<b>-17.3</b>	Missing anions
Site T1	36	40	0.0	1.4	-9.4	Missing anions
Site T5	56	62.2	-0.1	-3.6	-9.9	Missing cations
Spa Adit	2062	2740	-2.1	-3.2	<b>-24.7</b>	Missing cations
Sulphur Brook	94	109	0.0	-0.3	<b>-13.7</b>	Missing cations
US Road Adit	47	51.6	0.0	0.8	-9.7	Missing anions
US Shelton Abbey	56	65.3	-0.3	<b>-14.6</b>	<b>-14.5</b>	Missing cations
Vale View	88	101	-0.1	-3.4	<b>-13.1</b>	Missing cations
WCC Maintenance Yard GS	64	75	0.0	-2.1	<b>-14.6</b>	Missing cations
Whites Bridge	40	48	0.1	4.9	<b>-17.6</b>	Missing anions
Whites Bridge (GS)	-	-	-	-	-	-
GW1/05	1467	1880	2.3	4.8	<b>-21.9</b>	Missing anions
GW2/05	1160	1490	1.0	2.7	<b>-22.2</b>	Missing anions
MWDA1	1844	2550	-0.9	-1.5	<b>-27.7</b>	Missing cations
MWDA2	1096	1470	1.0	2.8	<b>-25.4</b>	Missing anions
MWET 1	1987	2720	0.5	0.8	<b>-26.9</b>	Missing anions
MWET 2	3263	4120	-0.1	-0.1	<b>-20.8</b>	Missing cations
MWPF 1	80	90	-0.1	-3.2	<b>-10.7</b>	Missing cations
MWSA2	2379	3000	2.5	3.4	<b>-20.7</b>	Missing anions
SG104	10508	13200	1.8	0.5	<b>-20.4</b>	Missing anions

Notes:

**Bold** indicates an exceedance of the acceptance criteria

The specific conductivity (SC) of the solutions can be used to further evaluate the internal consistency. The specific conductivity/total dissolved solids (SC/TDS) ratio of natural waters varies, but typically ranges from ranges from 1 to 1.8. An evaluation can be made of these analyses by examining the ratios of SC/TDS (see Table 9). The low ratios of less than 1 are generally due to samples with high TDS and SC. In these samples, there were also high sulphate values, and at high concentrations of sulphate, ion pairing occurs which results in the SC values being lower (i.e. not all the sulphate will provide independent anions).

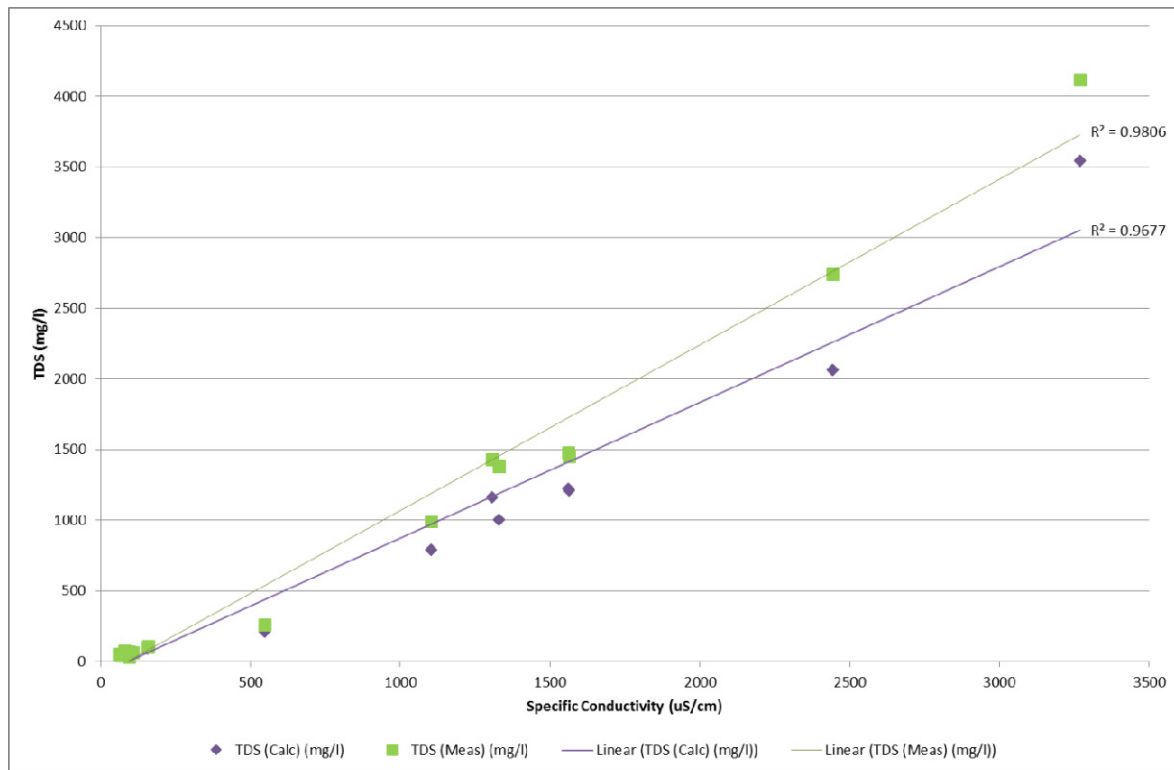


Avoca Bridge had a high SC/TDS-Meas ratio of 3.1 which also had one of the lowest measured TDS and at low levels, the relationships are less accurate. The majority of the ratios in Table 9 are within the range for natural waters and therefore the analyses are considered reliable.

**Table 9 Comparison of Specific Conductivity to Total Dissolved Solids (SC/TDS) Ratio**

Sample Description	Sample Type	Specific Cond.	TDS (Calc)	TDS (Meas)	Ratio	
		( $\mu\text{S}/\text{cm}$ )	( $\text{mg}/\text{l}$ )	( $\text{mg}/\text{l}$ )	SC/ TDS- Calc	SC/ TDS - Meas
Avoca Bridge	SW	94	53	30	1.8	3.1
Ballinacleish Bridge	SW	61	36	51	1.7	1.2
Cronebane Inter. Adit	Adit	1104	788	991	1.4	1.1
Cronebane Pit Lake	Adit	547	208	262	2.6	2.1
Cronebane Shallow Adit	Adit	3269	3545	4120	0.9	0.8
Deep Adit	Adit	1306	1159	1430	1.1	0.9
DS Deep Adit	SW	70	44	45.3	1.6	1.5
DS Shelton Abbey	SW	95	47	68	2.0	1.4
Lions Bridge	SW	70	40	51	1.7	1.4
Millrace	SW	1329	1002	1380	1.3	1.0
Road Adit	Adit	1564	1208	1450	1.3	1.1
Road adit Conf.	Adit	1560	1224	1480	1.3	1.1
Site T1	SW	68	36	40	1.9	1.7
Site T5	SW	107	56	62.2	1.9	1.7
Spa Adit	Adit	2444	2062	2740	1.2	0.9
Sulphur Brook	SW	159	94	109	1.7	1.5
US Road Adit	SW	87	47	51.6	1.9	1.7
US Shelton Abbey	SW	90	56	65.3	1.6	1.4
Vale View	SW	157	88	101	1.8	1.6
WCC Maintenance Yard GS	SW	80	64	75	1.2	1.1
Whites Bridge	SW	75	40	48	1.9	1.6
Whites Bridge GS	SW	-	-	-	-	-
GW1/05	GW	1722	1467	1880	1.2	0.9
GW2/05	GW	1469	1160	1490	1.3	1.0
MWDA1	GW	2300	1844	2550	1.2	0.9
MWDA2	GW	1347	1096	1470	1.2	0.9
MWET 1	GW	2201	1987	2720	1.1	0.8
MWET 2	GW	3396	3263	4120	1.0	0.8
MWPF 1	GW	154	80	90	1.9	1.7
MWSA2	GW	2447	2379	3000	1.0	0.8
SG104	GW	7943	10508	13200	0.8	0.6

Figure 2 Relationship of Specific Conductivity and Total Dissolved Solids (TDS) shows a strong positive correlation between SC with both the calculated ( $R^2=0.97$ ) and measured ( $R^2=0.98$ ) TDS.



**Figure 2 Relationship of Specific Conductivity and Total Dissolved Solids (TDS)**

### 3.4.3 Comparison of Total and Dissolved Metals

Total metals are the concentration of metals determined in an unfiltered sample (combination of metals contained in the solid sediments, colloidal particles and in the dissolved phase), while dissolved metals are those which pass through a 0.45µm membrane filter. Dissolved metals are more biologically available than total metals.

Normally the dissolved metal concentrations would be less than the total metals because they are a portion of the total concentration. This was checked for some of the key metals; aluminium, copper, iron and zinc, by calculating the ratio of total and dissolved metals to evaluate if the concentrations were different. Table B-1 in [Appendix B](#) shows the full tabulation of results. The dissolved metals were generally equal to or close to the total metals, indicating that the majority of the aluminium, copper, iron and zinc present were dissolved. For many of the river and stream samples however the total aluminium and iron were significantly higher than the dissolved portion. The total suspended solids in the river and stream samples ranged from <2 to 8 mg/l. The dissolved concentrations were higher than the total concentrations in about 30% of the aluminium results and 30% of the copper results with the majority of dissolved concentrations within 20% of the total concentrations which is considered acceptable.

## 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 10 provides a summary of the reported dissolved concentrations of the nine groundwater samples. 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 10 Summary of Dissolved Metal Concentrations in Groundwater**

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2.9	9	9	95.9	760000	140200	236450
Antimony	<0.16	9	5	0.08	2.18	0.67	0.81
Arsenic	<0.12	9	2	0.06 (0.6*)	13.6	2.01	-
Barium	<0.03	9	9	1.9	10	5.85	3.2
Cadmium	<0.1	9	9	0.32	92.9	25.1	28.5
Chromium	<0.22	9	9	0.945	22.5	8.2	7.6
Cobalt	<0.06	9	9	0.503	479	147	133
Copper	<0.85	9	9	9.15	79500	13690	25200
Iron	<19	9	8	9.5	130000	52080	47490
Lead	<0.02	9	9	0.239	89.3	20.9	31.9
Manganese	<0.04	9	9	19.3	38900	15920	15540
Mercury	<0.01	9	0	0.005	0.005	-	-
Molybdenum	<0.24	9	4	0.12 (1.2*)	0.646	0.49	0.43
Nickel	<0.15	9	9	1.28	177	66.8	53.2
Selenium	<0.39	9	8	0.195	5.87	2.13	2.1
Silver	<1.5	9	0	0.75	0.75	-	-
Thallium	<0.96	9	2	0.48 (4.8*)	1.88	1.65	-
Tin	<0.36	9	5	0.18	11.9	4.83	5.5
Uranium	<1.5	9	6	0.75 (7.5*)	53.8	10.8	16.3
Vanadium	<0.24	9	3	0.12 (1.2)*	0.748	0.47	0.46
Zinc	<0.41	9	9	37.9	118000	23700	37000

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 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 (95.9 µg/l) and copper (9.15 µg/l). SG104 is located immediately downgradient of Ballymurtagh Landfill had the highest concentrations of metals especially aluminium, cadmium, copper, nickel and zinc. Dissolved arsenic was only detected in two wells with highest concentration at MWSA2 of 13.6 µg/l.

#### 4.1.2 Surface Water Sample Results

Surface water samples were collected for two major categories: the first includes mine adit discharges and the pit lake and the second includes the Avoca River and tributaries. Table 11 provides a summary of the reported results of the 8 adit discharge samples and the one pit lake sample and Table 12 provides a summary of the dissolved metals of the 14 river and stream 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 and Pit Lake

**Table 11 Summary of Dissolved Metal Concentrations in Adit Discharges and Pit Lake**

Dissolved Metal	LOD (µg/l)	Number	Number of Detections	Minimum (µg/l)	Maximum (µg/l)	Mean (µg/l)	SDEV
Aluminium	<2.9	9	9	7290	294000	79500	95700
Antimony	<0.16	9	3	0.08 (0.8*)	5.15	1.58	1.72
Arsenic	<0.12	9	7	0.462	53.6	8.54	17.06
Barium	<0.03	9	9	0.649	15	7.75	4.69
Cadmium	<0.1	9	9	7.41	92	43.7	36.1
Chromium	<0.22	9	9	0.664	7.5	4.06	2.26
Cobalt	<0.06	9	9	8.72	238	102	73.6
Copper	<0.85	9	9	11	10200	3170	3800
Iron	<19	9	9	1330	156000	76250	44300
Lead	<0.02	9	9	108	2490	717	761
Manganese	<0.04	9	9	298	9310	5350	3541
Mercury	<0.01	9	0	0.005	0.005	-	-
Molybdenum	<0.24	9	2	0.12 (1.2*)	5.94	1.77	-
Nickel	<0.15	9	9	4.63	87.5	41.1	26.5
Selenium	<0.39	9	3	0.567	4.79	2.06	1.12
Silver	<1.5	9	0	0.75 (7.5*)	7.5*	-	-
Thallium	<0.96	9	0	0.48 (4.8*)	4.8*	-	-
Tin	<0.36	9	2	0.18 (1.8*)	6.64	2.12	-
Uranium	<1.5	9	1	0.75 (7.5*)	18.3	-	-
Vanadium	<0.24	9	1	0.12 (1.2*)	0.73	-	-
Zinc	<0.41	9	9	3350	103000	27000	31900

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 the adit discharges and the pit lake sample. The Cronebane Shallow Adit had the highest concentrations of dissolved metals including aluminium (294,000 µg/l), iron (156,000 µg/l) and zinc (103,000 µg/l). The lowest dissolved metals concentrations were found in the Millrace with the exception of iron which was lowest in the Cronebane Pit Lake (1,330 µg/l). The Millrace sample was collected approximately 45m downstream of the Deep Adit confluence and low concentrations indicate significant precipitation of metals along the stream channel.

## Rivers and Streams

**Table 12 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	<2.9	14	14	7.42	389	90.5	96.1
Antimony	<0.16	14	6	0.08	1.06	0.23	0.28
Arsenic	<0.12	14	14	0.331	0.654	0.44	0.10
Barium	<0.03	14	14	4.99	8.09	5.91	0.97
Cadmium	<0.1	14	9	0.05	0.688	0.30	0.24
Chromium	<0.22	14	14	0.246	1.1	0.48	0.2
Cobalt	<0.06	14	9	0.03	2.39	0.61	0.73
Copper	<0.85	14	12	0.425	16.8	8.19	6.25
Iron	<19	14	11	9.5	1050	167	280
Lead	<0.02	14	14	0.164	3.98	1.77	0.94
Manganese	<0.04	14	14	1.17	167	42.4	49.5
Mercury	<0.01	14	0	0.005	0.005	-	-
Molybdenum	<0.24	14	5	0.12	1.06	0.26	0.26
Nickel	<0.15	14	13	0.075	1.14	0.72	0.30
Selenium	<0.39	14	0	0.195	0.195	-	--
Silver	<1.5	14	0	0.75	0.75	-	-
Thallium	<0.96	14	0	0.48	0.48	-	-
Tin	<0.36	14	5	0.18	3.75	0.74	1.09
Uranium	<1.5	14	0	0.75	0.75	-	-
Vanadium	<0.24	14	1	0.12	0.24	-	-
Zinc	<0.41	14	14	4.66	338	125	109

Notes:

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

Dissolved metals were detected upgradient of the mining area at Ballinacleish Bridge and Lions Bridge with concentrations of aluminium at 37.1 and 38.3 µg/l, zinc at 15 and 26.4 µg/l and iron at 67.8 and 80.4 µg/l at the respective locations.

Site T1 (upstream of the main mining area) is the first sampling location on the Avoca River with the concentration of dissolved aluminium at 34.8 µg/l and zinc at 24.8 µg/l. 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 (103 µg/l), copper (14.4 µg/l) and zinc (67.2 µg/l).



Along the Avoca River the concentrations of dissolved metals were variable; the highest dissolved aluminium was 103 µg/l recorded at Whites Bridge, the highest dissolved copper (16.6 µg/l) and zinc (338 µg/l) were recorded at Wicklow County Council Maintenance Yard GS.

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 13. 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 13).

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 CaCO<sub>3</sub> (CDM, 2008) and the appropriate ecological assessment criteria are highlighted in bold in Table 13.

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 14. 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 13 and Table 14).

**Table 13 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	<b>0.14</b>	S.I. No. 272 of 2009	Good status
Ortho-phosphate as P	mg/l	0.035	<b>0.075</b>	S.I. No. 272 of 2009	Good status
pH	pH units		> <b>4.5</b> and < 9.0	S.I. No. 272 of 2009	Within range
Dissolved Oxygen	% Sat		<b>80 to 120</b>	S.I. No. 272 of 2009	Within range. Only relevant to surface water
Free Cyanide	mg/l	<b>0.01</b>	-	S.I. No. 272 of 2009	
Fluoride	mg/l	<b>0.5</b>	-	S.I. No. 272 of 2009	
Arsenic	µg/l	<b>25</b>	-	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)	≤ <b>0.45</b> (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 <sub>3</sub> (Class 1: <40 mg CaCO <sub>3</sub> /l, Class 2: 40 to <50 mg CaCO <sub>3</sub> /l, Class 3: 50 to <100 mg CaCO <sub>3</sub> /l, Class 4: 100 to <200 mg CaCO <sub>3</sub> /l and Class 5: ≥200 mg CaCO <sub>3</sub> /l)
Chromium	µg/l	<b>3.4</b>	-	S.I. No. 272 of 2009	
Copper	µg/l	<b>5</b> or 30	-	S.I. No. 272 of 2009	5 µg/l applies where the water hardness measured in mg/l CaCO <sub>3</sub> is ≤ 100; 30 µg/l applies where the water hardness > 100 mg/l CaCO <sub>3</sub> .
Lead	µg/l	<b>7.2</b>	-	S.I. No. 327 of 2012	
Mercury	µg/l	0.05	<b>0.07</b>	S.I. No. 327 of 2012	
Nickel	µg/l	<b>20</b>	-	S.I. No. 327 of 2012	
Zinc	µg/l	8 or <b>50</b> or 100	-	S.I. No. 272 of 2009	8 µg/l for water hardness with annual average values ≤ 10 mg/l CaCO <sub>3</sub> ; 50 µg/l for water hardness > 10 mg/l CaCO <sub>3</sub> and ≤ 100 mg/l CaCO <sub>3</sub> ; and 100 µg/l elsewhere.
<b>Supplementary standards:</b>					
Aluminium	µg/l	-	<b>1900</b>	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids
Barium	µg/l	-	<b>4</b>	Oak Ridge National Laboratory	Invertebrates and Salmon fish
Cobalt	µg/l	-	<b>5.1</b>	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids
Manganese	µg/l	-	<b>1,100</b>	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids
Uranium	µg/l	-	<b>2.6</b>	Oak Ridge National Laboratory	Invertebrates only - Lowest Chronic Value for Daphnids

Notes:

**Bold** indicates the selected assessment criteria for ecological health

**Table 14 Surface Water and Groundwater Assessment Criteria for Drinking Water**

Parameter	Unit	Parametric value
pH	pH units	>6.5 to <9.5
Chloride	mg/l	250
Conductivity	mS/cm	2.5
Free Cyanide	mg/l	0.05
Ammonium	mg/l	0.3
Fluoride	mg/l	1.5
Nitrate as NO <sub>3</sub>	mg/l	50
Nitrite as NO <sub>2</sub>	mg/l	0.5
Sulphate	mg/l	250
Sodium	mg/l	200
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
Mercury	µg/l	1
Nickel	µg/l	20
Selenium	µg/l	10

## 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. The dissolved metal concentrations are assessed as they are more biologically available than total metals and non-dissolved metals are generally removed from drinking water by filtration.

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

The pH was found to be acidic in the majority of groundwater samples with results ranging from 2.59 to 5.91 (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 with highest pH at GW1/05 (5.91 pH) which only exceeded the criteria for human health. The specific conductance ranged from 0.154 to 7.943 mS/cm with the lowest conductivity located at MWET1 and the highest at MWET2. The specific conductance exceeded the human health criteria (2.5 mS/cm) at GW1/05 and MWET2.

Sulphate levels greatly exceeded the criteria for human health of 250 mg/l in all of the monitoring wells with values ranging from 792 to 8,370 mg/l. One exception was at MWPF1 where sulphate was below the human health assessment criteria with a value of 32.5 mg/l. Ammonia exceeded both the ecological (0.14 mg/l) and human health (0.3 mg/l) assessment criteria in 4 monitoring wells with concentrations ranging from 0.791 to 0.998 mg/l. Fluoride was also present in 6 of the monitoring wells sampled, with all values exceeding the assessment criteria for ecology (0.5 mg/l) and human health (1.5 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 two detections of dissolved arsenic, only MWSA2 with a result of 13.6 µg/l exceeded the human health (10 µg/l) criteria.

The dissolved aluminium and copper concentrations at MWET2 (deep) (95.9 and 9.15 µg/l) were significantly lower than at MWET1 (shallow) which had concentrations of 107,000 and 8200 µg/l, respectively. MWET1 exceeded both the ecological and human health criteria for aluminium (1,900 and 200 µg/l) and copper (5 and 2000 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 9,140 µg/l in GW1/05 and 6,860 µg/l in GW2/05, both exceeded the ecological and human health criteria for copper (5 and 2000 µg/l). Levels of dissolved lead in GW1/05 exceeded the ecological assessment criteria of 7.2 µg/l and the human health criteria of 10 µg/l, with a value of 56.8 µg/l.

SG104 had the highest levels of metals (compared to the other monitoring wells) with dissolved aluminium (760,000 µg/l), cadmium (92.9 µg/l), copper (79,500 µg/l), lead (89.3 µg/l), manganese (38,900 µg/l), nickel (177 µg/l) and zinc (118,000 µg/l) exceeding the ecological and human health criteria. Dissolved barium (10 µg/l), cobalt (479 µg/l) and uranium (53.8 µg/l) were also highest in SG104 and exceeded the ecological health criteria. Levels of dissolved iron in SG104 exceeded the human health criteria of 200 µg/l, with a value of 33,600 µg/l.

The groundwater in the shallow well at the Deep Adit area MWDA1 showed higher metal concentrations than at MWDA2 (deep). This was especially the case for dissolved aluminium and copper with concentrations of 126,000 and 15,200 µg/l in MWDA1 and concentrations of 44,600 and 4,160 µg/l in MWDA2, respectively. However, both wells still exceeded the criteria for both ecological and human health for aluminium and copper. Both monitoring wells exceeded the ecological and human health criteria for cadmium (30.5 and 32.5 µg/l), manganese (9,160 and 8,460 µg/l) and nickel (73.1 and 58.5 µg/l). As well, the human health criteria of 200 µg/l for iron is exceeded in both wells (49,700 and 57,300 µg/l).

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 295 µg/l and the ecological assessment criteria for dissolved copper (5 µg/l) was exceeded with a value of 37.9 µg/l.

### 4.3.2 Surface Water Assessment

#### Adit Discharges and Pit Lake

The pH was found to be acidic in all adit discharges and the pit lake with results within the range of 2.28 to 3.57 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 acidity as HCl ranged from 96.7 mg/l in the Cronebane Pit Lake to 1,730 mg/l in the Cronebane Shallow Adit. The specific conductance ranged from 0.547 to 3.269 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 the majority 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 564 to 2,770 mg/l. Due to low flow conditions at the 850 adit, only a partial sample could be collected and therefore no sulphate value is available. Ammonia was detected in all of the adit discharges and the pit lake which exceeded the ecological criteria (0.14 mg/l) and the human health criteria for ammonia (0.3 mg/l), with values ranging from 0.282 to 7.91 mg/l. One exception was for the 850 Adit where ammonia was less than the detection limit. Concentrations of sulphate (159 mg/l) and ammonia (0.571 mg/l) were generally lower at Cronebane Pit Lake than the adit discharges.

The dissolved metal concentrations were high in all of the adit discharges and the pit lake. 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 3,350 to 103,000 µg/l which exceeded the ecological assessment criteria of 50 µg/l. Dissolved aluminium ranged from 7,290 to 294,000 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 discharge and pike lake and also the human health (2,000 µg/l) criteria in the Cronebane Shallow Adit, Cronebane Pit Lake, 850 Adit and Spa Adit where concentrations ranged from 3,440 to 10,200 µg/l.

Dissolved cadmium ranged from 7.41 to 92 µg/l which exceeded both the ecological (0.45 µg/l) and human health (5 µg/l) criteria. Dissolved cobalt ranged from 8.72 to 238 µg/l which exceeded the ecological criteria (5.1 µg/l). Dissolved lead ranged from 108 to 2,490 µg/l which exceeded both the ecological (7.2 µg/l) and human health (10 µg/l) criteria. Dissolved nickel ranged from 33.6 to 87.5 µg/l which exceeded both the ecological and human health criteria of 20 µg/l. Two exceptions were the Millrace (4.79 µg/l) and Cronebane pit Lake (4.63 µg/l).

Dissolved arsenic was detected in all of the adit discharges with the exception of the Spa Adit and the Millrace which were below the limit of detection. The 850 Adit exceeded the criteria for human health (10 µg/l) and ecological health (25 µg/l) with a recorded value of 53.6 µg/l.

Dissolved chromium was detected and exceeded the ecological assessment criteria of 3.4 µg/l in 850 Adit, Cronebane Shallow Adit, Deep Adit, Road Adit and Spa Adit ranging from a concentration of 3.54 to 7.5 µg/l.

Dissolved iron and manganese were also high in all adit discharges. Iron ranged from 1,330 to 156,000 µg/l, exceeding the human health assessment criteria of 200 µg/l at every location. Manganese ranged from 298 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).

### Rivers and Streams

Table 15 provides a summary of the reported values for rivers and streams 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 5.74 to 7 pH (field); however, all values were within acceptable ranges for ecological criteria (4.5 to 9 pH units). Acidity was below the limit of detection (<4 mg/l) at all river locations. The specific conductance was well within the criteria for human health of 2.5 mS/cm ranging from 0.061 to 0.159 mS/cm.

Nutrients in the river and stream samples collected were below the limit of detection for ortho-phosphate (<0.02 mg/l) and ammonia (<0.2 mg/l) with a few exceptions. Ammonia exceeded the ecological assessment criteria of 0.14 mg/l at Ballinacleish Bridge (0.219 mg/l) and Site T5 (0.279 mg/l) and both the ecological and human health assessment criteria (0.3 mg/l) at Wicklow County Council Maintenance Yard GS (0.479 mg/l). Ortho-phosphate was 0.0225 mg/l at Lions Bridge which was below the ecological assessment criteria of 0.075 mg/l.

The dissolved metal concentrations in the rivers and streams 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 US Road Adit to the Downstream Shelton Abbey location, with results ranging from 7.04 to 16.8 µg/l. The highest dissolved copper concentration was found in Sulphur Brook. Dissolved zinc exceeded the ecological assessment criteria (50 µg/l) from Wicklow County Council Maintenance Yard GS on the Avoca River to Downstream Shelton Abbey with results ranging from 98.7 to 338 µg/l. The ecological assessment criteria was also exceeded at Sulphur

Brook with a concentration of 98.7 µg/l. Dissolved aluminium was below the human health criteria of 200 µg/l at all locations with the exception of US Shelton Abbey (389 µg/l).

Dissolved cadmium exceeded the ecological assessment criteria (0.45 µg/l) from DS Deep Adit on the Avoca River to Avoca Bridge with results ranging from 0.456 to 0.688 µg/l. Dissolved lead did not exceed the ecological (7.2 µg/l) and human health (10 µg/l) assessment criteria at any of the river or stream sampling locations. 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 (Wicklow County Council Maintenance Yard GS and Site T5) on the Avoca River with concentration ranging from 473 to 1050 µg/l. Dissolved manganese exceeded the criteria for human health (50 µg/l) at three locations which ranged in concentration from 85.7 to 167 µg/l. Note that iron and manganese are not important criteria for human health (see Section 4.2.1).

**Table 15 Summary of Reported Values for Rivers and Streams and the Surface Water Assessment Criteria**

Sample Description	Date Sampled	pH (field)	Ammoniacal Nitrogen as N	Aluminium (diss.filt)	Cadmium (diss.filt)	Copper (diss.filt)	Iron (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
<b>Ecological Criteria</b>		4.5 to 9	0.14	1,900	0.45	5	-	1100	50
<b>Human Health Criteria</b>		6.5 to 9.5	0.3	200	5	2000	200	50	-
Ballinacleish Bridge	19/08/2015	5.74	0.219	37.1	<0.1	<0.8	67.8	5.97	15
Lions Bridge	19/08/2015	5.79	<0.2	38.3	<0.1	1.5	80.4	4.62	26.4
Site T1	19/08/2015	6.27	<0.2	34.8	<0.1	<0.8	74.3	3.48	24.8
Vale View	17/08/2015	6.67	<0.2	7.42	<0.1	1.17	9.5	4.52	32.9
Whites Bridge	18/08/2015	6.21	<0.2	103	0.179	14.4	58.8	15.7	67.2
Whites Bridge GS	18/08/2015	6.31	<0.2	12.7	<0.1	2.65	9.5	1.17	4.66
DS Deep Adit	18/08/2015	6.1	<0.2	124	0.456	7.04	43.5	26.4	208
US Road Adit	18/08/2015	5.99	<0.2	131	0.514	12.5	55.2	38.6	207
WCC Maintenance Yard GS	18/08/2015	6.19	0.479	66.9	0.688	16.6	1050	167	338
Site T5	18/08/2015	5.92	0.279	75.4	0.603	14.6	473	114	277
Avoca Bridge	18/08/2015	6.08	<0.2	99.1	0.619	12.1	158	85.7	241
Sulphur Brook	11/08/2015	7	<0.2	24.5	0.398	16.8	9.5	21.8	98.7
US Shelton Abbey	13/08/2015	6.43	<0.2	389	0.257	7.12	105	38.9	106
DS Shelton Abbey	13/08/2015	6.64	<0.2	124	0.265	7.28	141	65.2	108

**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 April to 31 August 2015 of Whites Bridge GS is reproduced in Figure 3 and for Wicklow County Council Maintenance Yard GS from 1 April to 27 July 2015 in Figure 4. 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  $5.55 \text{ m}^3/\text{s}$  at Whites Bridge GS and  $5.63 \text{ m}^3/\text{s}$  at Wicklow County Council Maintenance Yard GS are lower than the long term median of approximately  $8.3 \text{ m}^3/\text{s}$  and  $9.1 \text{ m}^3/\text{s}$  respectively (CDM Smith, 2015), which reflects the relatively low levels of rainfall during the monitoring period. Flow in June was particularly low with a baseline flow of  $2.06 \text{ m}^3/\text{s}$  at Whites bridge GS and  $1.9$  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.

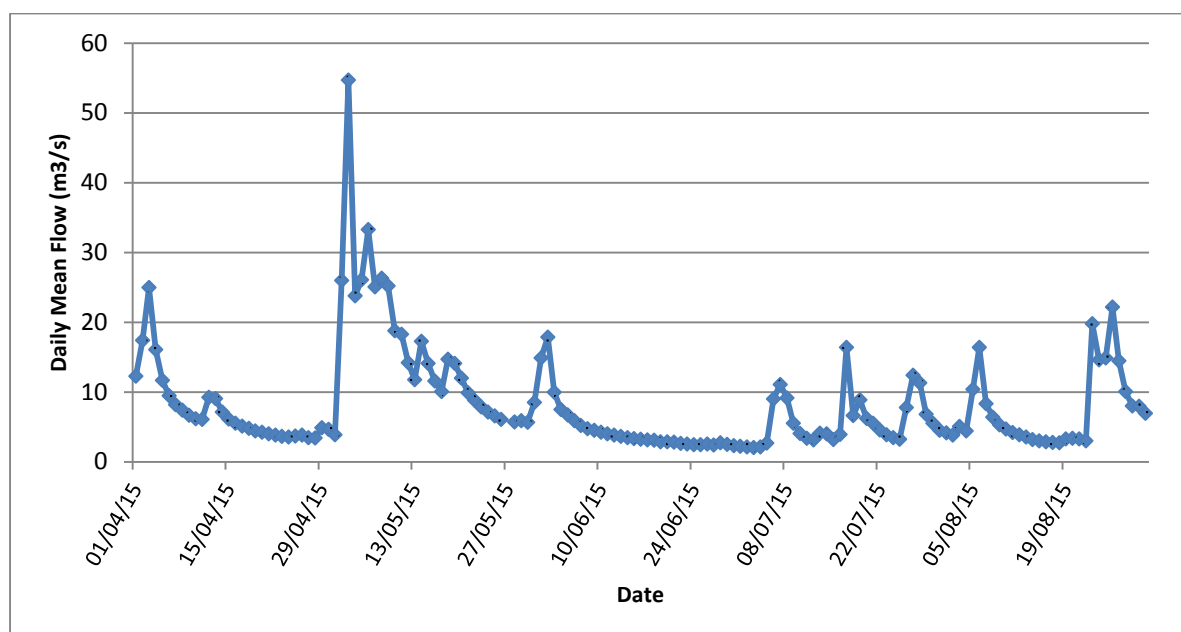
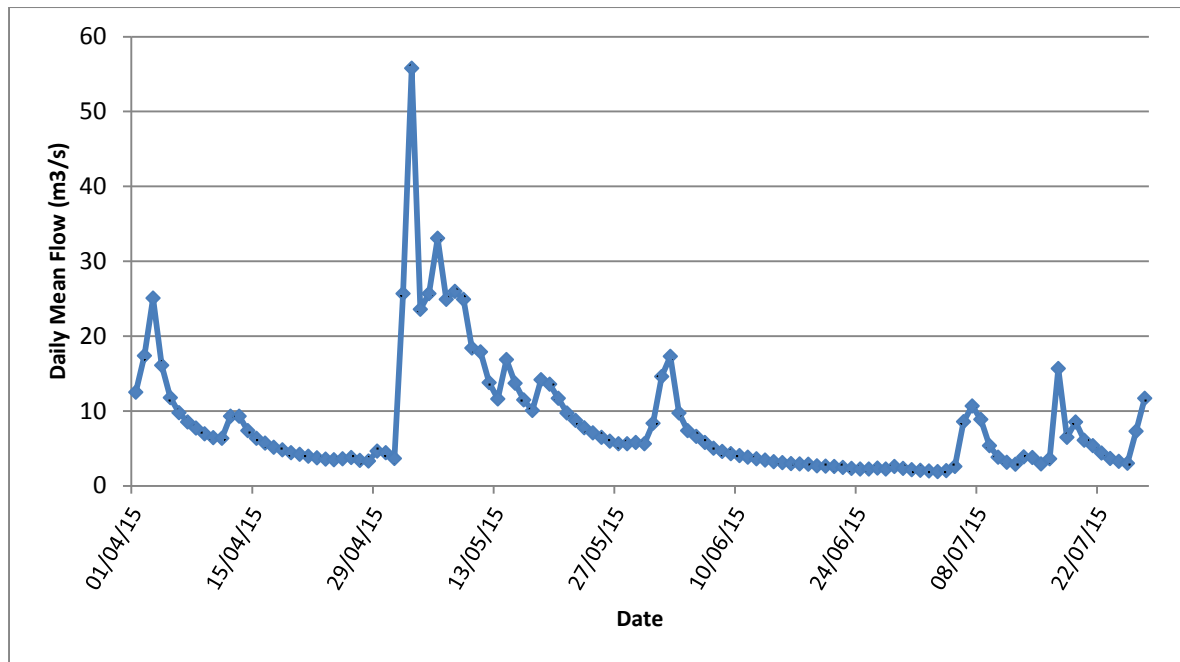


Figure 3 Mean Daily Flow (m³/s) at Whites Bridge (Station 10044) from 1 Apr to 31 Aug 2015



**Figure 4 Mean Daily Flow (m³/s) at Wicklow County Council Maintenance Yard (Station 10045) from 1 Apr to 27 Jul 2015**

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 Surface Water Sampling. Table 16 presents as a summary of the results from the flows measured in August 2015 at the time of sampling. All of the flow measurements on the main channel were performed on the same day. This gives a true representation of hydrogeological activity in the Avoca River including the average flow measurements. 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 19.5 l/s is considered a moderate flow as past records for the Deep Adit ranged from approximately 10 to 37.5 l/s. There was a very low flow (immeasurable) from the 850 Adit which was seeping into groundwater and therefore no flow was present at the 850 confluence with the Deep Adit. As discussed in section 1.5, no flow existed at the Deep Adit confluence to the Avoca River at the time of sampling because the total flow was being diverted to the Millrace through two channels and subsequently seeping into groundwater. The flow in the Millrace was measured at both channels where the flow was still channelised and therefore measureable, the total measured flow was 15.5 l/s. This indicates that there is a loss of flow which is likely due to dispersed flow along the channel and infiltration into the channel bed. Note that the Millrace sample was collected further downstream on the original Millrace channel and the flow was unable to be measured at this location because the flow was too dispersed.

The flow was measured at the Road Adit and the measured flow was 14.5 l/s. Past records for the Road Adit ranged from approximately 6 to 58 l/s (CDM, 2008). The flow was also measured at the Road Adit Confluence prior to the adit discharging to the river and the measured flow was 18.3 l/s. The difference in flow is likely due to two different flow measurement methods being employed.



**Table 16 Surface Water Flow Value Measured in August 2015**

Site Name	Flow m <sup>3</sup> /s	Flow l/s	Date	Notes
Ballinaclesh Bridge	0.95	950	19/08/2015	
Lions Bridge	1.44	1441	19/08/2015	
Vale View	0.01	11	17/08/2015	
Site T1	2.7	2679	18/08/2015	
Whites Bridge	2.8	2750	18/08/2015	
White's Bridge GS	2.8	2750	18/08/2015	Note that flow on 13/08/2015 was 3.59 m <sup>3</sup> /s
DS Deep Adit	2.8	2750	18/08/2015	
Upstream of Road Adit	2.8	2750	18/08/2015	
Wicklow County Council Maintenance Yard GS	2.8	2750	18/08/2015	
Site T5	2.4	2402	18/08/2015	
Avoca Bridge	3.0	3010	18/08/2015	
Upstream of Shelton Abbey	10.0	10040	13/08/2015	
Downstream of Shelton Abbey	10.0	10040	13/08/2015	
Sulphur Brook	0.056	56	11/08/2015	
850 Adit	-	-	17/08/2015	No measurable flow
Deep Adit	0.019	19.5	17/08/2015	
Deep Adit Confluence	-	-	17/08/2015	No measurable flow
Millrace	0.015	15.5	17/08/2015	
Road Adit	0.010	14.5	17/08/2015	
Road Adit Confluence	0.018	18.3	17/08/2015	
Cronebane Intermediate Adit	0.004	4.2	17/08/2015	
Cronebane Shallow Adit	0.0001	0.06	19/08/2015	
Ballygahan Adit	-	-	19/08/2015	No measurable flow
Spa Adit	0.000003	0.003	17/08/2015	
Cronebane Pit Lake	n/a	n/a	17/08/2015	

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

**Table 17 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
Cronebane Inter. Adit	19/08/2015	4.2	2.75	564000	203	42200	15.2	986	0.4	78500	28.2	1180	0.4	28200	10.1
Cronebane Shallow Adit	19/08/2015	0.06	2.29	2770000	13	294000	1.4	5450	0.0	156000	0.8	967	0.0	103000	0.5
Deep Adit	17/08/2015	19.5	3	843000	1420	106000	179	142	0.2	53800	90.6	2490	4.2	46800	78.8
Road Adit	17/08/2015	14.5	3.45	852000	1070	13300	16.7	305	0.4	65800	82.4	364	0.5	8290	10.4
Road Adit Confluence	17/08/2015	18.3	3.57	856000	1350	12900	20.4	299	0.5	65700	104	350	0.6	7200	11.4
Spa Adit	17/08/2015	0.003	2.28	1630000	0.4	161000	0.0	7710	0.0	112000	0.0	108	0.0	12900	0.0
Ballinacleish Bridge	19/08/2015	950	5.74	3400	279	37.1	3.1	0.425	0.0	67.8	5.6	1.1	0.1	15	1.2
Lions Bridge	19/08/2015	1441	5.79	4800	597	38.3	4.8	1.5	0.2	80.4	10	1.3	0.2	26.4	3.3
Site T1	18/08/2015	2679	6.27	3200	741	34.8	8.1	0.4	0.1	74	17.2	1	0.3	24.8	5.7
Vale View	18/08/2015	11	6.67	19700	19	7.42	0.0	1.17	0.0	9.5	0.0	0.164	0.0	32.9	0.0
Whites Bridge	18/08/2015	2750	6.21	5400	1280	103	24.5	14.4	3.4	58.8	14	1.27	0.3	67.2	16.0
Whites Bridge GS	18/08/2015	2750	6.31	4700	1120	12.7	3.0	2.65	0.6	9.5	2.3	0.792	0.2	4.66	1.1
DS Deep Adit	18/08/2015	2750	6.1	9700	2300	124	29.5	7.0	1.7	43.5	10.3	2.2	0.5	208	49.4
US Road Adit	18/08/2015	2750	5.99	12300	2920	131	31.1	12.5	3.0	55.2	13.1	2.47	0.6	207	49.2
WCC Maintenance Yard GS	18/08/2015	2750	6.19	29000	6890	66.9	15.9	16.6	3.9	1050	249	3.98	1.0	338	80.3
Site T5	18/08/2015	2402	5.92	21500	4460	75.4	15.7	14.6	3.0	473	98.2	2.68	0.6	277	57.5
Avoca Bridge	18/08/2015	3010	6.08	18800	4890	99.1	25.8	12.1	3.2	161	41.9	2	0.5	241	62.7
Sulphur Brook	18/08/2015	56	7	12400	60	24.5	0.1	16.8	0.1	9.5	0.1	2.14	0.0	98.7	0.5
US Shelton Abbey	13/08/2015	10040	6.43	8400	7290	389	337	7.12	6.2	105	91.1	1.53	1.3	106	91.9
DS Shelton Abbey	13/08/2015	10040	6.64	10300	8930	124	108	7.28	6.3	141	122	2	1.7	108	93.7

### Loading from Adit Discharges

The Deep Adit had aluminium, copper and zinc loads of 179, 0.2 and 78.8 kg/day and the Road Adit had loads of 16.7, 0.4 and 10.4 kg/day, respectively. The Deep Adit had a higher load of sulphate with 1,420 kg/day and dissolved iron with 90.6 kg/day and the Road Adit had 1,070 kg/day sulphate and 82.4 kg/day of iron. No loading results are available for the 850 adit because the flow was immeasurable at the time of sampling.

As discussed in Section 1.5 and displayed in Figure 1, the total Deep Adit discharge was diverted through two channels to the Millrace at time of sampling and seeping to groundwater; therefore, a Deep Adit Confluence sample and load value could not be obtained. In order to assess the level of infiltration along the Deep Adit channel a flow measurement was taken at the confluence of both Millrace channels. The combined flow of both channels was 15.4 l/s which is 4.1 l/s less than the measured flow upstream at the Deep Adit Portal (19.5 l/s) and suggests likely infiltration occurring in the channel.

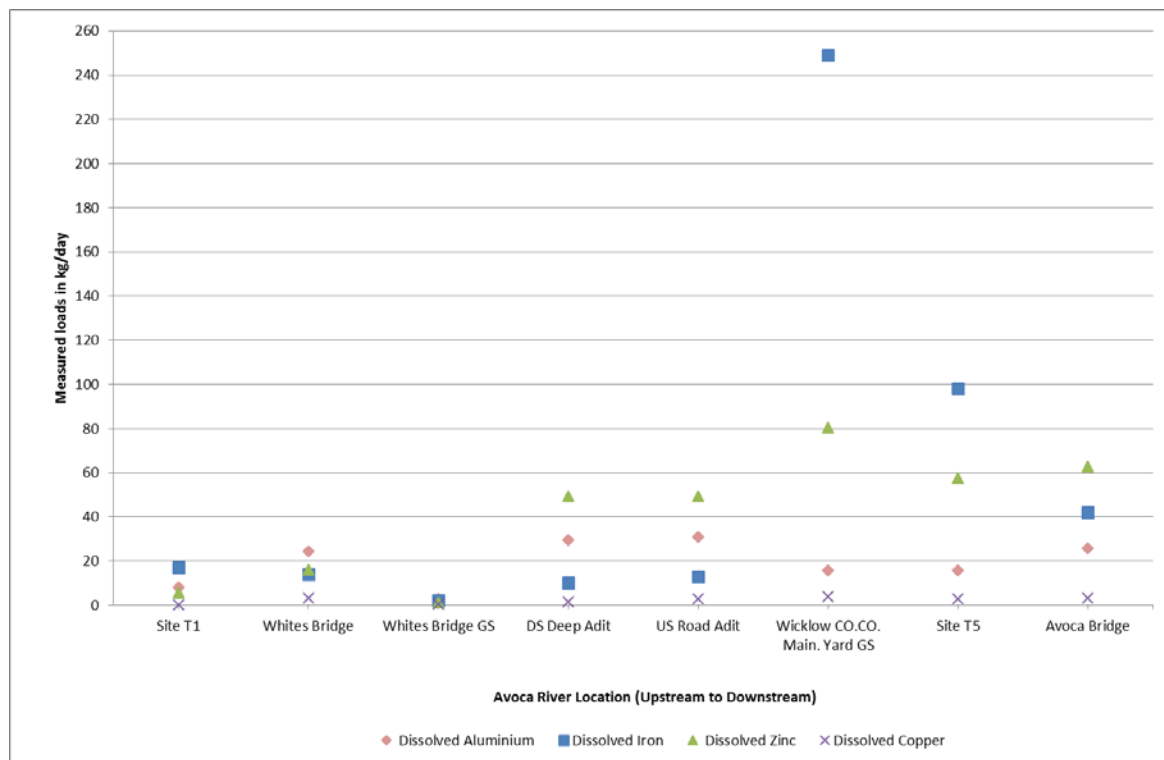
A sample was obtained along the original Millrace channel prior to the flow dispersing and seeping to groundwater (see Map 3 in [Appendix A](#)). The concentrations of sulphate and the dissolved metals were lower in the Millrace compared to the Deep Adit Portal which indicates significant precipitation of dissolved metals. The concentrations of aluminium decreased from 106,000 to 7,290 µg/l, copper from 142 to 11 µg/l and zinc from 46,800 to 3,350 µg/l.

The Cronebane Intermediate Adit had dissolved metals loads of 15.2 kg/day for aluminium, 28.2 kg/day iron and 10.1 kg/day zinc. The Cronebane Shallow Adit and Spa Adit were of minor importance in terms of dissolved metals loads to the Avoca River, either because of absence of surface flow to the river or due to low loads (either low concentrations or low flows). Loads from these adits range from 0.04 to 1.41 kg/day for aluminium and 0.002 to 0.03 kg/day for copper. The Ballygahan Adit was dry at the time of sampling.

### Avoca River Loadings

Background loads upstream of the Avoca Mining Area of metals were present which is evident from the calculated loads at Ballinacleish Bridge, Lions Bridge and Site T1. The dissolved metal loads at Site T1 were 8.06 kg/day for aluminium, 0.10 kg/day for copper, 17.2 kg/day for iron, 0.26 kg/day for lead and 5.74 kg/day for zinc. Figure 5 graphically shows the calculated loads of dissolved aluminium, copper, iron and zinc 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.

An increase in loads occurs at Whites Bridge with loads of dissolved aluminium at 24.47 kg/day, iron at 14 kg/day, zinc at 16 kg/day and copper at 3.42 kg/day. There was a significant decrease in dissolved aluminium 3.02 kg/day, iron 2.26 kg/day, copper 0.63 kg/day and zinc 1.1 kg/day loads, 90 metres downstream at Whites Bridge GS. Note that only three quarters of the transect was sampled at Whites Bridge due to health and safety concerns and the full transect was sampled at Whites Bridge GS. This variation in sampling technique is potential factor in the apparent decrease of dissolved metals along this stretch.



**Figure 5 Calculated Loads of Dissolved Aluminium, Iron, Zinc and Copper in kg/day in Avoca River in August 2015**

The DS Deep Adit location on the Avoca River is downstream of the Deep Adit confluence which was dry at the time of sampling in August 2015. Therefore, the calculated loads at DS Deep Adit assesses the level of diffuse flow and groundwater contribution from the flooded Millrace area. As indicated in Figure 5, a significant increase in loads occurs at the DS Deep Adit compared to Whites Bridge and Whites Bridge GS with 29.46 kg/day aluminium, 1.67 kg/day copper, 10.34 kg/day iron, 0.51 kg/day lead and 49.42 kg/day zinc at the DS Deep Adit.

Taking into account the calculated dissolved metal loads at the Deep Adit portal the loading results at DS Deep Adit would be expected to be higher. However, a loss in dissolved metal loads is apparent between the Deep Adit portal and The DS Deep Adit sampling location with aluminium loads decreasing from 179 to 29.5 kg/day, iron decreasing from 90.6 to 10.3 kg/day and zinc decreasing from 78.8 to 49.4 kg/day. This signifies extensive infiltration and precipitation of iron and metals on the surface and in the alluvial material resulting in a secondary source of diffuse load to the Avoca River. Note that the flooded Millrace area located parallel to the Avoca River extended further downstream than the DS Deep Adit sampling location and therefore loads would be expected to increase further at the US Road Adit located approximately 420m downstream.

At the US Road Adit sampling location, the measured loads are slightly higher compared to the DS Deep Adit with aluminium at 31.1 kg/day, copper at 2.97 kg/day, iron at 13.1 kg/day and lead at 0.59 kg/day. A negligible decrease in zinc load occurred which was calculated at 49.2 kg/day.

The Wicklow County Council Maintenance Yard GS sampling location is located downstream of the Road Adit discharge since October 2014. The loads would be expected to be 51.5 kg/day for aluminium, 117 kg/day for iron and 60.6 kg/day for zinc to account for the loading at US Road Adit

(31.1 kg/day aluminium, 13.1 kg/day iron and 49.2 kg/day zinc) and the Road Adit Confluence (20.4 kg/day aluminium, 104 kg/day iron and 11.4 kg/day zinc). However, the loadings were determined slightly higher at Wicklow County Council Maintenance Yard GS for iron (250 kg/day) and for zinc (80.3 kg/day). The calculated loads for aluminium were lower at 15.9 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 98.18 kg/day for iron and 57.5 kg/day for zinc. The measured load for aluminium was 15.65 kg/day which was similar to the measured load at Wicklow County Council Maintenance Yard GS.

There was an apparent increase in the dissolved iron and zinc loads from 91.1 kg/day for iron and 91.9 kg/day for zinc US Shelton Abbey to 122 kg/day for iron and 93.7 kg/day for zinc DS Shelton Abbey. The measured aluminium loads decreased from 337 US Shelton Abbey to 108 DS Shelton Abbey. The calculated loads for dissolved copper and lead were similar at the upstream and downstream locations of Shelton Abbey.

Two tributaries to the Avoca River were sampled: Vale View and Sulphur Brook. Both tributaries had insignificant loads relative to the adit discharges, with the highest loading of 0.48 kg/day for zinc at Sulphur Brook.

## 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 Oct 2001 to Aug 2015), Figure 7 (Road Adit from Oct 2001 to Aug 2015) and Figure 8 (Avoca River at Avoca Bridge from Oct 2001 to Aug 2015).

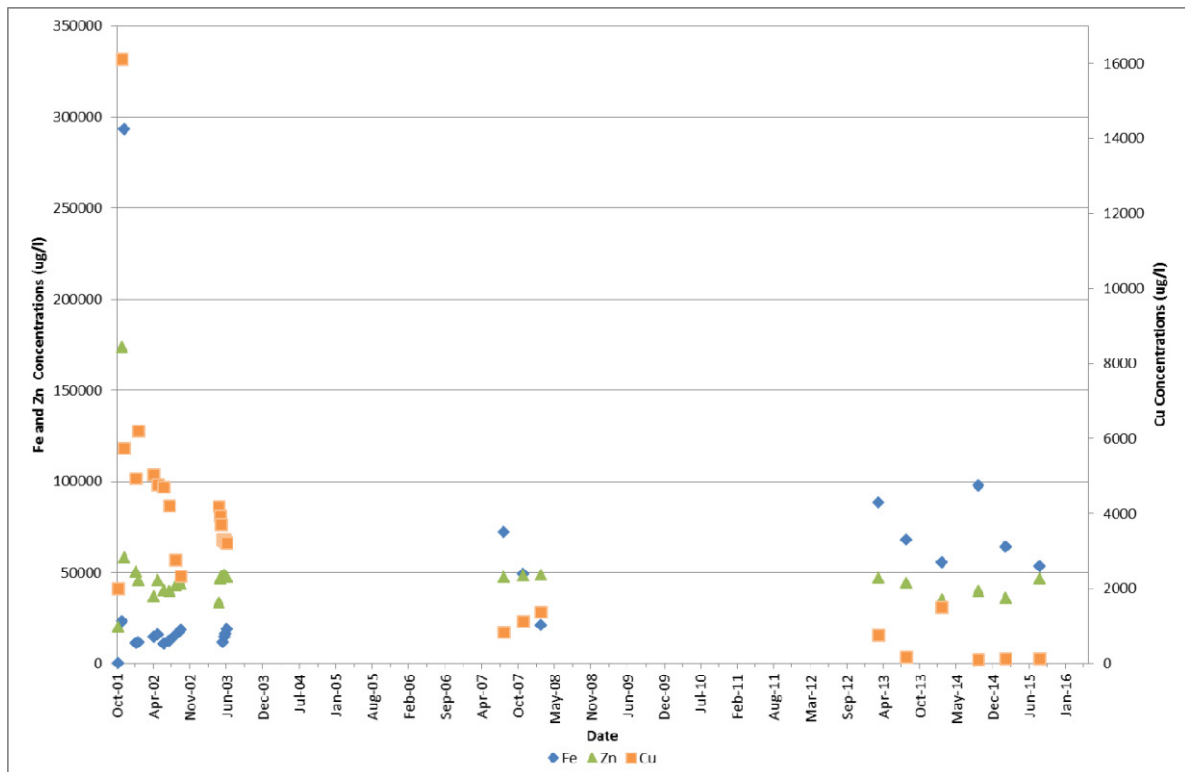
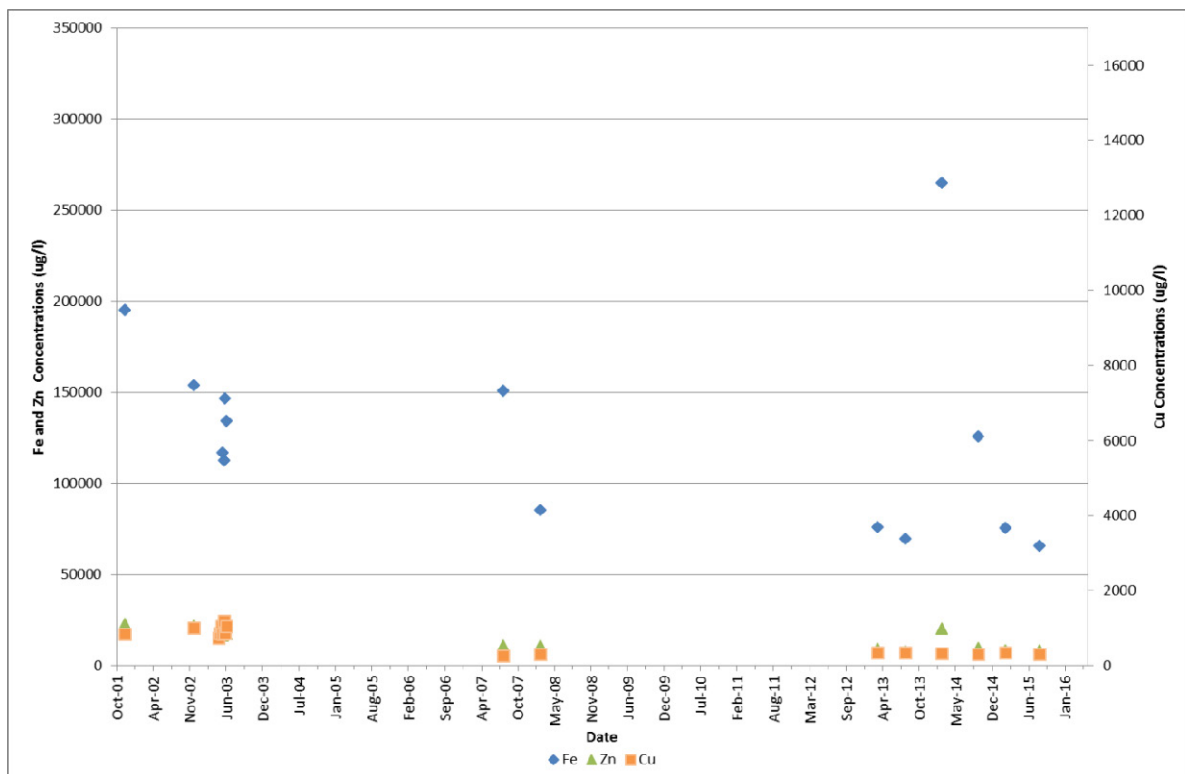
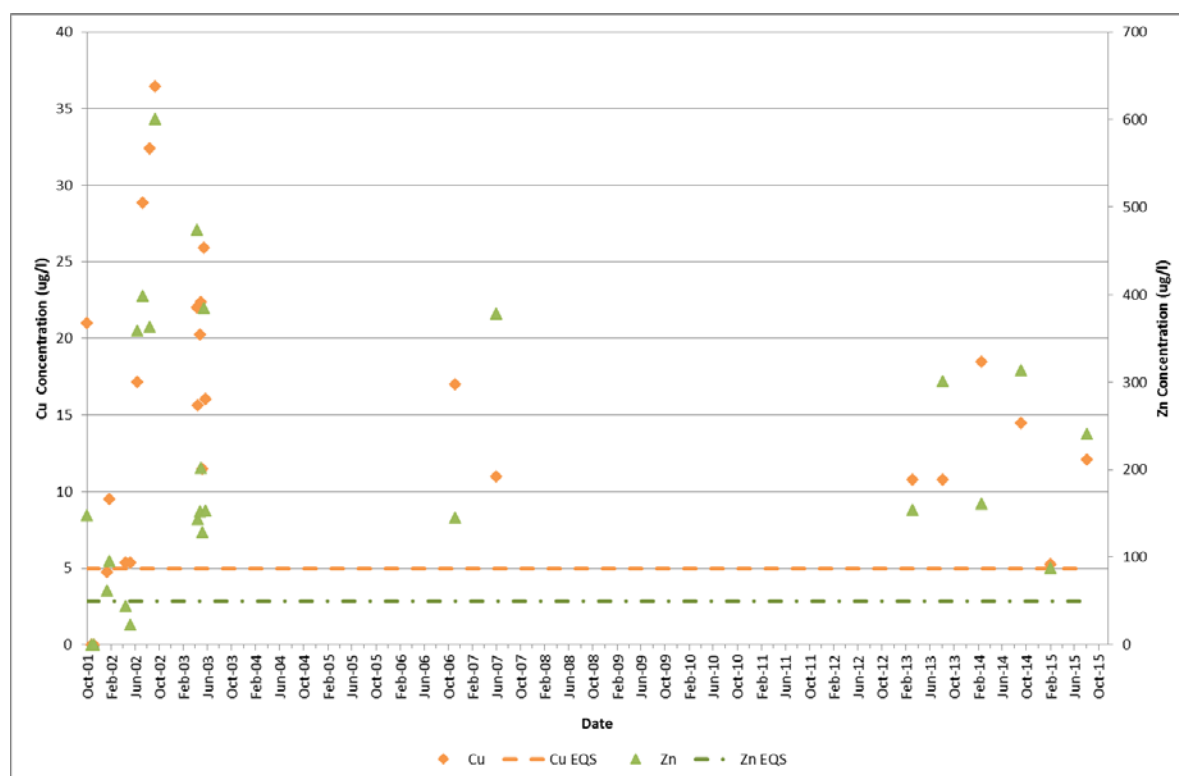


Figure 6 Concentration trends for dissolved copper, zinc and iron within the Deep Adit Discharge (Oct 2001 to Aug 2015)







**Figure 8 Concentration trends for dissolved copper and zinc at Avoca Bridge compared with the environmental quality objective (EQS) (Oct 2001 to Aug 2015)**

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

**Table 18 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.

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

**Table 19 Mann-Kendall Trend Analysis of data for Deep Adit, Road Adit and Avoca Bridge**

Sample location	Parameter	October 2001 to February 2015			June 2007 to February 2015		
		P value	S value	Trend	P value	S value	Trend
Deep Adit	Copper	0	-263	Decreasing	0.0589	-16	No Trend
	Zinc	0.3232	-23	No Trend	0.0382	-18	Decreasing
	Iron	0.0003	138	Increasing	N/A	N/A	Not Calculated
Road Adit	Copper	0.0178	-52	Decreasing	0.3553	4	No Trend
	Zinc	0.0004	-82	Decreasing	0.1328	-10	No Trend
	Iron	0.0107	-43	Decreasing	0.868	-12	No Trend
Avoca Bridge	Copper	0.2436	-29	No Trend	N/A	N/A	Not Calculated
	Zinc	0.1794	38	No Trend	0.274	-5	No Trend

Notes:

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

The confidence coefficient is 0.95.

Not calculated: insufficient statistical evidence of a significant trend

The results of the Mann-Kendall analysis for October 2001 to August 2015 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 and 7.

The results of the Mann-Kendall analysis for June 2007 to August 2015, show that dissolved zinc is decreasing in the Deep Adit and that there were no other trends for dissolved zinc, iron or copper for this time period in the adit discharges.

Figure 8 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 2001-2015 period and the 2007-2015 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 20 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) and February 2015 (R5) and the low flow sampling events in August 2013 (R2), September 2014 (R4) and August 2015 (R6). As can be observed from Table 20, the concentrations of dissolved aluminium, copper, iron and zinc were very similar in each sampling event with a few exceptions. Dissolved copper in the Deep Adit was significantly lower in concentration in August 2013, September 2014 and August 2015 compared with the high flow sampling, however it was also low in February 2015 when the flow in the Deep Adit was lower than other winter sampling events. The concentration of dissolved iron at Avoca Bridge is quite variable and dissolved zinc is higher in concentration during the low flow sampling events in August 2013, September 2014 and August 2015.

Table 20 also shows that the calculated loads of dissolved aluminium, copper, iron and zinc were all significantly lower in August 2013, September 2014 and August 2015 due to the low flow conditions. Similar flow conditions measured at the Deep Adit in February 2015 resulted in relatively low calculated loads of dissolved metals.

**Table 20 Seasonal Variation of Concentrations and Calculated Loads of Dissolved Metals in the Adits and at Avoca Bridge from 2013-2015**

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
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
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

**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 prior to purging. Table 21 provides the measured depth to groundwater and calculated groundwater elevations. All groundwater level data are contained in Appendix C of the Data Report. The groundwater elevations varied between 25.54 to 32.67 m Ordnance Datum (OD) in the Avoca Mining Area. These groundwater elevations were between 0 to 0.4 metres higher than the elevations measured in February 2015. The groundwater elevations were consistent with the hydraulic gradient towards the Avoca River. MWSA2 is located downgradient of Shelton Abbey Tailings which is in a different part of the catchment and the groundwater elevation is much lower than that of the West and East Avoca.

**Table 21 Measured Groundwater Levels and Calculated Elevation August 2015**

Borehole Identifier	Date	Time	Depth to Groundwater (m bTOC)	Depth to Groundwater (m bgs)	Groundwater Elevation (m OD)
MWDA1	11/08/2015	13:15	6.23	5.63	26.56
MWDA2	11/08/2015	11:30	6.35	5.62	26.27
MWPF1	12/08/2015	8:45	4.63	4.04	26.86
MWET1	12/08/2015	10:30	7.36	6.79	26.03*
MWET2	12/08/2015	12:00	7.26	6.56	26.11*
GW1/05	12/08/2015	15:20	5.26	4.62	25.54*
GW2/05	12/08/2015	14:20	5.37	4.54	25.58*
SG104	12/08/2015	16:50	25.50	Unknown	32.67*
MWSA2	13/08/2015	9:00	8.59	8.31	1.58

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 9 shows the groundwater elevations of the 5 wells located in the Avoca Mining Area from 1 April to 11 August 2015. Figure 10 shows the groundwater elevation at MWSA2 at Shelton Abbey Tailings Facility between 1 April and 11 August 2015. Data are missing for MWPF1 (1 April to 5 June 2015) and MWDA1 (1 April to 10 July 2015) due to data logger repairs and MWET1 and MWET2 from 1 April to 5 June 2015 due to batteries depleting.

Figure 9 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.

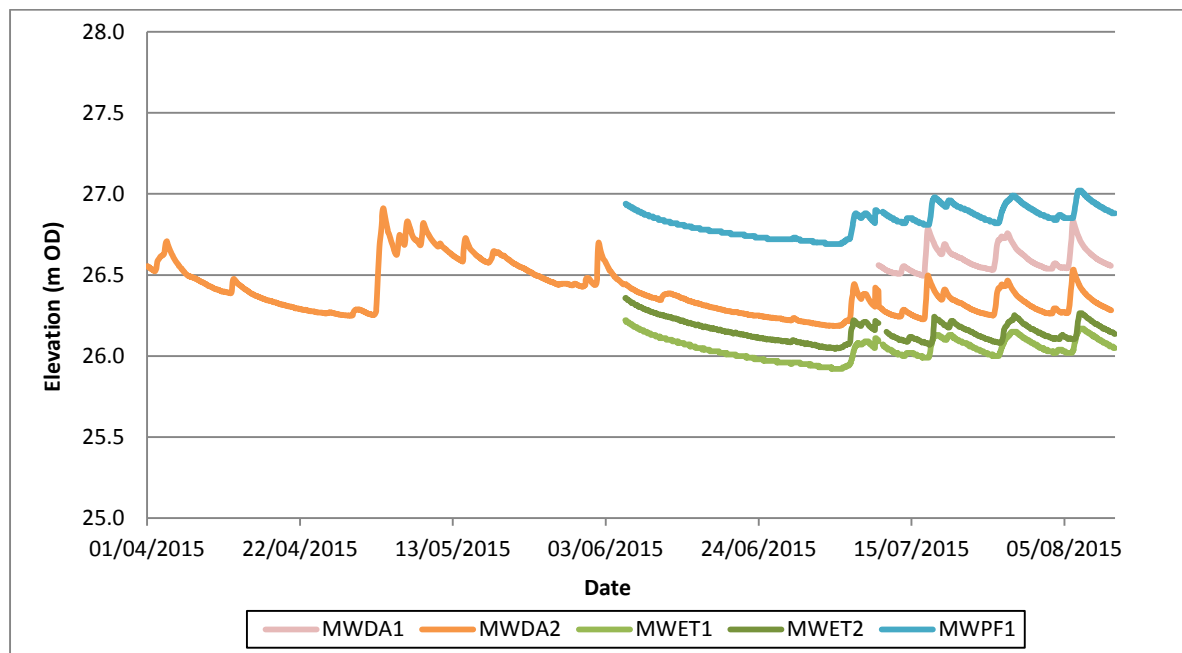


Figure 9 Groundwater Elevations in the Avoca Mining Area from 1 Apr to 11 Aug 2015

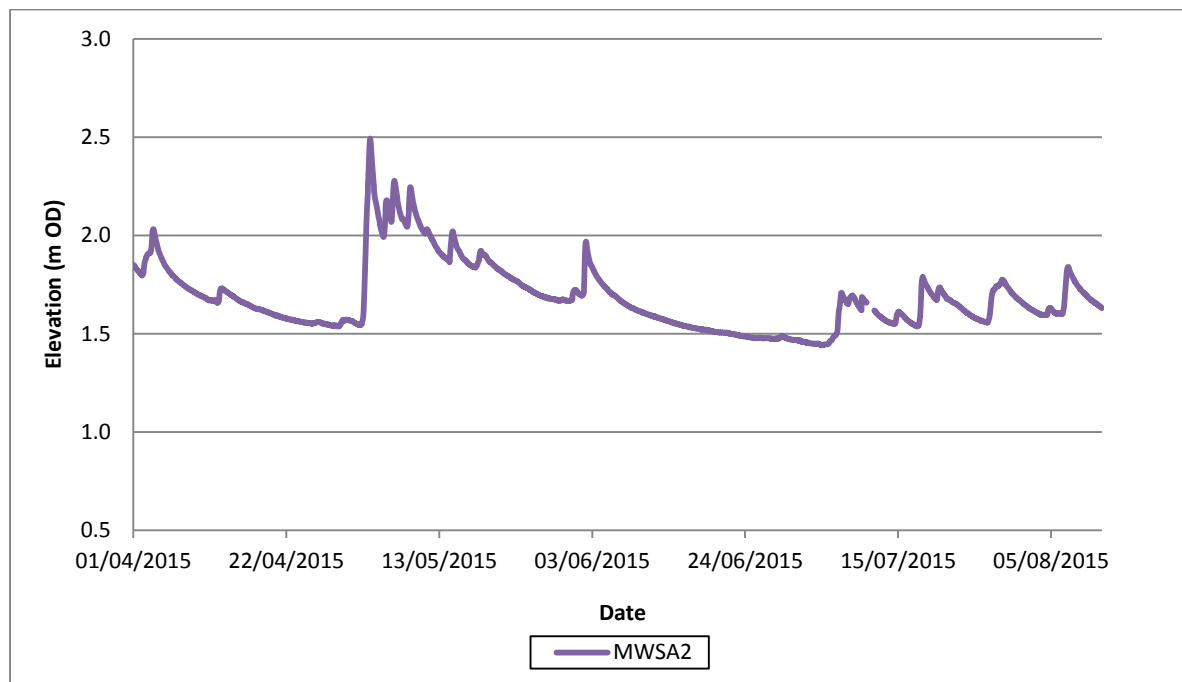


Figure 10 Groundwater Elevation at Shelton Abbey from 1 Apr to 11 Aug 2015

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.

There was a marginal downward gradient between the alluvial well GW2/05 and top of bedrock (GW1/05) at this location (Table 21).

MWPF1 was replaced with a new data logger and all the loggers were serviced by CDM Smith in July 2015. New OTT firmware was installed, the batteries were replaced, the water levels were recalibrated and the outside of the instruments were cleaned.

## 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 1 April to 3 August 2015 for Whites Bridge GS and Wicklow County Council Maintenance Yard GS are reproduced in Figure 11. Data are missing for GS 10045 from 3 to 30 August due to battery failure. 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.

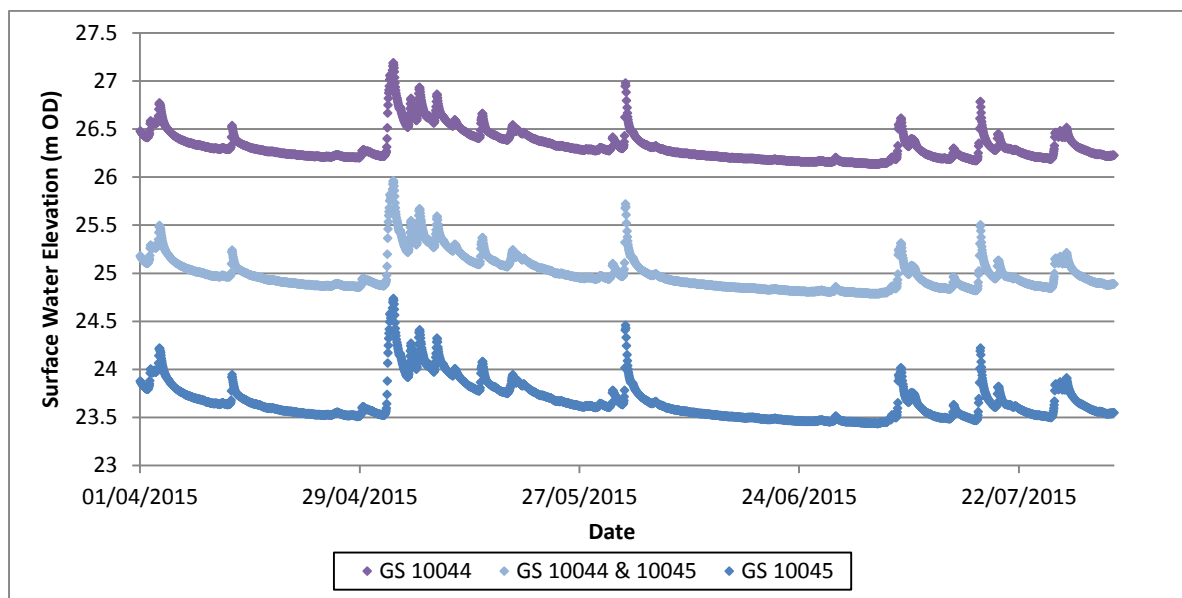


Figure 11 Elevation of the Avoca River at GS 10044 and GS 10045 at the Deep Adit Area from 1 April to 3 August 2015

## 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. However, water level data was unavailable for GS 10045 for the period 3 to 30 August 2015 due to battery failure and therefore the river water elevation could not be estimated. The estimated surface water elevations for the emergency tailing area for the period 1 April to 3 August 2015 are displayed on Figure 11 (GS 10044 & GS 10045);
- For SG104 the water elevation from Wicklow Maintenance Yard County Council (GS 10045) was unavailable; and
- The river water level at MWSA2 was unable to be determined because there are no gauges available at a nearby location.

Table 22 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 2015. These values are similar to previous rounds in both direction and magnitude with an estimated mean gradient of 0.008, 0.002 and 0.017 for MWDA1, MWDA2 and MWPF1 respectively.

**Table 22 Calculated Groundwater Gradients for August 2015**

Borehole Identifier	Date	Time	Groundwater Elevation (m OD)	Water Elevation at Perpendicular Stream Point (m OD)	Distance to Perpendicular Stream Point (m)	Gradient
MWDA1	11/08/2015	13:15	26.56	26.24	40	0.008
MWDA2	11/08/2015	11:30	26.27	26.24	40	0.001
MWPF1	12/08/2015	8:45	26.86	26.23	44	0.016
MWET1	12/08/2015	10:30	26.03*	ND	72	ND
MWET2	12/08/2015	12:00	26.11*	ND	72	ND
GW1/05	12/08/2015	15:20	25.54*	ND	74	ND
GW2/05	12/08/2015	14:20	25.58*	ND	74	ND
SG104	12/08/2015	16:50	32.67*	ND	142	ND
MWSA2	13/08/2015	9:00	1.58	Not available	45	Not available

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

ND No water level data available from station 10045 for this time period due to battery failure

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

Hourly water level data for both gauges on the Avoca River: Whites Bridge GS (EPA station 10044) and the Wicklow County Council Maintenance Yard GS (EPA Station 10045) were obtained from the EPA for the monitoring period. Groundwater elevation data were plotted against the recorded elevations of the Avoca River as shown in Figure 12 for the deep adit area and Figure 14 the

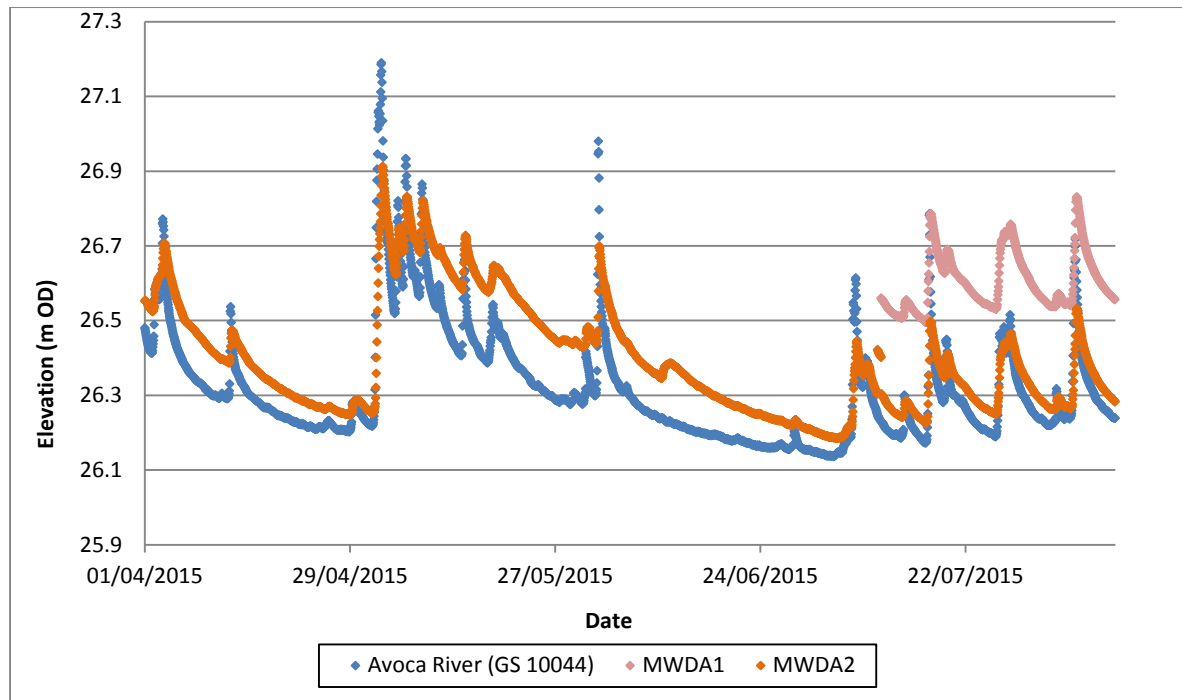
emergency tailings area. Both figures demonstrate that there is a direct relationship between the river stage and the groundwater levels in both areas. Rises in river levels are accompanied by rises in groundwater levels.

Figure 12 shows that in the recorded data several significant hydrological (rainfall) events occurred in May and June 2015 which resulted in groundwater levels rising. For example groundwater levels rose by approximately 0.7 metres between 2 and 3 May 2015. This peak was in response to river levels which rose by up to 1 metre during the same event. High groundwater levels were recorded mid-way through the monitoring period due to the occurrence of numerous high rainfall events. Rainfall totals were all above their Long-Term Average (LTA) for May (Met Eireann, 2015). However, relatively low levels of rainfall in June resulted in an overall decrease in groundwater levels at the deep adit area and the emergency tailings area. Several small hydrological events occurred in July and August which resulted in gradual aquifer recharge at both locations.

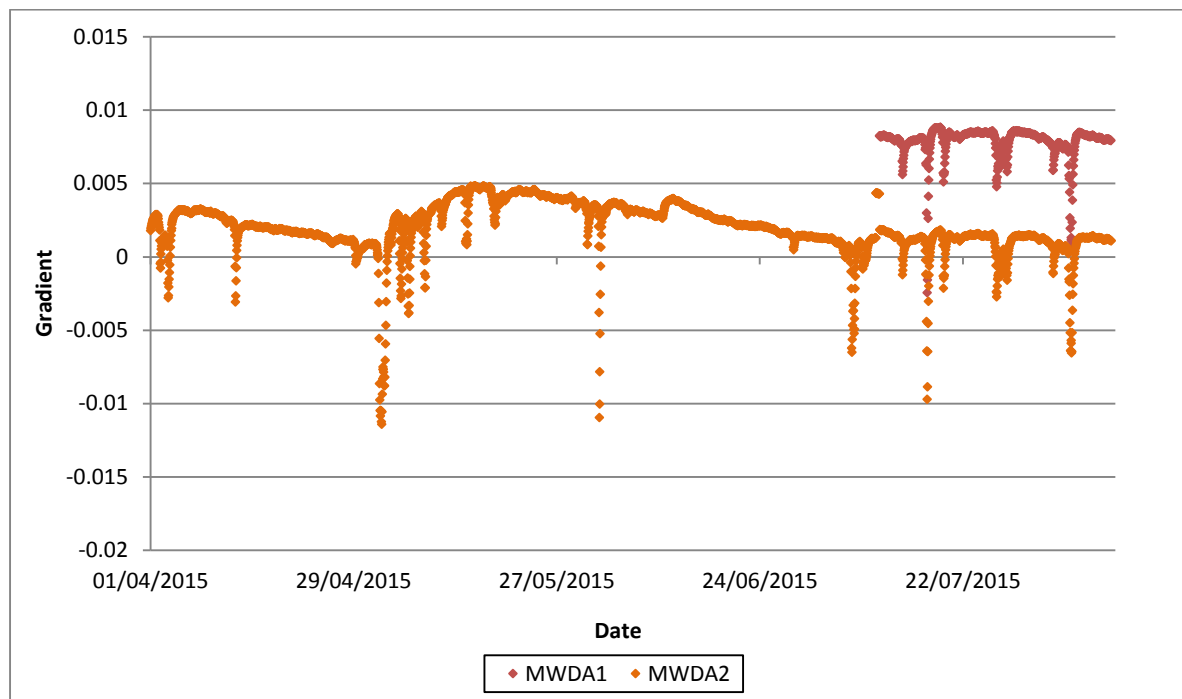
Figure 13 and Figure 15 show the calculated gradient to the Avoca River at the deep adit area (MWDA1, MWDA2) and the emergency tailings area (MWET1, MWET2) from 1 April to 11 August 2015 and 5 June to 11 August 2015 respectively based on hourly elevation data. Both figures show that as river stages change 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, Figures 12 and 13 show that a negative gradient occurs during periods of high flow, particularly when there was a rapid rise in water level. On 2 and 3 May 2015 a significant hydrological (rainfall) event resulted in groundwater levels rising in MWDA1 and MWDA2 by approximately 0.7 metres. A negative gradient can be observed during this period between the river and MWDA2, as shown in Figure 13. During the 2 and 3 May period the river water level also rose (approximately 1 metre) but more rapidly which resulted in water moving into the monitoring well area, apparent from the rise in groundwater levels. It is likely the river water moved into an unsaturated zone, which could result in mobilising new metals if they were not exposed before. A similar hydrological event occurred on 1 June 2015. MWDA2 which is located in the deeper alluvium appears to respond less to the river than MWDA1 and may be more seasonally influenced (e.g. aquifer storage). A positive gradient existed for over 90% of the monitoring period for MWDA2 with a minimum gradient of minus 0.011 and an average gradient of 0.002.

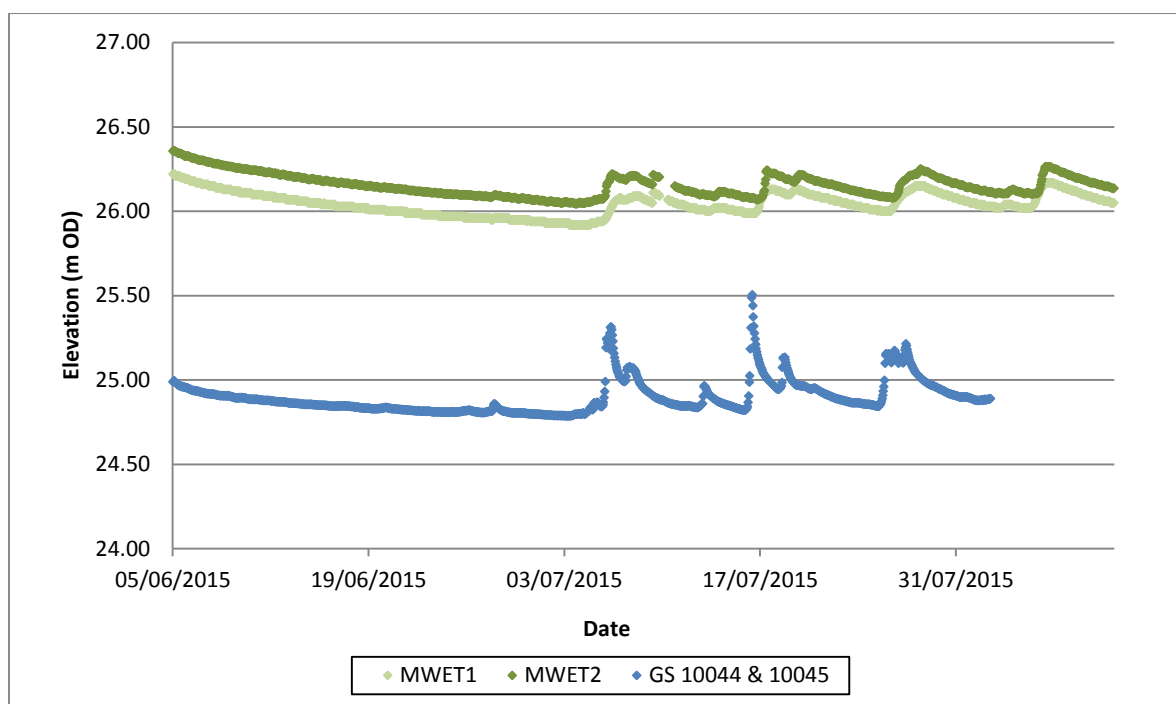
For MWET1 and MWET2 only positive gradients were observed during the monitoring period with a minimum gradient of 0.007 (MWET1) and a maximum of 0.37 (MWET2). Note that the elevations are based on the GPS survey of the boreholes and the river water elevations were estimated using both the Whites Bridge GS elevation and the Wicklow County Council Maintenance Yard gauges because they are located equidistance between the gauges.



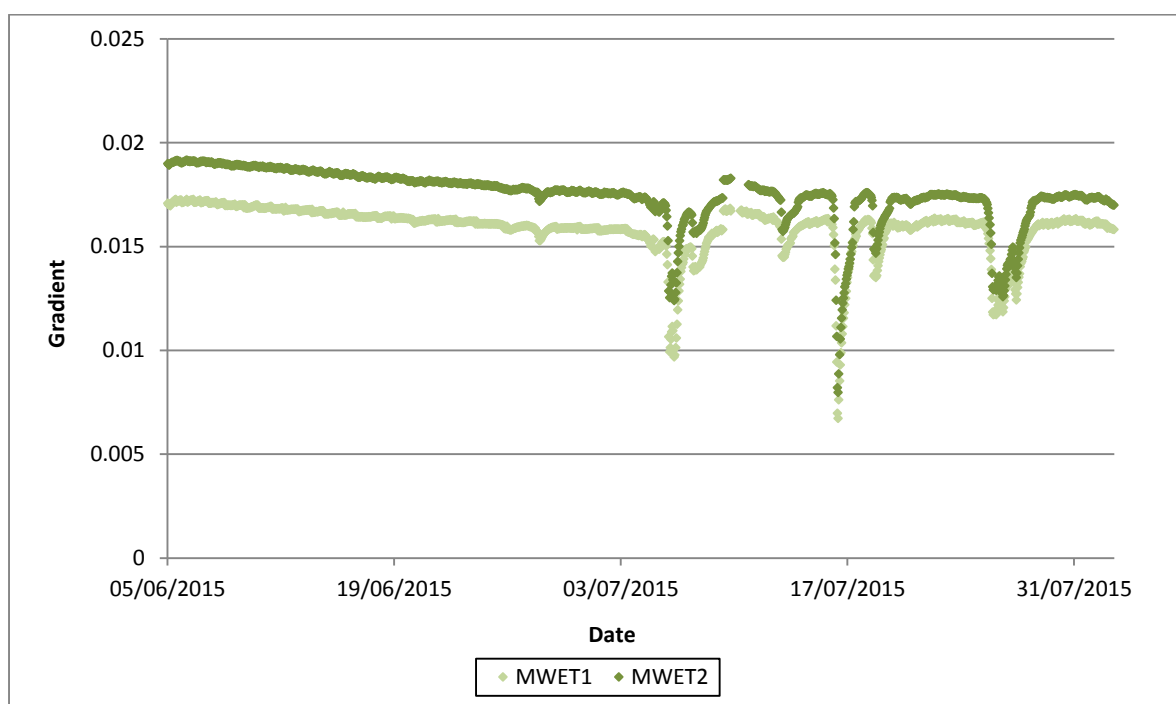
**Figure 12 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044) at the Deep Adit Area from 1 April to 11 August 2015**



**Figure 13 Calculated Groundwater Gradient to the Avoca River at the Deep Adit Area from 1 April to 11 August 2015**



**Figure 14 Comparison of Groundwater Elevation and Elevation of the Avoca River (GS 10044 & 10045) at the Emergency Tailings Area from 5 June to 11 August 2015**



**Figure 15 Calculated Groundwater Gradient to the Avoca River at the Emergency Tailings Area from 5 June to 11 August 2015**

## 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 Whites Bridge, zinc load increased from 5.74 to 16 kg/day which is a 64 % increase. The only surface water input in this segment is from Vale View which contributes very little load (0.03 kg/day). This indicates that the increase in loading is primarily due to diffuse load;

- Between Whites Bridge and Whites Bridge GS, zinc load decreases from 16 kg/day to 1.1 kg/day which is a decrease of 93%. A variation in sampling technique between both locations may have had an influence on this decrease i.e. a partial transect sampled at Whites Bridge due to health and safety and a full transect sampled at Whites Bridge GS;
- Between Whites Bridge GS and DS Deep Adit on the Avoca River, the zinc load increases significantly from 1.1 to 49.4 kg/day which is a 98% increase. The increase in zinc load at DS Deep Adit is likely primarily due to the diffuse load of the Deep Adit discharge which was diverted through the Millrace and subsequently seeping to groundwater (see Figure 1); and
- Between DS Deep Adit and US Deep Adit on the Avoca River, zinc load remains similar (49.4 to 49.2 kg/day).

Between US Road Adit and Wicklow County Council Maintenance Yard GS, zinc load increases from 49.2 to 80.3 kg/day which is a 39% increase. The Road Adit (confluence sample) contributed 11.4 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)

Between Wicklow County Council Maintenance Yard GS and Site T5, zinc load decreased from 80.3 to 57.5 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.

### 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 taken from the deviation plots. The deviation plots compare the measured flow against the rating curve flow. The deviation plots were obtained from the EPA for the Whites Bridge GS and the Wicklow County Council Maintenance Yard GS. The total number of gauging's at Whites Bridge GS was 26 and the difference between the measured flow and the flow rating curve ranged from 0.010 to 1.22 m<sup>3</sup>/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 m<sup>3</sup>/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 9 % 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 it has been shown that the Avoca River and its interaction 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. This indicates that the flooded Millrace area (Whites Bridge GS to downstream of DS Deep Adit) is likely contributing diffuse load to the River.

This is particularly evident in the measured zinc load results from the August 2015 sampling event, in the stretches of river between Site T1 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 at Whites Bridge and from DS Deep Adit to Downstream Shelton Abbey with results ranging from 67.2 to 338 µg/l.



## Section 7

# Summary and Recommendations

### 7.1 Summary of Findings

Nine groundwater monitoring wells were sampled and analysed in August 2015 and water levels were measured. Twenty-three surface water locations were sampled and analysed in August 2015 with flows measured at 17 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. SG104 located immediately downgradient of Ballymurtagh Landfill had the highest concentrations of dissolved metals especially aluminium, cadmium, copper, manganese, nickel and zinc.
- The Cronebane Shallow Adit was the adit discharge with the highest concentrations of metals including aluminium, cadmium, iron and zinc. The Cronebane Shallow, Ballygahan and Spa adits are of minor importance in terms of metals loads to the Avoca River, either because of absence of direct flow to the river or due to 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, several 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 7.04 to 16.6 µg/l. Similarly, dissolved zinc exceeded the ecological assessment criteria (50 µg/l) at Whites Bridge and all river locations from DS Deep Adit to the Downstream Shelton Abbey location with results ranging from 67.2 to 338 µg/l. Dissolved cadmium exceeded the ecological assessment criteria of 0.45 µg/l from DS Deep Adit to Avoca Bridge 0.456 to 0.619 µg/l. The highest value for dissolved iron was recorded at 1050 µg/l at Wicklow County Council Maintenance Yard GS located downstream of the Road Adit discharge on the Avoca River.

- The total discharge from the Deep Adit portal was diverted through the Millrace and subsequently seeping into groundwater in August 2015. This is likely contributing diffuse loads of dissolved metals to the Avoca River. Concentrations of dissolved zinc increased from 4.66 µg/l at Whites Bridge GS to 208 µg/l at DS Deep Adit which exceeded the ecological assessment criteria of 50 µg/l. Dissolved copper increased from 2.65 µg/l at Whites Bridge GS to 7.04 µg/l at DS Deep Adit which exceeded the ecological assessment criteria of 5 µg/l.
- The results of the Mann-Kendall analysis for October 2001 to August 2015 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 zinc, copper and iron were decreasing in the Road Adit. At Avoca Bridge no statistically significant trend was present for dissolved zinc or dissolved copper for both the 2001-2015 period and the 2007-2015 period.
- As river stages change hydraulic gradients to or from the river also change. Gradients are predominantly positive which suggests that the Avoca River is a net gaining river from the alluvium during the monitoring period. The implication is that the spoil and the alluvial areas either side of the river contribute contaminant load to the river. This is especially evident in the measured zinc load results, in the stretches of river between Site T1 and Whites Bridge and between White Bridge GS and DS Deep Adit where the diffuse load accounts for a large portion of the zinc loading to the Avoca River.

## 7.2 Recommendations for the Monitoring Programme

Recommendations for future monitoring at the former Avoca mining site as well as a review of the monitoring which has been undertaken from 2013-2015 will be presented in a summary report due December 2015.

## Section 8

### References

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

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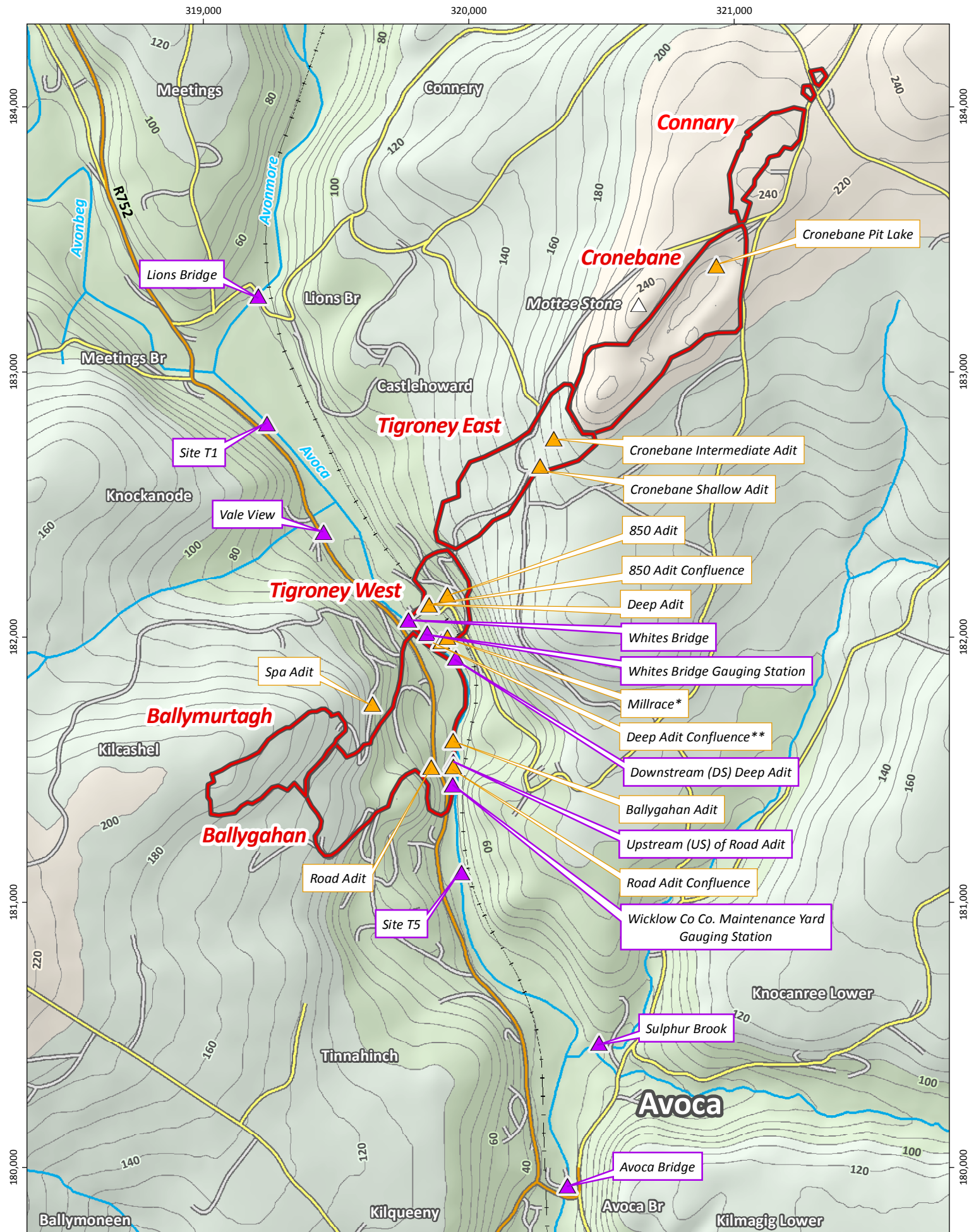
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# Appendix A

## Figures



## Map 1 - Avoca - Main Area

Drawn by: OC Date: 13/11/2015

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02\_GIS\_Tasks\13\_MonRptR6\MXD\01\_AvocaMon1.mxd

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**CDM Smith**

### Legend

#### Sampling Locations

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

\*Deep Adit discharge was diverted through two channels in Millrace area, so the sampling location was relocated  
 \*\*No sample was collected as former channel was dry and all flow is diverted through Millrace channels

#### Mines

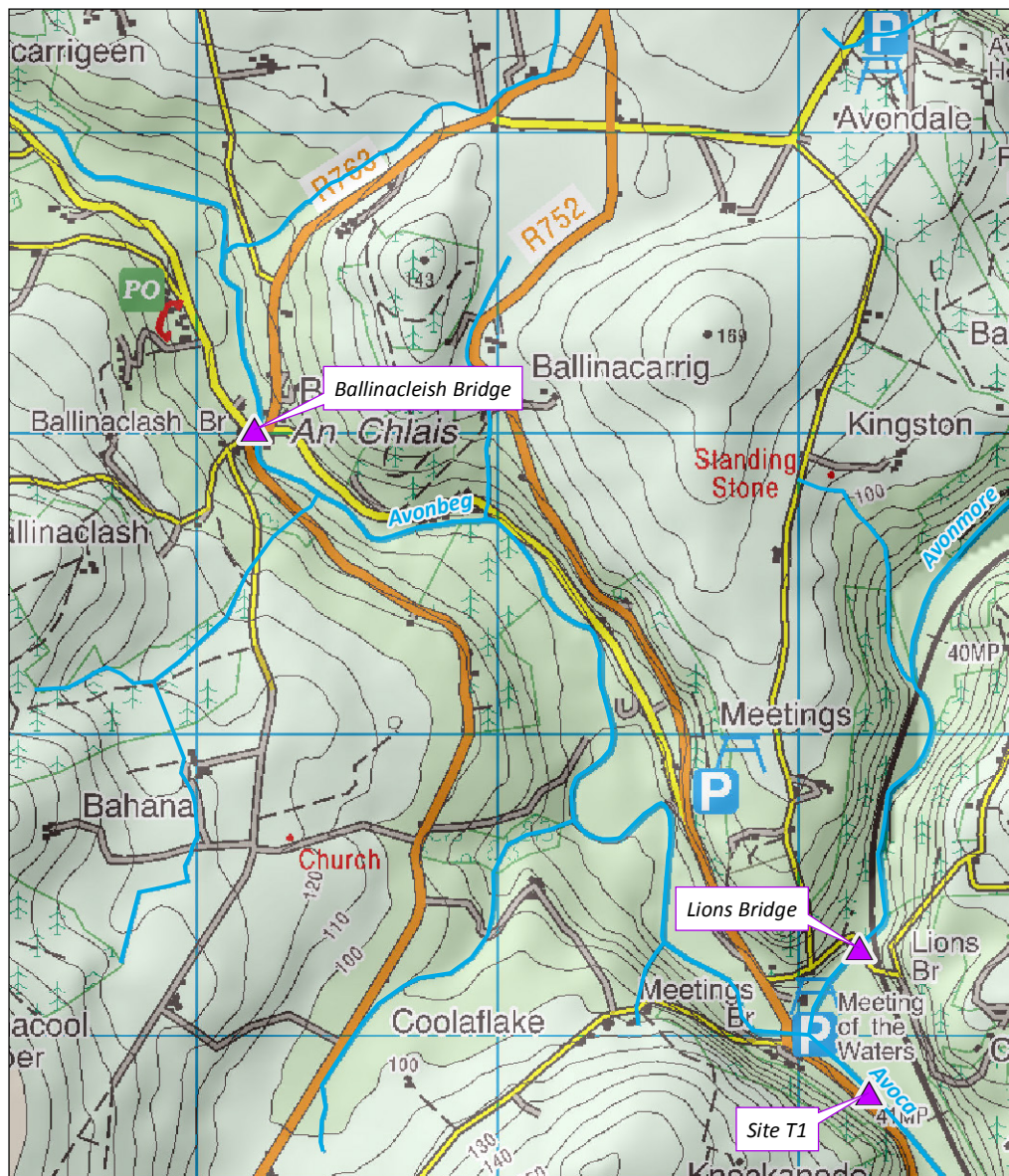
- Mining Area
- Rivers



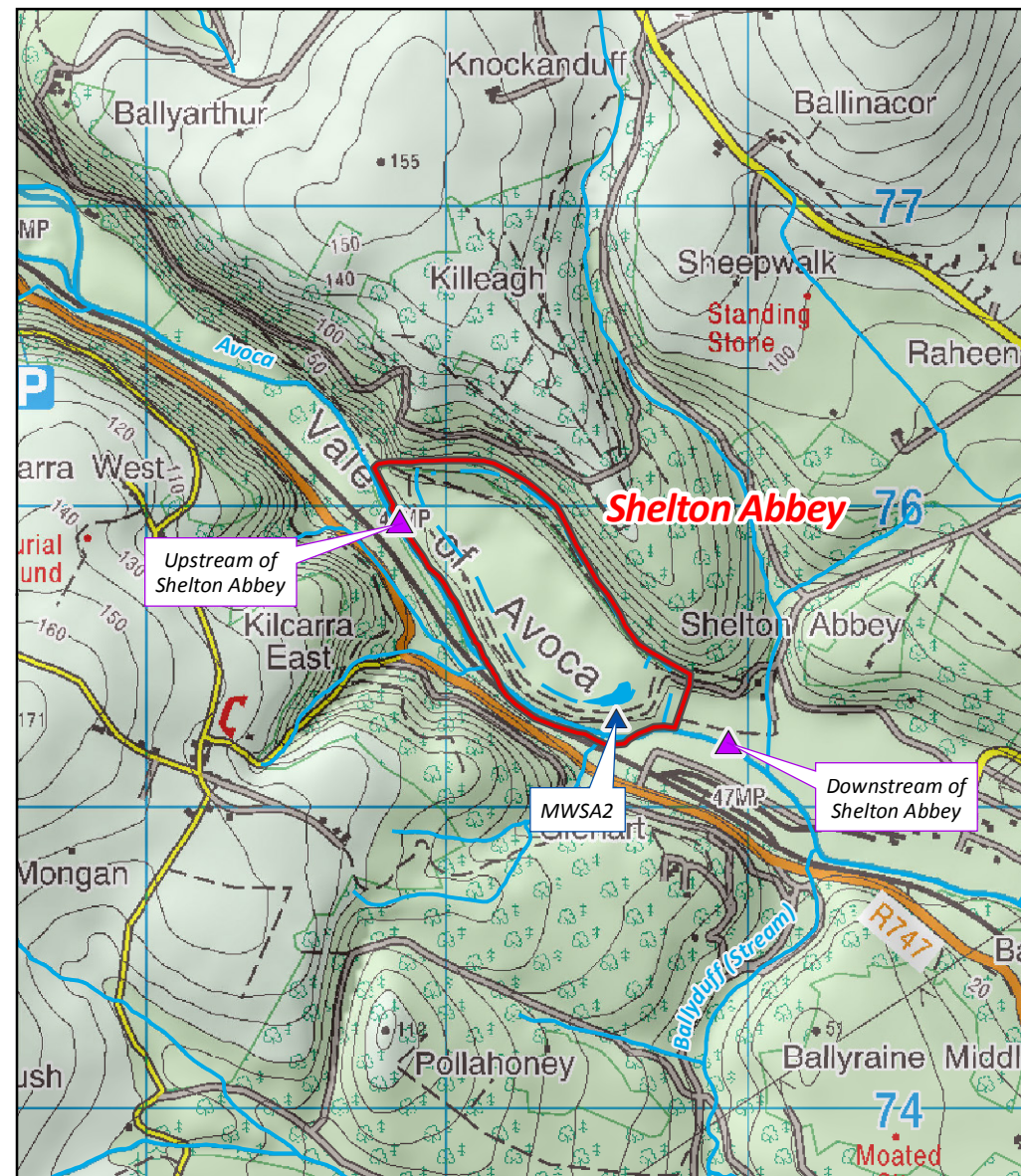
Scale is 1:18,000

0 125 250 500 m





**Ballinacleish**



**Shelton Abbey**

## Map 2 - Avoca - Ballinacleish and Shelton Abbey

Drawn by: OC Date: 13/11/2015

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02\_GIS\_Tasks\13\_MonRptR6\MXD\02\_AvocaMon2.mxd

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Smith**

### Legend

#### Sampling Locations

- ▲ Surface water (Rivers and Streams)
- ▲ Surface water (Adit discharges)
- ▲ Groundwater (Shelton Abbey)

#### Mines

⬭ Mining Area

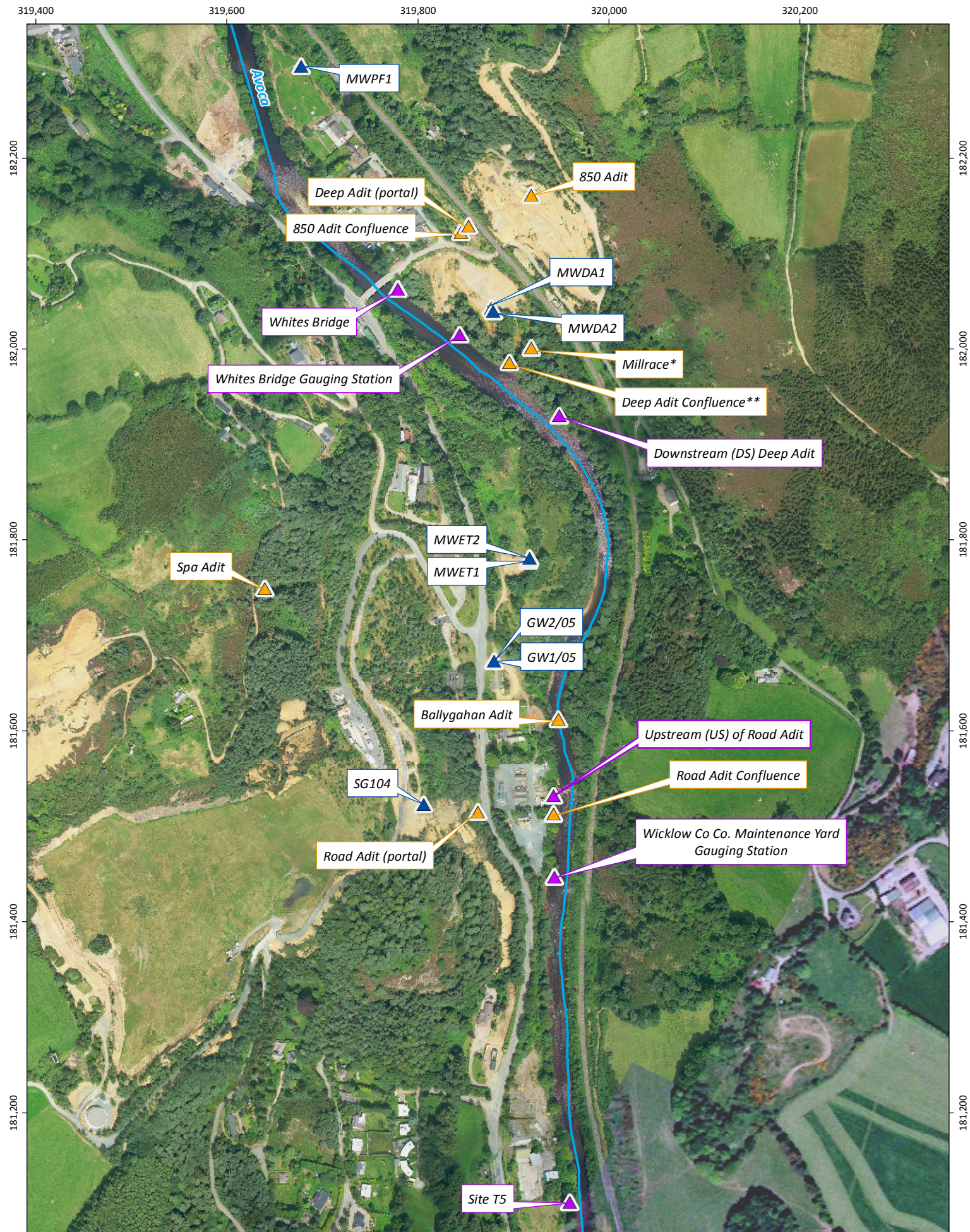
— Rivers

Scale is 1:25,000

0 250 500  
m







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

Drawn by: OC Date: 13/11/2015

Internal Project Reference: Q:\95500-95999\95735\40 Documents Generated\GIS\02\_GIS\_Tasks\13\_MonRptR6\MXD\03\_AvocaMonGW.mxd

Source: © DCENR Lidar Survey (2007)

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#### Legend

##### Sampling Locations

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

— Rivers



Scale is 1:5,000

0 50 100  
m

\*Deep Adit discharge was diverted through two channels in Millrace area, so the new sampling location was relocated

\*\*No sample was collected as former channel was dry and all flow is diverted through Millrace channels



## Appendix B

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### Analytical Data Tables and Assessment Criteria

Table B-1 Comparison of Total versus Dissolved Metals R6

Sample Description	Date Sampled	Suspended solids, Total	Aluminium (tot.unfilt)	Aluminium (diss.filt)	Ratio diss to total Aluminium	Copper (tot.unfilt)	Copper (diss.filt)	Ratio diss to total Copper	Iron (tot.unfilt)	Iron (diss.filt)	Ratio diss to total Iron	Zinc (tot.unfilt)	Zinc (diss.filt)	Ratio diss to total Zinc
	Units	mg/l	µg/l	µg/l		µg/l	µg/l		µg/l	µg/l		µg/l	µg/l	
MWDA1	11/08/2015	-	168000	126000	0.75	15100	15200	1.01	51200	49700	0.97	25900	18600	0.72
MWDA2	11/08/2015	-	50700	44600	0.88	3380	4160	1.23	56000	57300	1.02	42100	37500	0.89
SULPHUR BROOK	11/08/2015	<2	25	24.5	0.98	16.7	16.8	1.01	34.5	9.5	0.28	92.6	98.7	1.07
850 ADIT	17/08/2015	-	-	67200		-	10200		-	106000		-	28100	
AVOCA BRIDGE	18/08/2015	4	585	99.1	0.17	22	12.1	0.55	394	158	0.40	267	241	0.90
BALLINACLEISH BRIDGE	19/08/2015	<2	57.5	37.1	0.65	2	0.425	0.21	118	67.8	0.57	16.8	15	0.89
CRONEBANE INTER ADIT	19/08/2015	<2	44200	42200	0.95	880	986	1.12	69700	78500	1.13	31800	28200	0.89
CRONEBANE PIT LAKE	19/08/2015	<2	12200	12500	1.02	3410	3440	1.01	1510	1330	0.88	5730	5380	0.94
CRONEBANE SHALLOW ADIT	19/08/2015	5	293000	294000	1.00	5740	5450	0.95	180000	156000	0.87	103000	103000	1.00
DEEP ADIT	17/08/2015	<2	82500	106000	1.28	126	142	1.13	51700	53800	1.04	39200	46800	1.19
DS DEEP ADIT	18/08/2015	<2	553	124	0.22	12.4	7.04	0.57	135	43.5	0.32	232	208	0.90
DS SHELTON ABBEY	13/08/2015	<2	351	124	0.35	11.5	7.28	0.63	290	141	0.49	145	108	0.74
GW1/05	12/08/2015	-	75600	78300	1.04	8600	9140	1.06	5520	4870	0.88	12900	11800	0.91
GW2/05	12/08/2015	-	105000	55500	0.53	7730	6860	0.89	208000	130	0.00	9750	7210	0.74
LIONS BRIDGE	19/08/2015	<2	25	38.3	1.53	2	1.5	0.75	110	80.4	0.73	21	26.4	1.26
MILLRACE	17/08/2015	3	80000	7290	0.09	126	11	0.09	44200	47100	1.07	38100	3350	0.09
MWET 1	12/08/2015	-	126000	107000	0.85	8800	8200	0.93	137000	130000	0.95	12400	9240	0.75
MWET 2	12/08/2015	-	56.8	95.9	1.69	2	9.15	4.58	107000	97900	0.91	4570	6060	1.33
MWPF 1	12/08/2015	-	325	295	0.91	43.5	37.9	0.87	44.6	9.5	0.21	46	37.9	0.82
MWSA2	13/08/2015	-	70200	90300	1.29	200	114	0.57	111000	90500	0.82	4840	4870	1.01
ROAD ADIT	17/08/2015	<2	12700	13300	1.05	320	305	0.95	68000	65800	0.97	7700	8290	1.08
ROAD ADIT CONFLUENCE	17/08/2015	<2	12900	12900	1.00	334	299	0.90	65200	65700	1.01	7780	7200	0.93
SG104	12/08/2015	-	998000	760000	0.76	71400	79500	1.11	67800	33600	0.50	134000	118000	0.88
SITE T1	19/08/2015	<2	233	34.8	0.15	4.9	0.425	0.09	118	74.3	0.63	95.9	24.8	0.26
SITE T5	18/08/2015	4	770	75.4	0.10	28.4	14.6	0.51	704	473	0.67	324	277	0.85
SPA ADIT	17/08/2015	<2	159000	161000	1.01	7610	7710	1.01	126000	112000	0.89	13200	12900	0.98
US ROAD ADIT	18/08/2015	3.5	693	131	0.19	22.9	12.5	0.55	165	55.2	0.33	273	207	0.76
US SHELTON ABBEY	13/08/2015	2	348	389	1.12	11.8	7.12	0.60	243	105	0.43	147	106	0.72
VALE VIEW	17/08/2015	<2	25	7.42	0.30	2	1.17	0.59	50.4	9.5	0.19	5.69	32.9	5.78
WCC MAIN YARD GS	18/08/2015	8	835	66.9	0.08	29.8	16.6	0.56	1220	1050	0.86	373	338	0.91
WHITES BRIDGE	18/08/2015	<2	234	103	0.44	19.4	14.4	0.74	111	58.8	0.53	63.3	67.2	1.06
WHITES BRIDGE GS	18/08/2015	<2	149	12.7	0.09	7.63	2.65	0.35	101	9.5	0.09	51.8	4.66	0.09

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

Table B-2 Comparison of Groundwater and Surface Water Results to Assessment Criteria R6

Sample Description	Type	Date Sampled Units	Acidity as HCL mg/l	Alkalinity, Total as CaCO3 mg/l	Hardness as CaCO3 mg/l	Ammoniacal Nitrogen as N mg/l	Chloride mg/l	COD, unfiltered mg/l	Specific Conductance @ deg.C (field) mS/cm	Cyanide, Free mg/l	Dissolved solids, Total mg/l	Fluoride mg/l	Nitrate as NO3 mg/l	Nitrite as NO2 mg/l	Oxygen, dissolved (field) % Sat	pH (field) pH Units	Phosphate (ortho) as P mg/l	Sulphate mg/l	Sodium (diss.filt) mg/l	Suspended solids, Total mg/l
Ecological Criteria			-	-	-	0.14	-	-	-	0.01	-	0.5	-	-	80 to 120*	4.5 to 9	0.075	-	-	-
Human Health Criteria			-	-	-	0.3	250	-	2.5	0.05	-	1.5	50	0.5	-	6.5 to 9.5	-	250	200	-
MWDA1	GW	11/08/2015	-	1	1	0.869	10.6	-	1.469	0.025	2550	3.66	6.6	0.025	53.4	3.46	0.0427	1440	7.88	-
MWDA2	GW	11/08/2015	-	1	1	0.235	14.6	-	2.201	0.025	1470	0.854	1.1	0.025	2.3	3.18	0.01	792	12.9	-
GW1/05	GW	12/08/2015	-	1	1	0.1	14.7	-	3.396	0.025	1880	0.25	7.64	0.025	1.7	5.91	0.0219	1080	11	-
GW2/05	GW	12/08/2015	-	1	1	0.998	16.8	-	2.3	0.025	1490	0.25	7.44	0.025	2.5	2.59	0.01	852	11.3	-
MWET 1	GW	12/08/2015	-	1	1	0.791	32.4	-	0.154	0.025	2720	1.53	0.15	0.025	72.3	4.35	0.01	1460	20.3	-
MWET 2	GW	12/08/2015	-	49.9	61	0.262	15.7	-	7.943	0.025	4120	28.9	0.15	0.025	29.6	2.78	0.01	2340	23.8	-
MWPF 1	GW	12/08/2015	-	2.5	3	0.1	15.8	-	1.347	0.025	90	0.25	6.97	0.025	2.1	3.4	0.01	32.5	8.27	-
MWSA2	GW	13/08/2015	-	1	1	0.978	15.6	-	2.447	0.025	3000	2.64	0.15	0.025	2.2	3.88	0.01	1710	9.77	-
SG104	GW	12/08/2015	-	1	1	0.1	15	-	1.722	0.025	13200	5.87	0.75	0.025	27.2	3.47	0.01	8370	6.1	-
850 Adit	Adit	17/08/2015	-	-	1	0.1	-	-	2.243	0.025	-	-	-	0.025	82	2.38	-	-	10.9	-
Cronebane Intermediate Adit	Adit	19/08/2015	350	1	1	0.398	13.5	16	1.104	0.025	991	36.2	0.15	0.025	11.9	2.75	0.01	564	8.49	1
Cronebane Pit Lake	Pit Lake	19/08/2015	96.7	1	1	0.571	7.9	3.5	0.547	0.025	262	0.25	1.28	0.025	80.1	3	0.01	159	4.35	1
Cronebane Shallow Adit	Adit	19/08/2015	1730	1	1	0.636	14.5	26.5	3.269	0.025	4120	15.5	0.15	0.025	32	2.29	0.01	2770	7.57	5
Deep Adit	Adit	17/08/2015	442	1	1	0.393	13.8	12.6	1.306	0.025	1430	1.64	0.15	0.025	35.7	3.34	0.01	843	8.68	1
Road Adit	Adit	17/08/2015	206	1	1	7.88	32.6	44.8	1.564	0.025	1450	20.4	1.96	0.025	33	3.45	0.01	852	22.2	1
Road Adit Conf.	Adit	17/08/2015	193	1	1	7.91	32.4	23.6	1.56	0.025	1480	21	1.9	0.025	87.6	3.57	0.01	856	23.9	1
Spa Adit	Adit	17/08/2015	1030	1	1	1.1	10.6	19.5	2.444	0.025	2740	14.7	0.15	0.025	90.9	2.28	0.0225	1630	5.84	1
Millrace	Adit	17/08/2015	443	1	1	0.282	13.7	12.9	1.329	0.025	1380	2.13	0.15	0.025	76.1	3.23	0.01	837	8.94	3
Sulphur Brook	River	11/08/2015	2	21.8	27	0.1	15.3	3.5	0.159	0.025	109	0.25	24.4	0.025	93.6	7	0.01	12.4	10.3	1
Avoca Bridge	River	18/08/2015	2	9	11	0.1	8.9	8.21	0.094	0.025	30	0.25	3.69	0.025	98.4	6.08	0.01	18.8	7.64	4
Ballinacleish Bridge	River	19/08/2015	2	12	15	0.219	8	10.5	0.061	0.025	51	0.25	4.3	0.025	91.8	5.74	0.01	3.4	7.31	1
DS Deep Adit	River	18/08/2015	2	10.8	13	0.1	8.8	8.35	0.07	0.025	45.3	0.25	4.02	0.025	98.2	6.1	0.01	9.7	7.25	1
DS Shelton Abbey	River	13/08/2015	2	10.7	13	0.1	9.4	11.7	0.095	0.025	68	0.25	5.56	0.025	93	6.64	0.01	10.3	6.62	1
Lions Bridge	River	19/08/2015	2	14.5	18	0.1	9.4	16.6	0.07	0.025	51	0.25	4.23	0.025	92.2	5.79	0.0225	4.8	7.09	1
Site T1	River	19/08/2015	2	13.5	16	0.1	8.5	8.7	0.068	0.025	40	0.25	3.47	0.025	93.8	6.27	0.01	3.2	7.11	1
Site T5	River	18/08/2015	2	8	10	0.279	9.4	3.5	0.107	0.025	62.2	0.25	3.63	0.025	95.9	5.92	0.01	21.5	7.56	4
US Road Adit	River	18/08/2015	2	10	12	0.1	9.1	10.2	0.087	0.025	51.6	0.25	3.9	0.025	98.4	5.99	0.01	12.3	7.39	3.5
US Shelton Abbey	River	13/08/2015	2	28.6	35	0.1	9.3	8.41	0.09	0.025	65.3	0.25	5.58	0.025	98.3	6.43	0.01	8.4	6.73	2
Vale View	River	17/08/2015	2	23.2	28	0.1	13.5	3.5	0.157	0.025	101	0.25	13.8	0.025	101.4	6.67	0.01	19.7	7.57	1
WCC Maintenance Yard GS	River	18/08/2015	2	5.5	7	0.479	9.3	3.5	0.08	0.025	75	0.25	3.44	0.025	96.1	6.19	0.01	29	7.67	8
Whites Bridge	River	18/08/2015	2	11.3	14	0.1	9	7.51	0.075	0.025	48	0.25	4.02	0.025	90.9	6.21	0.01	5.4	7.29	1
Whites Bridge GS	River	18/08/2015	2	69	84	0.1	9	3.5	0.073	0.025	46.7	0.25	4.05	0.025	95	6.31	0.01	4.7	R	1

xx Exceeds Ecological Assessment Criteria  
xx Exceeds Human Health Assessment Criteria  
xx Exceeds both Ecological and Human Health Criteria  
xx Less than the Limit of Detection (LOD) - Value taken to be 0.5 of the LOD  
- Not analysed or no assessment criteria  
\* Only applies to rivers or streams (i.e. not discharges or groundwater)  
R Result rejected

Table B-2 Comparison of Groundwater and Surface Water Results to Assessment Criteria R6

Sample Description	Type	Date Sampled	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)	Lead (diss.filt)	Manganese (diss.filt)	Mercury (diss.filt)	Molybdenum (diss.filt)	Nickel (diss.filt)	Selenium (diss.filt)	Silver (diss.filt)	Thallium (diss.filt)	Tin (diss.filt)	Uranium (diss.filt)	Vanadium (diss.filt)	Zinc (diss.filt)
		Units	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Ecological Criteria			1,900	-	25	4	0.45	3.4	5.1	5	-	7.2	1100	0.07	-	20	-	-	-	-	2.6	-	50
Human Health Criteria			200	5	10	-	5	50	-	2000	200	10	50	1	-	20	10	-	-	-	-	-	-
MWDA1	GW	11/08/2015	126000	0.599	0.06	2.72	30.5	22.5	99.1	15200	49700	3.2	9160	0.005	0.309	73.1	0.942	0.75	0.48	8.13	6.95	0.12	18600
MWDA2	GW	11/08/2015	44600	0.888	0.06	4.09	32.5	4.21	120	4160	57300	1.93	8460	0.005	0.646	58.5	1.36	0.75	1.01	11	4.05	0.12	37500
GW1/05	GW	12/08/2015	78300	1.79	0.6	5.44	28.8	4.98	125	9140	4870	56.8	6000	0.005	1.2	58.5	5.87	0.75	4.8	11.2	7.5	1.2	11800
GW2/05	GW	12/08/2015	55500	2.18	0.6	1.9	19.6	4.9	86.4	6860	130	0.243	4060	0.005	1.2	41	5.76	0.75	4.8	11.9	7.5	1.2	7210
MWET 1	GW	12/08/2015	107000	0.229	0.06	2.59	18.1	9.11	138	8200	130000	6.29	6790	0.005	0.346	55.9	1.09	0.75	1.88	0.577	7.7	0.351	9240
MWET 2	GW	12/08/2015	95.9	0.08	2.97	7.93	1.76	1.01	103	9.15	97900	0.997	33900	0.005	0.12	16.7	0.982	0.75	0.48	0.18	1.77	0.12	6060
MWPF 1	GW	12/08/2015	295	0.08	0.06	9.48	0.32	0.945	0.503	37.9	9.5	0.239	19.3	0.005	0.379	1.28	0.195	0.75	0.48	0.18	0.75	0.12	37.9
MWSA2	GW	13/08/2015	90300	0.08	13.6	8.5	1.55	7.21	176	122	95200	28.7	36000	0.005	0.12	119	1.44	0.75	0.48	0.18	7.37	0.748	4870
SG104	GW	12/08/2015	760000	0.08	0.06	10	92.9	18.9	479	79500	33600	89.3	38900	0.005	0.12	177	1.57	0.75	0.48	0.18	53.8	0.258	118000
850 Adit	Adit	17/08/2015	67200	0.8	53.6	4.92	48.7	7.5	110	10200	106000	192	9310	0.005	1.2	61.9	1.95	7.5	4.8	1.8	7.5	1.2	28100
Cronebane Intermediate Adit	Adit	19/08/2015	42200	0.8	6.13	8.66	83.3	2.46	61.2	986	78500	1180	2250	0.005	1.2	36.2	1.95	7.5	4.8	1.8	7.5	1.2	28200
Cronebane Pit Lake	Pit Lake	19/08/2015	12500	0.08	0.462	8.02	14.5	0.664	22.2	3440	1330	632	493	0.005	0.12	4.63	0.567	0.75	0.48	0.18	0.75	0.12	5380
Cronebane Shallow Adit	Adit	19/08/2015	294000	0.08	6.96	3.98	92	5.3	188	5450	156000	967	8600	0.005	0.12	87.5	1.51	7.5	0.48	1.49	18.3	0.734	103000
Deep Adit	Adit	17/08/2015	106000	0.8	2.02	7.92	89.2	4.14	118	142	53800	2490	4610	0.005	1.2	50.2	1.95	7.5	4.8	1.8	7.5	1.2	46800
Road Adit	Adit	17/08/2015	13300	5.15	3.1	15	11	3.54	90.8	305	65800	364	7690	0.005	5.94	36.2	1.95	7.5	4.8	6.64	7.5	1.2	8290
Road Adit Conf.	Adit	17/08/2015	12900	3.49	3.35	14.6	10.2	2.39	84.9	299	65700	350	6940	0.005	3.79	33.6	4.79	7.5	4.8	1.8	7.5	1.2	7200
Spa Adit	Adit	17/08/2015	161000	2.19	0.6	6.04	37.1	7.21	238	7710	112000	108	7960	0.005	1.2	55.3	1.95	7.5	4.8	1.8	7.5	1.2	12900
Millrace	Adit	17/08/2015	7290	0.8	0.6	0.649	7.41	3.32	8.72	11	47100	171	298	0.005	1.2	4.79	1.95	7.5	4.8	1.8	7.5	1.2	3350
Sulphur Brook	River	11/08/2015	24.5	1.06	0.336	8.09	0.398	0.504	0.181	16.8	9.5	2.14	21.8	0.005	1.06	0.912	0.195	0.75	0.48	3.75	0.75	0.12	98.7
Avoca Bridge	River	18/08/2015	99.1	0.626	0.334	5.62	0.619	0.303	1.32	12.1	161	2	85.7	0.005	0.518	0.801	0.195	0.75	0.48	2.6	0.75	0.12	241
Ballinacleish Bridge	River	19/08/2015	37.1	0.08	0.481	7.14	0.05	0.47	0.03	0.425	67.8	1.1	5.97	0.005	0.12	0.633	0.195	0.75	0.48	0.18	0.75	0.12	15
DS Deep Adit	River	18/08/2015	124	0.162	0.395	5.46	0.456	0.426	0.543	7.04	43.5	2.15	26.4	0.005	0.12	0.769	0.195	0.75	0.48	0.18	0.75	0.12	208
DS Shelton Abbey	River	13/08/2015	124	0.08	0.467	5.15	0.265	0.468	0.691	7.28	141	2	65.2	0.005	0.12	1.14	0.195	0.75	0.48	0.18	0.75	0.12	108
Lions Bridge	River	19/08/2015	38.3	0.08	0.654	4.99	0.05	0.322	0.03	1.5	80.4	1.3	4.62	0.005	0.12	0.534	0.195	0.75	0.48	0.18	0.75	0.12	26.4
Site T1	River	19/08/2015	34.8	0.282	0.544	5.66	0.05	0.459	0.03	0.425	74.3	1.13	3.48	0.005	0.407	0.253	0.195	0.75	0.48	1.01	0.75	0.12	24.8
Site T5	River	18/08/2015	75.4	0.21	0.334	5.38	0.603	0.419	1.7	14.6	473	2.68	114	0.005	0.12	0.871	0.195	0.75	0.48	0.563	0.75	0.12	277
US Road Adit	River	18/08/2015	131	0.08	0.348	6.13	0.514	0.479	0.796	12.5	55.2	2.47	38.6	0.005	0.12	0.911	0.195	0.75	0.48	0.18	0.75	0.12	207
US Shelton Abbey	River	13/08/2015	389	0.08	0.473	5.23	0.257	0.441	0.513	7.12	105	1.53	38.9	0.005	0.12	0.9	0.195	0.75	0.48	0.18	0.75	0.12	106
Vale View	River	17/08/2015	7.42	0.08	0.384	7.51	0.05	0.582	0.03	1.17	9.5	0.164	4.52	0.005	0.12	0.488	0.195	0.75	0.48	0.18	0.75	0.12	32.9
WCC Maintenance Yard GS	River	18/08/2015	66.9	0.276	0.331	5.18	0.688	0.246	2.39	16.6	1050	3.98	167	0.005	0.246	1.12	0.195	0.75	0.48	0.825	0.75	0.12	338
Whites Bridge	River	18/08/2015	103	0.08	0.493	5.5	0.179	0.462	0.239	14.4	58.8	1.27	15.7	0.005	0.302	0.708	0.195	0.75	0.48	0.18	0.75	0.12	67.2
Whites Bridge GS	River	18/08/2015	12.7	0.08	0.558	5.74	0.05	1.1	0.03	2.65	9.5	0.792	1.17	0.005	0.12	0.075	0.195	0.75	0.48	0.18	0.75	0.24	4.66

xx Exceeds Ecological Assessment Criteria  
xx Exceeds Human Health Assessment Criteria  
xx Exceeds both Ecological and Human Health Criteria  
xx Less than the Limit of Detection (LOD) - Value taken to be 0.5 of the LOD  
- Not analysed or no assessment criteria  
\* Only applies to rivers or streams (i.e. not discharges or groundwater)  
R Result rejected