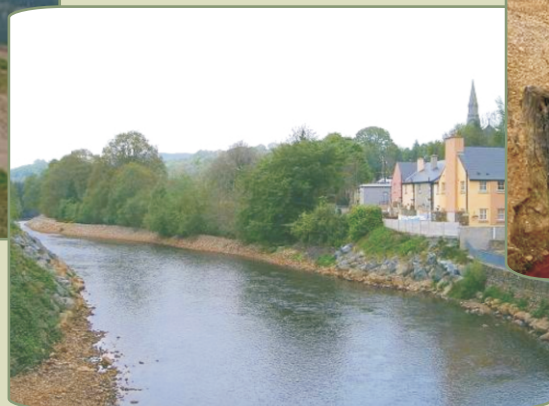**CDM**

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The Department of Communications, Energy and Natural Resources

Feasibility Study for Management and Remediation of the Avoca Mining Site - Volume 2

December 2008

Investigative Reports:
   Data Report
   Conceptual Site Model
   Human Health Risk Assessment
   Ecological Risk Assessment

Report

The Department of Communications, Energy and Natural Resources

Feasibility Study for Management and Remediation of the Avoca Mining Site

Conceptual Site Model (Phase 2)

October 2008

Draft Report

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Section 1
Introduction

A preliminary (Phase 1) evaluation and conceptual site model (CSM) for the Avoca Mine Site (Site) (includes East Avoca, West Avoca, and Shelton Abbey) was prepared in May 2007 (CDM 2007). The Phase 1 CSM Report is attached (see Phase 1 Reports). The preliminary CSM was based on historical data, most of which was at least 10 years old. In order to supplement the existing data, the following additional activities were performed:

- Collected flow and water quality data at five stations (transects) on the Avoca River

- Collected flow and water quality data for seven adits (Deep, Road, Intermediate, Cronebane Shallow, Ballygahan, Kilmacoo, and Spa)

- Collected and analyzed 33 "near bank" water samples from the Avoca River

- Installed 6 new groundwater wells at four locations

- Analyzed samples from 16 monitoring and homeowner wells

- Installed water level data loggers in the six new groundwater wells

- Collected 11 bed sediment samples from the Avoca River

- Collected stage measurements at the staff gauge location at the northern end of the County Wicklow yard

- Collected and analyzed 2 pit lake samples, 5 seep samples, and 1 runoff sample

- Collected and analyzed 98 surface spoil samples for metals and sulfur (from 13 spoils piles)

- Analyzed 28 test pit spoil samples for metals and sulfur

- Analyzed 27 borehole subsoil and spoil samples for metals and sulfur

- Collected 44 farm field soil samples for metals

- Collected and analyzed 9 vegetation samples for selected metals

Most of the data were collected during the sampling event which occurred July 30 through August 27, 2007. However, some data, including the sampling of the new monitoring wells and the installation of the data loggers did not occur until the November 14-16, 2007 sampling event. Additional data were also collected February 19-21, 2008.

The results of the investigations are presented in full in the Data Report (attached), although specific data will be included within various sections to illustrate and support the data analysis and interpretation.

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Section 2
Spoils Characterization

2.1 Total Metals and Arsenic (ICPMS)

The spoils and tailings were analyzed for metals by both XRF and by ICPMS in order to determine if any variability exists among spoil piles that would allow remediation efforts to be focused on the more important metals sources. Due to the elevated detection limit for zinc and the poor correlation between the XRF and laboratory results for some metals, the following analysis will rely on the commercial laboratory data (ICPMS) rather than the field XRF data. More samples were analyzed at the laboratory than planned to make sure the evaluations based only on laboratory ICPMS would be adequate.

An evaluation of the data indicated that there was no substantial geographical variation in the spoils or tailings concentrations that would justify a detailed geostatistical evaluation. Therefore, the data were interpreted using a basic statistical approach. A rigorous evaluation to determine the data distribution, data transformation, and use of nonparametric tests were not deemed necessary. Given the goals of the metals and arsenic measurements within the wastes (i.e., to select areas for possible remediation including removal), a more rigorous evaluation was not needed. However, in cases where the mean and median values are not fairly equivalent, a skewed data distribution may exist, and the median values will be used to compare waste sources.

An initial evaluation of the waste material indicates that there is no apparent difference between surface samples and those at depth in terms of total concentrations of metals and arsenic. Therefore, all data (surface samples, test pits, and borehole samples) were evaluated together for each waste source.

2.1.1 Spoils

A summary of the ICPMS arsenic and selected metals concentrations within the spoils is presented in Tables 2-1 through 2-4, while the complete data set is included in the attached Data Report.

Table 2-1 Summary Statistics of Arsenic Concentrations in Spoils (mg/kg)

	Connary		Mt. Platt	East Avoca	Tigroney West			West Avoca		
	SP25[1]	SP31	SP20/20A	SP10	SP2	SP4	SP5	SP33	SP34	SP37/37A
Minimum	484	73	231	147	18	8	173	807	103	13
Maximum	3509	2708	1046	569	2893	942	935	2506	3903	1262
Mean	1139	1016	551	321	874	425	707	1657	1333	180
Median	**894**	**853**	**511**	**288**	**761**	**350**	**804**	**1657**	**1394**	**30**
Standard Deviation	998	726	185	133	860	339	285	N/A	910	331
Number of Samples	8	16	34	10	17	5	6	2	23	17

[1]   The spoil pile ID as defined by Gallagher et. al, 1997

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In general, arsenic concentrations are higher in the West Avoca spoils than for other areas. As will be discussed in the next section, arsenic-bearing minerals such as arsenopyrite, were more abundant in the banded sulfide ore of the Pond Lode than for the other ore bodies in the area, which may explain the higher arsenic concentrations in West Avoca.

Table 2-2 Summary Statistics of Lead Concentrations in Spoils (mg/kg)

	Connary		Mt Platt	East Avoca	Tigroney West			West Avoca		
	SP25	SP31	SP20/20A	SP10	SP2	SP4	SP5	SP33	SP34	SP37/ 37A
Minimum	7330	802	942	580	24	112	1312	4594	188	23
Maximum	78441	41353	24266	4570	74877	21753	9872	28363	2827	22838
Mean	32667	15539	4427	1874	12989	7208	6976	16479	1356	2421
Median	**24522**	**12022**	**3552**	**1645**	**7464**	**5915**	**7687**	**16479**	**1234**	**107**
Standard Deviation	23101	13391	4028	1222	19715	8508	3098	N/A	681	6000
Number of Samples	8	16	34	10	17	5	6	2	23	17

Lead concentrations were highest in the Connary spoils and in pile SP33 in West Avoca. The higher concentrations at Connary are probably related to the higher levels of lead-bearing ore minerals in the lead-zinc "Kilmacooite" ore and the less efficient processing techniques used when these older spoils were produced (approximately 100 years ago). There was also a lead-zinc lode at West Avoca that may have been the source of the spoils at SP33.

Table 2-3 Summary Statistics of Copper Concentrations in Spoils (mg/kg)

	Connary		Mt Platt	East Avoca	Tigroney West			West Avoca		
	SP25	SP31	SP20/20A	SP10	SP2	SP4	SP5	SP33	SP34	SP37/ 37A
Minimum	671	81	150	631	56	74	1420	1076	111	20
Maximum	7078	2957	1337	2339	11334	1763	4586	2822	1658	2588
Mean	3171	959	638	1297	3427	1169	2750	1949	581	349
Median	**2177**	**836**	**559**	**1238**	**1966**	**1517**	**2361**	**1949**	**571**	**51**
Standard Deviation	2520	867	316	561	4256	723	1417	N/A	336	708
Number of Samples	8	16	34	10	17	5	6	2	23	17

The median copper concentrations are generally about 2,000 mg/kg for most of the spoils. However, lower concentrations are observed for Mt. Platt, SP34 and SP37/37A at West Avoca, and to some extent East Avoca. The low concentrations for Mt. Platt are likely due to leaching of copper from the overburden (above the ore body) over geologic time. The reason for the lower median copper concentrations for SP34, SP37/37A and East Avoca are unknown, but may be the result of reprocessing of spoils during the modern mining era.

Table 2-4 Summary Statistics of Zinc Concentrations in Spoils (mg/kg)

	Connary		Mt Platt	East Avoca	Tigroney West			West Avoca		
	SP25	SP31	SP20/20A	SP10	SP2	SP4	SP5	SP33	SP34	SP37/ 37A
Minimum	215	65	47	132	85	49	153	141	44	83
Maximum	1313	883	663	366	7404	415	947	733	791	444
Mean	596	355	216	217	1722	209	444	437	157	160
Median	**578**	**214**	**188**	**213**	**399**	**212**	**235**	**437**	**91**	**121**
Standard Deviation	345	294	119	70	2303	137	389	N/A	165	94
Number of Samples	8	16	34	10	17	5	6	2	23	17

Zinc shows a similar trend as for lead, with the highest median values for Connary (SP25) and West Avoca (SP33). The source of the zinc is likely the same as for lead (i.e., kilmacooite type ore), although the differences in concentrations are less pronounced (possibly due to zinc leaching preferentially to lead as will be discussed later).

2.1.2 Tailings

As shown in Table 2-5, concentrations of arsenic and metals are generally lower in the tailings than for the spoils.

Table 2-5 Arsenic and Metals Concentration within the Tailings (mg/kg)

	Emergency Tailings				Shelton Abbey			
	Arsenic	Lead	Copper	Zinc	Arsenic	Lead	Copper	Zinc
Minimum	58	57	254	113	26	39	67	69
Maximum	1562	2649	3850	3446	198	3651	1372	2141
Mean	420	838	1342	864	134	848	508	470
Median	**120**	**605**	**859**	**145**	**141**	**373**	**374**	**136**
Standard Deviation	646	1041	1430	1452	66	1382	479	822
Number of Samples	5	5	5	5	6	6	6	6

The Emergency Tailings and Shelton Abbey Tailings are fairly similar in terms of arsenic and zinc, but lead and copper appears to be somewhat higher in the Emergency Tailings than the Shelton Abbey Tailings. However, given the low number of samples (5 to 6), the difference may not be significant.

2.2 EMP

2.2.1 Introduction

The metals results for the spoil piles indicates that the concentrations of lead and arsenic are elevated, yet these parameters are low or even below detection limits within the adit discharges and other inputs to the Avoca River. In the Phase 1 CSM, the reasons for the relatively low mobility of arsenic and lead (compared to copper and zinc) were discussed, but at the time there was not enough information to make definitive evaluations. In addition, the in-vitro lead and arsenic results indicate that

these elements have low bioavailability (see Human Health Risk Assessment for more details) and therefore also probably low mobility.

In order to further evaluate the bioavailability and leachability of lead and arsenic, as well as copper and zinc, Electron Microprobe (EMP) analyses were performed on eight spoil samples and four tailings samples collected from, boreholes, test pits, and from the surface (Table 2-6). A detailed evaluation of the EMP analyses is provided in Appendix A.

Table 2-6 Summary of Samples Analyzed by Electron Microprobe

Sample ID	Location	Depth (m)	Type	Collection Method	Depth Classification
SA-17S	Mt Platt (SP20)[1]	0.15	Spoils	Grab	Surface
SA-7A	Shelton Abbey	0.15	Tailings	Grab	Surface
SA-9	West Avoca (SP34B)	0.15	Spoils	Grab	Surface
SA-12	Connary (SP22)	0.15	Spoils	Grab	Surface
BH-WA1 2.55	West Avoca (SP34B)	2.55	Spoils	Borehole	Subsurface
BH-MP1 8	Mt Platt (SP20)	8	Spoils	Borehole	Subsurface
BH-SA1 17.5	Shelton Abbey	17.5	Tailings	Borehole	Subsurface
BH-ET1 2	Emergency Tailings	2	Tailings	Borehole	Subsurface
BH-MP2 16	Mt Platt (SP20)	16	Spoils	Borehole	Subsurface
BH-ET1 7.5	Emergency Tailings	7.5	Tailings	Borehole	Subsurface
TP-CO4 0.3-0.4	Connary (SP31)	0.3	Spoils	Test Pit	Subsurface
TP-CO3 0.9-1.35	Connary (SP31)	0.9	Spoils	Test Pit	Subsurface

[1]   The spoil pile ID as defined by Gallagher et al., 1997 are provided in parentheses.

Analyses on a single grain of soil or a single crystal of a precipitate were accomplished using an EMP. Not only can analyses be made on particles as small as 1 micron, but the EMP also provides a visual picture of the soil at magnifications ranging from 40 to 90,000 times. The visual mode is referred to as the "backscatter mode." Information about the relative atomic number of the compounds can be obtained in the backscatter mode due to the contrast in brightness between the low atomic number compounds and the compounds with high atomic numbers. For example, arsenic and iron compounds, which have high mean atomic numbers, tend to be bright white in backscatter mode, while silica compounds, with lower mean atomic numbers, are gray and organic carbon is nearly black. Direct visual inspection of the soil also provides information on the associations, morphology, and any reaction rims on the particles, all of which provide insight into the geochemical history of the sample. Soil samples were analyzed on a JEOL 8600 Superprobe located in the Department of Geological Sciences, University of Colorado, Boulder, Colorado.

2.2.2 Results

The forms of arsenic, lead, copper, and zinc appear to be determined by:

■ The type of ore from which the mine waste was derived (i.e., supergene vs. sulfide zone and West Avoca vs. East Avoca)

■ The type of mine waste (tailings vs. spoils)

■ The depth of burial and age of the mine waste (surface sample vs. subsurface and relatively old spoils vs. newer spoils)

The buried supergene ore derived from the Cronebane Pit and now comprising Mount Platt contains a mixture of primary sulfide minerals and secondary phases. A copper sulfide mineral was found in one of the samples, which is consistent with the supergene copper minerals covellite (CuS), chalcocite (Cu_2S) or digenite (Cu_8S_9), all of which have been identified within the Cronebane Ore (Gallagher et al. 1997). The other distinctive feature of the Mount Platt samples was the relative abundance of iron oxyhydroxides. The overburden which was removed from the Cronebane area to access the ore consisted of significant gossan in the form of limonite ($FeOOH \bullet nH_2O$), goethite ($FeOOH$), and hematite (Fe_2O_3) (Gallagher et al. 1997). Plumbojarosite was also present and appears to be an important form of lead and arsenic. The presence of secondary plumbojarosite, even at a depth of 16 m (BH-MP2 16) suggests that the phase may have been formed within the oxidized portion of the ore body and represents part of the gossan cap overlying the ore.

In contrast, buried spoils derived from the sulfide zone (BH-WA1 2.55) contained metals and arsenic in the form of primary sulfides, including an iron-arsenic sulfide. According to Gallagher et al. (1997), arsenopyrite occurred throughout the Pond Lode, but was most abundant within the upper zones where concentrations reportedly reached 1 percent. Arsenopyrite was not found in any other sample, which is consistent with the rarity of the mineral in East Avoca. The buried spoils, while less oxidized than the surface spoils did contain evidence of oxidation, such as relic pyrite grains and cubic-shaped voids in quartz. However within the surface spoils, primary sulfides were rare, and when present were in the form of a remnant core within an otherwise oxidized grain. The samples from Connary showed less variation between the surface and subsurface samples, with secondary phases common in both types of sample. The reason for the lack of variation is probably due to the fact that the subsurface Connary samples were taken from test pits, which were relatively shallow (0.3-1.35 m) and the age of the Connary spoils which are much older than many of the other spoils. According to Gallagher et al. (1997), the Connary spoils are on the order of 100 years old. By contrast, many of the larger spoil piles on the site (i.e., West Avoca [SP34 and SP34B] and Mt. Platt [SP20 and SP20A]) have only existed since the 1960s to 1980s period.

In general, the tailings were less oxidized than the spoils, exhibiting abundant sulfides with sharp grain edges. The surface tailings contained a mixture of secondary phases and rare primary sulfides while the buried tailings contained metals and arsenic almost exclusively within primary sulfide minerals. There was no obvious difference between the buried Emergency Tailings and those from Shelton Abbey (no surface tailings were present in the Emergency Tailings area).

Another significant finding was that copper and zinc are abundant within the primary minerals (chalcopyrite and sphalerite) but much less abundant in the

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secondary oxyhydroxides and hydroxysulfates. On the other hand, lead and arsenic were present in high concentrations in both the primary minerals (arsenopyrite, pyrite, and anglesite) and in the secondary phases (plumbojarosite and phosphates). The implications of this finding will be discussed in the following section.

2.2.3 Discussion

The mineralogy found in the mine waste samples can be divided into two categories;

- Primary minerals
- Secondary minerals

The primary and secondary mineral forms of arsenic, lead, copper, and zinc are summarized in Table 2-7 below.

Table 2-7 Summary of the Forms of Arsenic, Lead, Copper, and Zinc

Parameter	Primary Phase(s)	Secondary Phases
Arsenic	pyrite (arsenopyrite)[1]	plumbojarosite, schwertmannite, iron oxyhydroxide, (Al-phosphates)
Lead	anglesite[2] (galena)	plumbojarosite, Al-phosphates, (schwertmannite, iron oxyhydroxide)
Copper	chalcopyrite[2], (covellite, chalcocite, etc.)	(plumbojarosite, schwertmannite, iron oxyhydroxide)
Zinc	sphalerite[2]	(plumbojarosite, schwertmannite, iron oxyhydroxide)

[1]   Phases in parenthesis were a less important form of the element than the phases which are not in parenthesis.

[2]   Most likely phase present based on the mineralogy of the ore body

The conversion of the primary phases to secondary phases is due to oxidation, either within the ore body itself (such as for the Cronebane ore) or, more commonly, within the shallower more oxygenated zones on the mine waste. The oxidation of arsenic-bearing pyrite, sphalerite, and chalcopyrite, and the dissolution of anglesite results in pore water with high concentrations of arsenic, lead, zinc, copper and sulfate. Under the low pH conditions of the pore water, the mineral plumbojarosite is stable. However, based on the EMP results, lead and arsenic are incorporated into the phase to a much greater extent than copper and zinc. The result is that arsenic and lead are removed from the pore water, while copper and zinc stay in solution, where they are eventually transported to the Avoca River. The formation of arsenic-bearing plumbojarosite explains the low mobility and bioavailability of lead and arsenic within the mine wastes, despite the high concentrations within the waste materials themselves.

2.3 Acid Generating Potential
2.3.1 Spoils

Numerous tests are currently used to evaluate the acid generating potential of mine wastes. One of the oldest and best established methods is the Acid-Base Accounting

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(ABA) method (Sobek et al. 1978). In the test, both the neutralization potential (as mg/kg calcium carbonate, $CaCO_3$) and acid generating potential (mg/kg $CaCO_3$) are determined. The neutralization potential is the amount of neutralizing bases, such as carbonate, present in the sample and is determined by titrating the sample with hydrochloric acid. The acid generating potential can be calculated using several methods, including total sulfur (determined using different methods) and pyritic sulfides. The ABA is determined by subtracting the acid generating potential from the neutralizing potential. A negative ABA indicates that the material has the potential to generate acidity. The ABA results for the spoils are presented in Table 2-8.

Table 2-8 Summary Statistics of ABA Results for the Spoils (ton $CaCO_3$/kt)[1]

	Connary		Mt Platt	East Avoca	Tigroney West			West Avoca	
	SP25	**SP31**	**SP20/20A**	**SP10**	**SP2**	**SP4**	**SP5**	**SP34**	**SP37/ 37A**
Minimum	-113	-83	-148	-65	-922	-18	-171	-42	-26
Maximum	-14	-15	-8	0	-10	-18	-18	-2	7
Mean	-70	-57	-26	-23	-283	-18	-63	-26	-12
Median	**-73**	**-64**	**-17**	**-13**	**-215**	**-18**	**-43**	**-32**	**-18**
Standard Deviation	38	32	34	29	337	N/A	55	17	17
Number of Samples	6	4	15	4	6	1	6	6	3

[1] Determined from Total Sulfur

All of the samples had some degree of acid generating potential (all values are negative). The neutralization potential was usually zero. Only 6 samples out of the 55 samples analyzed had neutralization potentials greater than zero, and these were most often buried (borehole and test pit samples). Most of the ABA median values are fairly consistent; however, a notable exception is SP2 (in the Deep Adit/Ore bins area) which had an order of magnitude more acid generating potential than for the other spoil piles.

One disadvantage of using the ABA test is that it assumes all of the dissolution reactions involved are rapid. For the dissolution of neutralizing minerals such as feldspars, the assumption is often not valid, which tends to under-predict the acid generating potential of the wastes. Therefore, a test has more recently been developed called the Net Acid Generating (NAG) test (EGI 2002). In the NAG test, hydrogen peroxide is used to oxidize any sulfides present in the sample. The acid generated, then reacts with any neutralizing minerals present in the sample within a given time frame. The NAG test uses the acid produced from the sample, which is often less aggressive than the hydrochloric acid procedure used in the ABA. However for the Avoca samples, the neutralization potential was usually zero, so it was apparently not over predicted in this case. The results for the NAG test are presented in Table 2-9.

Table 2-9 Summary Statistics of NAG Results for the Spoils (kg H$_2$SO$_4$/t)

	Connary		Mt Platt	East Avoca	Tigroney West			West Avoca	
	SP25	SP31	SP20/20A	SP10	SP2	SP4	SP5	SP34	SP37/ 37A
Minimum	0	5	3	0	7	8	8	5	0
Maximum	8	8	79	38	95	8	52	43	10
Mean	5	6	13	14	46	8	23	19	6
Median	**6**	**6**	**7**	**8**	**39**	**8**	**15**	**14**	**8**
Standard Deviation	3	2	19	17	41	N/A	18	14	5
Number of Samples	6	4	15	4	6	1	6	6	3

The NAG results are consistent with the ABA results, with SP2 having a much higher median value than for the other piles. As SP2 is very close to the Avoca River, the high acid generating potential could have an immediate impact on the river.

Another measure of the acid generating potential of a mine waste is pyritic sulfide. Because the Avoca materials generally have no neutralization potential, the sulfide content can be used to directly determine acid generating potential (acidity from jarosite is not included). The results are shown in Table 2-10.

Table 2-10 Summary Statistics of Pyritic Sulfide Results for the Spoils (kg H$_2$SO$_4$/t)

	Connary		Mt Platt	East Avoca	Tigroney West			West Avoca	
	SP25	SP31	SP20/20A	SP10	SP2	SP4	SP5	SP34	SP37/ 37A
Minimum	0.00	0.00	0.00	0.00	0.02	0.06	0.06	0.00	0.01
Maximum	0.38	0.19	1.19	0.90	15.00	0.06	1.60	1.15	0.11
Mean	0.22	0.11	0.16	0.24	3.95	0.06	0.48	0.25	0.06
Median	**0.27**	**0.12**	**0.06**	**0.02**	**2.17**	**0.06**	**0.17**	**0.07**	**0.06**
Standard Deviation	0.15	0.09	0.31	0.44	5.70	N/A	0.60	0.45	0.05
Number of Samples	6	4	15	4	6	1	6	6	3

Again, SP2 has by far the highest acid gerating potential (based on sulfide content).

2.3.2 Tailings

The acid generating potential for the tailings are similar to the spoils (with the exception of SP2).

Table 2-11 ABA, NAG, and Pyritic Sulfides within the Tailings

	Emergency Tailings			Shelton Abbey		
	ABA (t CaCO$_3$/kt)	NAG (kgH$_2$SO$_4$/t)	Pyritic Sulfide (kgH$_2$SO$_4$/t)	ABA (t CaCO$_3$/kt)	NAG (kgH$_2$SO$_4$/t)	Pyritic Sulfide (kgH$_2$SO$_4$/t)
Minimum	-1360	38	0.46	-92	45	0.88
Maximum	-27	117	21.30	-42	67	2.68
Mean	-475	66	7.52	-67	56	1.78
Median	**-39**	**42**	**0.79**	**-67**	**56**	**1.78**
Standard Deviation	766	45	11.94	N/A	N/A	N/A
Number of Samples	3	3	3	2	2	2

Given the low number of samples the differences in acid generating potential between the Emergency Tailings and Shelton Abbey are negligible.

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Section 3
Adit Discharges, Loads, and Trends

3.1 Kilmacoo Adit

The Kilmacoo adit discharge was found along the road leading northwest from Connary Cross Roads (Figure 3-1).

Figure 3-1 Kilmacoo Adit discharge along the road that leads northwest from Connary Cross Roads (July 2007).

The portal site was not discovered, but is believed to be buried. The elevated metals concentrations and fairly low pH (Table 3-1) suggest that the discharge is mine related.

Table 3-1 Loading for the Kilmacoo Adit (July 2007)

Parameter	Concentration (µg/L)	Load (kg/day)[1]
Iron	461	0.02
Aluminum	4,017	0.13
Copper	311	0.01
Zinc	2,655	0.09
Lead	2,176	0.07
Sulfate	63,000	2.05
pH (su)	4.62	—

[1]   Based on a flow rate of 32,618 L/day

Lead concentrations are particularly high. However, the water flows to the northwest approximately parallel to the Avoca River, toward the Avonmore. The water likely infiltrates to groundwater before reaching the Avonmore, which is located about 3 km away. In addition, the overall metals loads within the drainage are low (Table 3-1) and would have little impact on the Avonmore should the flow migrate that far. Therefore, the Kilmacoo discharge should have little or no effect on the water quality of the Avoca River.

3.2 Madam Butler's Adit

Madam Butler's adit at one time flowed into Sulfur Brook and had a noticeable impact on the water quality of the Avoca River. However, as discussed in the Phase 1 CSM, the discharge has since been piped to an area where the water does not directly discharge to surface water. Some reports indicated that the Madam Butler adit water was being used to supply a man-made pond excavated at the site of a newly constructed house. However, analyses (called "valve box seep") suggest that the water is not consistent with an adit discharge (see Table 3-2).

Table 3-2 Analyses for the Valve Box Seep (August 4, 2007)

Parameter	Concentration (µg/L)
Iron	<2
Aluminum	69
Copper	12
Zinc	115
Lead	8
Sulfate	N/A[1]
pH (su)	5.82

[1]   Not analyzed

While the exact location of the Madam Butler's Adit discharge is unknown, it is believed that the water infiltrates through soil to groundwater, which would have an indirect effect on the Avoca River via groundwater gains by the river (see Sections 4 and 5 of this report for more details).

3.3 Intermediate Adit

The Intermediate Adit (also called Cronebane Intermediate Adit) flows from an opening in the southeast wall of the East Avoca Pit and across the bottom of the pit

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forming a lake on the southwest end (Figure 3-2). Analyses indicate that the quality of the pit lake water is virtually identical to the Intermediate Adit (see attached Data Report), suggesting that other inputs to the pit pond are minimal.

Figure 3-2 East Avoca Pit, showing the Intermediate Adit discharge flowing into the pit pond (April 2007).

The metals loading of the Intermediate adit was by far the highest of any of the "mine site" adit discharges (see Tables 3-3 and 3-4).

Table 3-3 Water Quality Data Over Time for the Intermediate Adit

Parameter[2]	Result – November 1993[1] (µg/L)	Result – July 2007 (µg/L)
Iron	2,311,000	107,700
Aluminum	2,153,000	71,360
Copper	53,000	3,198
Zinc	440,000	33,030
Lead	800	1,352
Sulfate	22,000,000	799,000
pH (su)	2.2	4.31

[1] Flynn (1994)
[2] Units in µg/L unless noted otherwise. All metals analyses for July 2007 are dissolved.

Table 3-4 Loading for the Intermediate Adit over Time

Parameter[2]	Load – November 1993[1] (kg/day)	Load – July 2007[1] (kg/day)
Iron	1702	79.3
Aluminum	1586	38.9
Copper	39	2.36
Zinc	324	24.3
Lead	0.60	1.00
Sulfate	16,202	588

[1]   Based on a flow rate of 736,445 L/day measured in July 2007

The flow measured in July 2007 (736,445 L/day) was about half of the flow of the Deep Adit, which is believed to be the ultimate destination of the water from the Intermediate Adit. The recent loads, shown in the second column of Table 3-4, shows that the metals contributed to the Deep Adit discharge are also significant (see Section 3.6 of this report for more details).

A comparison of the November 1993 data with July 2007 indicate about an order of magnitude decrease in metals concentrations and loads in the discharge over 14 years. The reason for the decrease is unknown, but may be related to the types of analyses performed in 1993 vs. 1997. The analyses from November 1993 are not designated as either dissolved concentrations (filtered samples) or total (unfiltered samples). The 1993 analyses may be total analyses, which would include the particulates suspended within the water. The brown color of the water suggests that suspended particles are present in the water (Figure 3-2). However, a comparison of the total vs. dissolved concentrations indicates that many of the parameters are about the same for the total and dissolved analyses (i.e. aluminum, copper, cadmium, lead, etc.) while others such as iron about twice as high for the total analysis (but not an order of magnitude higher). A seasonal variation is also possible. Often, adit discharge concentrations are higher during high flow due to flushing of metals from the mine workings. The November 2007 results for the Cronebane Shallow Adit (presented below) suggest that seasonal variations from low flow to high flow can result in the observed increases in metals concentrations.

3.4 Cronebane Shallow

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 (Figure 3-3) 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).

Figure 3-3 Cronebane Shallow Adit discharge (April 2007).

The metals concentrations in the Cronebane Shallow discharge are nearly as high as for the Intermediate Adit (Table 3-5), but the flow is about 40 times less (18,347 L/day).

Table 3-5 Water Quality Data Over Time for the Cronebane Shallow Adit

Parameter[2]	Result – November 1993[1] (µg/L)	Result – July 2007[2] (µg/L)	Result – November 2007[2] (µg/L)
Iron	410,000	22,640	193,000
Aluminum	493,000	36,700	344,900
Copper	45,000	8,921	9,218
Zinc	182,000	85,900	110,200
Lead	5,100	1,334	1,301
Sulfate	6,350,000	3,215,000	3,691,000
pH (su)	2.3	3.92	—

[1]   Flynn (1994)
[2]   Units in µg/L unless noted otherwise. Metals are dissolved concentrations.

Due to the low flows, the metals loadings are minimal, as shown in the second column of Table 3-6.

Table 3-6 Loading for the Cronebane Shallow Adit Over Time

Parameter[2]	Load – November 1993[1] (kg/day)	Load – July 2007 (kg/day)	Load – November 2007[1] (kg/day)
Iron	7.52	0.41	3.52
Aluminum	9.05	0.67	6.33
Copper	0.83	0.16	0.17
Zinc	3.34	1.57	2.02
Lead	0.09	0.02	6.02
Sulfate	117	59	68

[1]   Based on a flow rate of 18,347 L/day measured in July 2007

A comparison of the November 1993 concentrations to those for July 2007 shows a similar order of magnitude decrease as for the Intermediate adit. However, in this case, data are available for November 2007 (fourth column, Table 3-5). With the exception of copper, the concentrations in November 1993 and November 2007 are of the same order of magnitude. These results suggest that the Intermediate Adit would have similar concentrations in November 2007 as for November 1993.

3.5 Wood Adit

The Wood Adit is located in the wood just west of the East Avoca Pit within the grounds of the Castlehoward estate. The adit appears to have had flowing water at one time, as there is a gulley carved into the ground adjacent to the opening. However, at the time of the sampling activities in July-August 2007 only standing water was present and was inaccessible.

3.6 Deep Adit

The Deep Adit is located northeast of Whites Bridge and is the main mine drainage for East Avoca (Figure 3-4). The water flows from the portal into a ditch that runs semi-parallel to the Avoca for about 60 m before turning southwest and flowing into the river. The flow of the Deep Adit in July 2007 was about 1,390,000 L/day. Dissolved concentrations for the Deep Adit are presented in Table 3-7 for analyses performed in February 2007(GSI), June 2007 (GSI), July 2007 (CDM), November 2007 (CDM), and February 2008 (CDM).

Figure 3-4 Deep Adit Discharge (April 2007).

Table 3-7 Loading for the Deep Adit Near the Portal

Parameter	July 2007[1] Conc (µg/L)	July 2007[1] Load (kg/day)	June 2007[2] Conc (µg/L)	June 2007[2] Load (kg/day)	February 2007[3] Conc (µg/L)	February 2007[3] Load (kg/day)	November 2007[4] Conc (µg/L)	November 2007[4] Load (kg/day)	February 2008[5] Conc (µg/L)	February 2008[5] Load (kg/day)
Iron	72,340	101	19,200	16.8	24,750	52	49,220	68	21,080	44
Aluminum	102,600	143	97,670	116	110,200	229	84,020	117	131,800	274
Copper	845	1.18	1,359	1.6	1,829	3.81	1,133	1.6	1,380	2.87
Zinc	47,620	66	48,070	57	37,950	79	48,630	68	48,860	102
Lead	1,717	2.39	1,434	2.2	1,483	3.09	1,339	1.9	2,247	4.68
Sulfate	—	—	1,111,000	1,315	1,205,000	2,509	963,000	1,339	1,047,000	2,180
pH (su)	—	—	3.06	—	3.33	—	—	—	—	—

[1] Based on a flow rate of 1,390,082 L/day
[2] Based on a flow rate of 1,183,680 L/day (collected by GSI)
[3] Based on a flow rate of 2,082,240 L/day (collected by GSI)
[4] Load assumes a flow rate of 1,390,082 L/day (same as July 2007)
[5] Load assumes a flow rate of 2,082,240 L/day (same as February 2007)

The flow was about a third higher in February 2007 than in July 2007, while the concentrations were generally similar (except for iron which was lower in February). The result is that the loadings are about a third higher. The concentrations for February 2008 were similar to those for February 2007, resulting in similar loading.

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A comparison of the July 2007 loadings for the Intermediate Adit to those for the Deep Adit show that the Intermediate Adit discharge makes up a very significant proportion of the loads. For example, 78.5 percent of the iron, 27.2 percent of the aluminum, 36.8 percent of the zinc, and 41.8 percent of the lead loads within the Deep Adit discharge are contributed by the Intermediate Adit. The copper contribution was 200 percent (copper loads were twice as high in the Intermediate Adit as for the Deep Adit), suggesting that copper is being attenuated within the workings.

The concentration trends for the Deep Adit (like the other adits) appear to have a strong seasonal component. Figure 3-5 shows the copper, zinc, and iron concentration trends from 1993 through 2007.
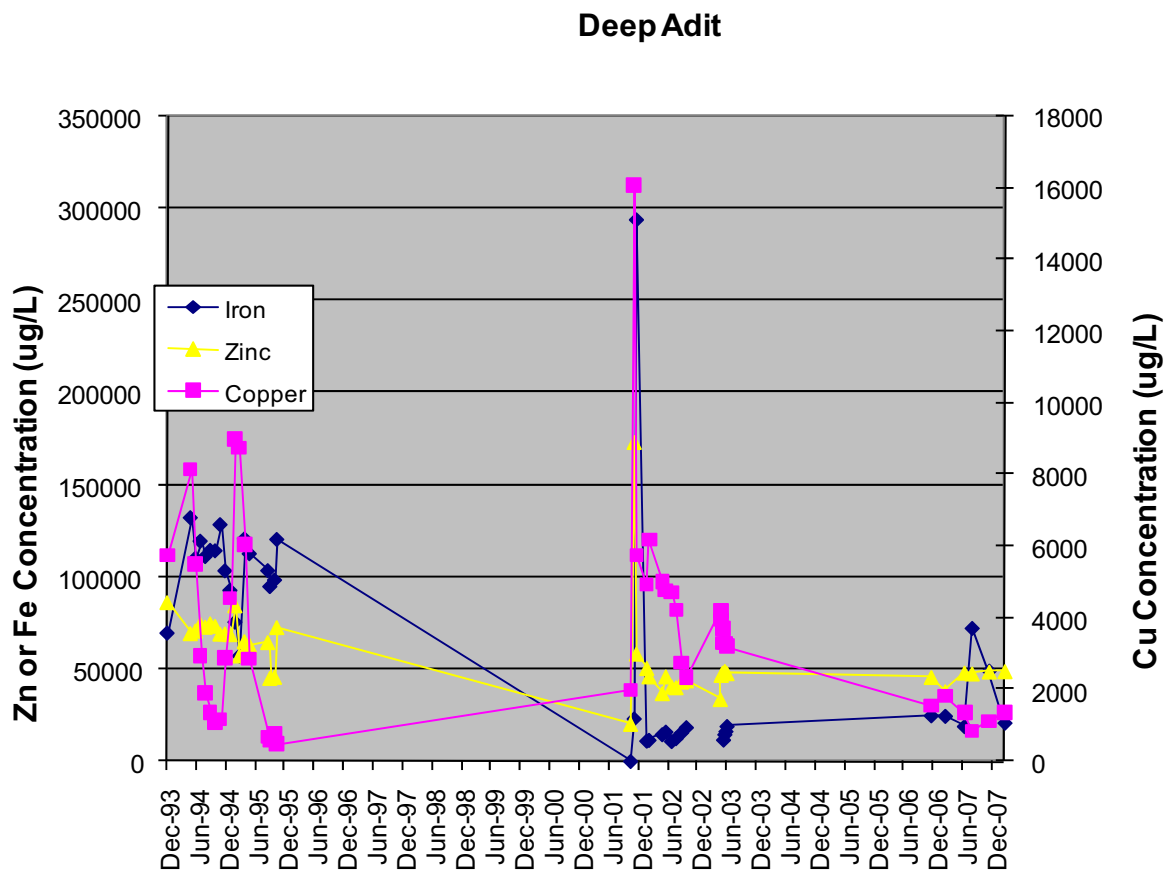
Deep Adit

Figure 3-5 Concentration trends for copper, zinc, and iron within the Deep Adit discharge 1993-2007.

Although a general declining trend over time may be inferred, in general this is obscured by the significant seasonal fluctuations, as shown by the spikes which occur within a given year (especially 2001). The implication is that calculations used for sizing water treatment systems should be performed to take into account extreme seasonal fluctuations.

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3.7 Road Adit

The Road Adit is located adjacent to Rathdrum Road at the base of the County Wicklow landfill (formerly the Pond Lode Pit). The concentrations and loads for February and July 2007 are shown in Table 3-8.

Table 3-8 Loading for the Road Adit Near the Portal

Parameter	July 2007[1]		February 2007[2]		June 2007[3]		February 2008[4]	
	Conc (µg/L)	Load (kg/day)	Conc (µg/L)	Load (kg/day)	Conc (µg/L)	Load (kg/day)	Conc (µg/L)	Load (kg/day)
Iron	150,700	252	131,500	299	101,300	117	85,390	194
Aluminum	20,930	35	20,450	46	17,600	20	28,520	65
Copper	268	0.45	361	0.82	230	0.27	309	0.70
Zinc	10,950	18	37,950	86	10,370	12	11,060	25
Lead	308	0.51	384	0.87	289	0.33	366	0.83
Sulfate	—	—	1,401,000	3,184	1,652,000	1,913	2,171,000	4,933
pH (su)	—	—	3.93	—	3.80	—	—	—

[1] Based on a flow rate of 1,670,880 L/day
[2] Based on a flow rate of 2,272,320 L/day (collected by GSI)
[3] Based on a flow rate of 1,157,760 (collected by GSI)
[4] Load assumes a flow rate of 2,272,320 L/day (same as February 2007)

The results are similar to those for the Deep Adit, in that the concentrations for February 2007 and July 2007 were similar (except for zinc, which was about three times higher in February 2007 than in July 2007). The February 2007 flows were about a fourth higher in February than in July. The February 2008 concentrations were very consistent with those for July 2007, except iron concentrations were lower in February 2008.

The trends in metals concentrations for the Road Adit between 1994 and 2007 are shown in Figure 3-6. Again, there appears to be a downward trend over the years, but this is overshadowed by seasonal fluctuations.
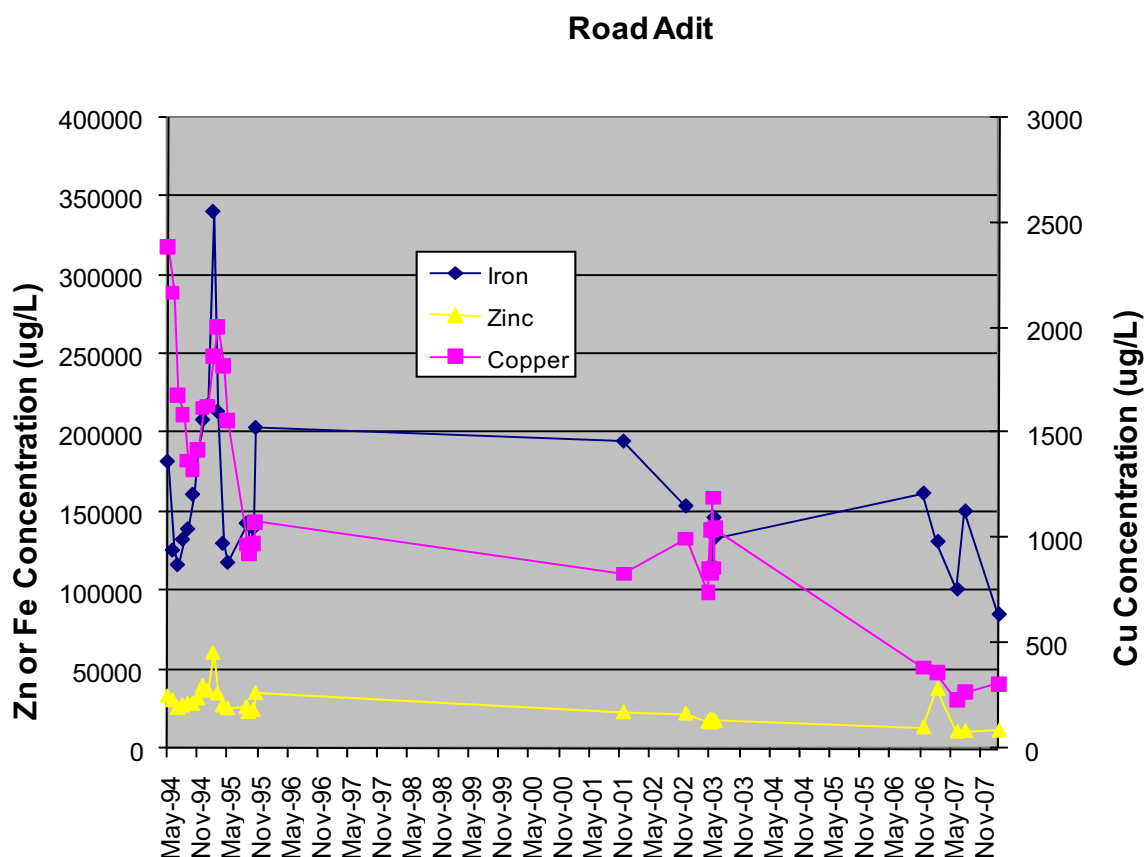
Road Adit

Figure 3-6 Concentration trends for copper, zinc, and iron within the Road Adit discharge 1993-2007.

3.8 Ballygahan Adit

The Ballygahan Adit discharges through a 4-inch pipe directly into the Avoca River just north of the County Wicklow yard. The concentrations and loads (using a field-estimated flow) are presented in Table 3-9.

Table 3-9 Loading for the Ballygahan Adit (July 2007)

Parameter	Concentration (µg/L)	Load (kg/day)
Iron	10,800	0.06
Aluminum	99,110	0.54
Copper	5,237	0.03
Zinc	21,680	0.12
Lead	237	0.001
Sulfate	2,072,000	11.3
pH (su)	3.80	—

[1]   Based on a flow rate of 5,468 L/day

In general, the loads are insignificant, as will be discussed in more detail in Section 5.

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3.9 Spa Adit

The Spa Adit is located in West Avoca on a hillside about 150 m northwest of (and about 40 m above) the County Wicklow recycling center. The discharge exits from a break in a pipe within what appears to be a bulkheaded adit (Figure 3-7). In July 2007, the discharge was observed soaking into the ground, but a gulley formed beneath the pipe suggests that at some time in the past surface flow was present.

Figure 3-7 Spa Adit showing bulkhead and discharge exiting the break in the pipe (August, 2007).

The concentrations and loads for the Spa Adit are presented in Table 3-10.

Table 3-10 Loading for the Spa Adit (July 2007)

Parameter	Concentration (µg/L)	Load (kg/day)
Iron	15,420	0.03
Aluminum	21,730	0.04
Copper	8,390	0.02
Zinc	14,300	0.03
Lead	102	0.0002
Sulfate	2,044,000	3.69
pH (su)	3.50	—

1   Based on a flow rate of 1,806 L/day

Because 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.

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Section 4
Hydrogeology and Water Balance

4.1 Hydrological Summary

The Avoca River catchment, shown in Figure 4-1, drains eastward from the Wicklow Mountains to Arklow on the coast. It covers an area of approximately 645.6 km², and includes the Avonbeg and Avonmore Rivers, which form the Avoca River at their confluence at the Meeting of the Waters, approximately 1.5 km north of the mine area. The Avoca River subsequently merges with the Aughrim tributary about 5 km to the south of the mine area. Several tributaries empty into the Avoca River in the vicinity of the mine area. The important tributaries include Vale View, Red Road, and Sulphur Brook.

Topography of the Avoca catchment is characterised by steep-sided river valleys and undulating upland areas. Land use is dominated by forestry and blanket bogs in the upper parts of the Avoca catchment and pastures in the lower reaches. Within the Avoca mining area, the abandoned mines are located along a NNW-SSE trending topographic ridge surrounded by flat-lying pasture.

4.1.1 Precipitation

There is a significant rainfall gradient from west to east across the catchment. Median annual rainfall (1961-1990) ranges from greater than 2,000 mm/yr in the mountains to 990 mm/yr on the coast. Median annual rainfall at the mine site is approximately 1,100 mm/yr, while potential evapotranspiration (PE) is estimated to be approximately 540 mm/yr (Met Eireann 2007).

4.1.2 River Flow

There are no stream flow gauges on the Avoca River near the mine site. The nearest stream gauge with

Figure 4-1 The Avoca Catchment

good rating curves is Station 10002 (Rathdrum) on the Avonmore River, approximately 7 km to the north (see Figure 4-1). The flow record of Station 10002, reproduced in Figure 4-2, shows measured flows ranging from >40 m³/s (following major rainfall events) to less than 1-2 m³/s during low-flow conditions (mostly in late summer).
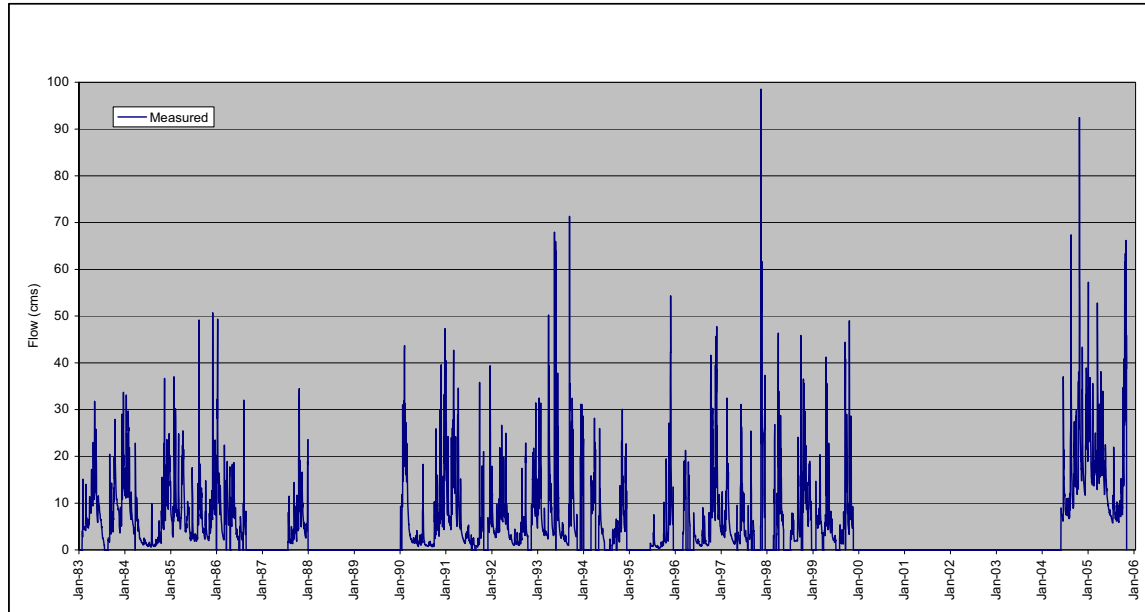
Figure 4-2 Measured Flow at Station 10002 on the Avonmore River

While a permanent gauging station does not exist at the Avoca mine site, flows were estimated from rainfall-runoff modeling as part of the Eastern River Basin District project (CDM 2007). Calibrating initially to measured flows at Station 10002 on the Avonmore River and Station 10028 on the Aughrim River, the estimated flow in cms (cubic metres per second) just downstream of the Avoca mine site for the period 1993–2005 is depicted in Figure 4-3. The wide range of simulated flow conditions implies a rapid response to rainfall which in turn is a function of the physical characteristics of the Avoca catchment (high rainfall, steep topography, this soil cover, low permeability bedrock). The estimated flow for the period on Figure 4-2 ranged from 1.12 to 144.5 cms with a mean of 15.6 cms. The estimated Q95 (flow exceeded 95 percent of the time) was 0.97 cms.

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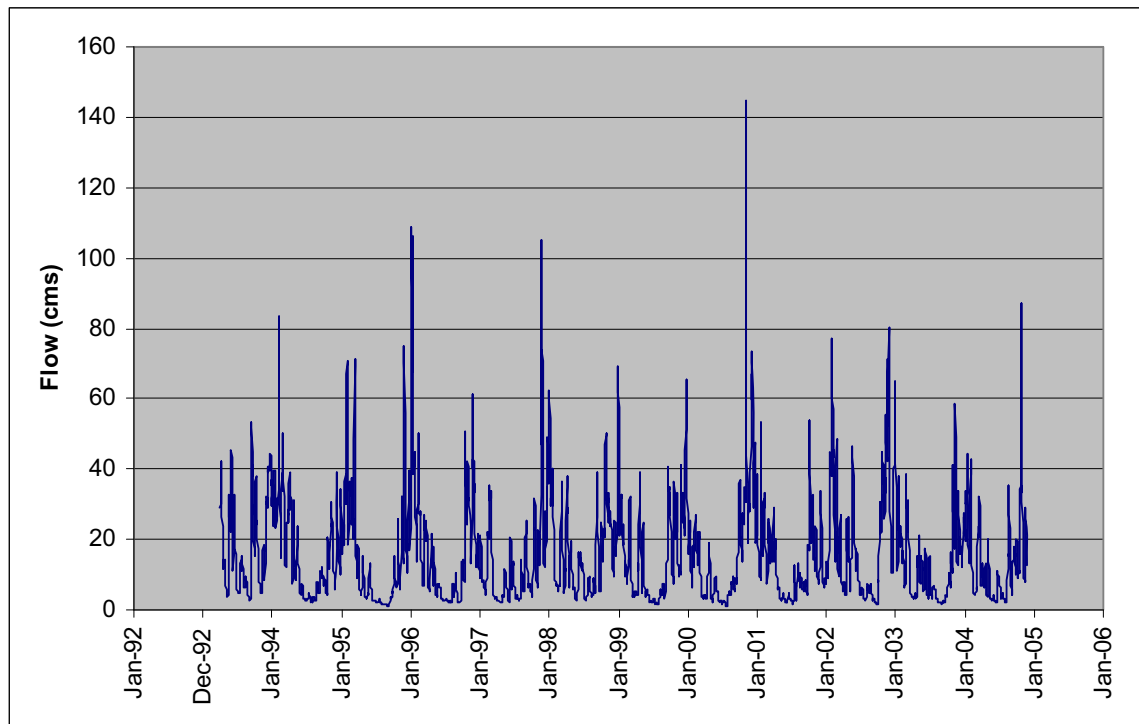
Figure 4-3 Net Simulated Flow of the Avoca River Near the Avoca Mines

Although there are no flow recorders on the Avoca River near the mine area, there is a staff gauge at the southern end of County Wicklow's maintenance yard, where river height is recorded manually (mostly) on a daily basis. Figure 4-4 shows the recorded river stage height between June 2007 and late-January 2008.

There is no rating curve for the staff gauge, so the recorded stage heights cannot be converted to river flows, but the graph nonetheless demonstrates: a) the flashy nature and recession characteristics of the Avoca River, and b) shows a considerable increase in stage height in January 2008 compared to the autumn months of 2007. In addition, during the field program (July 27-August 3, 2007) when the tracer and flow studies and sampling were performed, stage height was approximately 1.5 times higher than in June 2007.

4.2 Conceptual Hydrogeologic Model

The Avoca mine site is underlain by Ordovician metasediments, mainly dark grey slates and rhyolitic volcanics. 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.
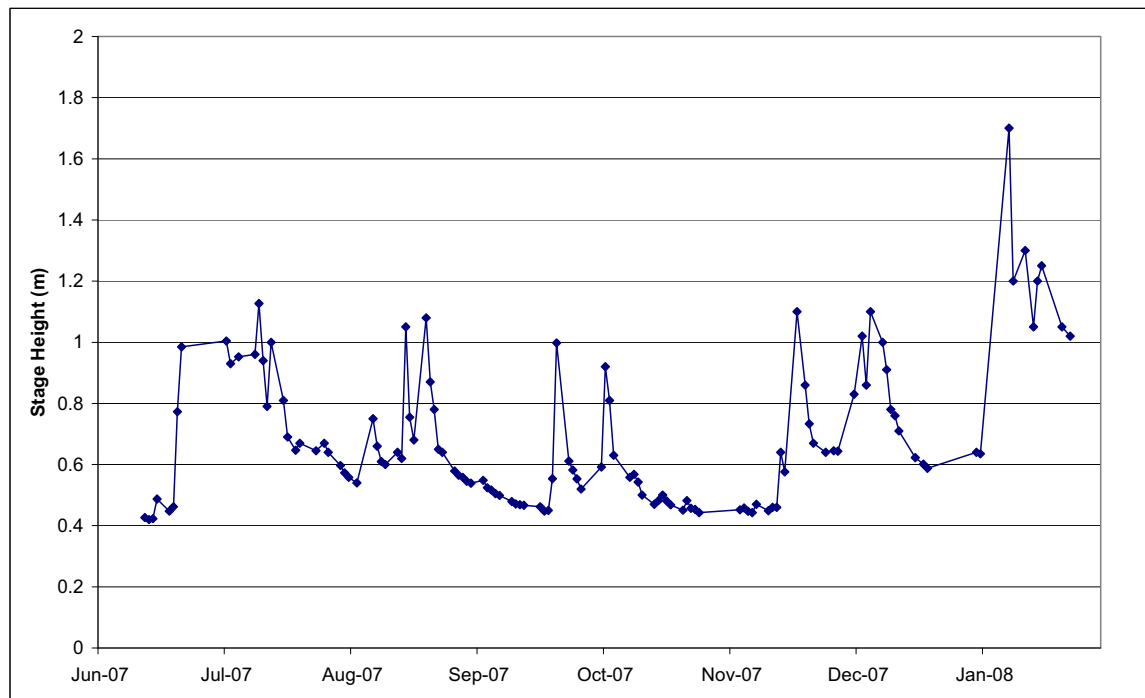
Figure 4-4 Stage Height of the Avoca River at the County Wicklow Maintenance Yard

In terms of groundwater yield, the GSI classifies the bedrock in the Avoca mines area as poorly productive, viz:

- Pl - Poor aquifer, generally unproductive except for local zones
- Pu - Poor aquifer, generally unproductive

Movement of water, and groundwater pathways specifically, are difficult to decipher in this hydrogeological setting due to a lack of monitoring wells and paucity of groundwater data in the Avoca area. However, the following section explores potential pathways based on observations of similar rock types elsewhere in Ireland and specific knowledge of groundwater conditions in other parts of county Wicklow.

Water movement in poorly productive bedrock is broken down into three primary pathways:

- Surface runoff (overland flow)
- "Interflow" (flow in subsoils and/or along the top of bedrock)
- "Deep" Groundwater

4.2.1 Surface Runoff

Surface drainage follows topography. 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). The water that collects within the pits infiltrates into the bedrock and underground systems of the mine workings or

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flows directly into underground workings. Surface runoff that is not captured by the pits flows overland towards other localised topographic depressions (where it partly infiltrates) and the Avoca River valley (where it discharges into the Avoca River).

4.2.2 "Interflow"

"Interflow" is defined in this report as the flow that takes place at the very top of bedrock, near or at the contact with the overlying subsoils. The interface between the top of bedrock and subsoil materials is chemically weathered and comprises a dense network of shallow fractures which is (conceptually) more interconnected than fractures at greater depth. As such, "interflow" represents a transition zone between subsoils and underlying bedrock. Interflow in the mine area is typically captured by the open pits or underground workings. 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. Outcrops in the Avoca mines area suggest the transition zone is rubbly (broken up), partly as a result of weathering and partly as a result of the scouring effect of ice sheets during the last glaciation period. The shallow fractures at the top of bedrock are locally infilled with clayey sediments, which may be derived from overlying subsoils or be due to chemical weathering of the bedrock. The infilling imparts local-scale heterogeneity to the transition zone.

4.2.3 "Deep" Groundwater

Terminology aside, "deep" groundwater is considered to be groundwater flow in bedrock proper, beneath the transition zone. "Deep" groundwater flow at Avoca occurs in discrete fractures or fracture zones which represent zones of enhanced permeability. Varying degrees of rock deformation can be observed in the open pits on both side of the Avoca River, and these deformations influence bedrock permeability. Bedrock is deformed by both folding and faulting; both of which are associated with fracturing and permeability development. Thus, "deep" groundwater flow is heterogeneous, following lines of structural geologic weakness. 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.

4.3 Recharge and Groundwater Flow

Recharge from rainfall to bedrock is expected to occur quickly as a function of the limited soil and subsoil thicknesses in upland areas. Bedrock has a finite ability to accept recharge on account of its low storage and transmissive properties. A maximum recharge limit or 'cap' of approximately 100 mm/yr has been suggested for areas underlain by poorly productive rocks (GSI, 2005; National Working Group on Groundwater, 2005; Moe et al., 2008).

Recharge that is rejected from the deeper bedrock will either flow along the shallow fractured zone at the top of bedrock (transition zone) or as surface runoff when the

recharge capacity of the transition zone is reached. The weathered nature of shallow bedrock in the transition zone would impart heterogeneity to shallow groundwater occurrence and flow.

The present distribution of wells in the Avoca area does not allow for a precise definition of groundwater flow directions in deep bedrock, but in concept, groundwater flows from upland areas towards the Avoca River, generally following topography. In the mines area, the underground shafts serve as hydraulic sinks, whereby natural ground water flow is locally deflected and captured by the underground mine workings. The mine workings therefore act as preferential pathways for the captured water, emerging in the mine adits in the Avoca valley.

Albeit of a preliminary nature, the groundwater flow map presented by Flynn (1996), reproduced in Figure 4-5, is a reasonable depiction of the potentiometric surface in the mines area. Most of the wells identified, surveyed and measured are believed to be installed in shallow bedrock, to 30 metres depth, though some wells may be deeper. Flow gradients in bedrock are steep, reflecting the steep topography of the mines area.

Drilling data from Avoca, as reported by O'Suilleabhain (1996), indicates highly fractured rock to depths of 20-30 m. Water levels from bedrock wells in upland areas in 1995 were measured 5-15 metres below ground surface. Pumping tests carried out in nearby supply wells at Redcross and Roundwood (in the Maulin and Kilmacrea Formations, respectively) indicate
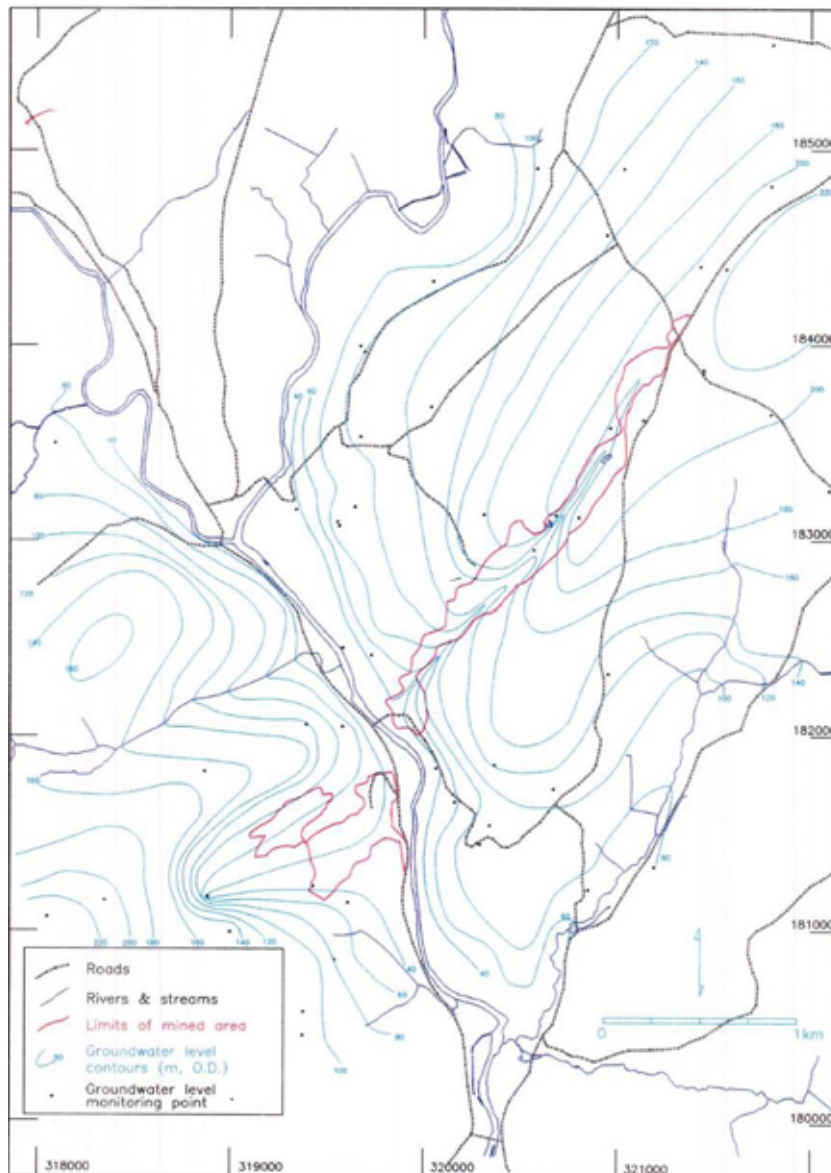
Figure 4-5 Potentiometric Surface Map of Avoca, 1994/1995 (from Flynn, 1996)

transmissivity values of approximately 30 m²/day (Woods 2003), although these wells represent locally productive zones (fault zones of Pl aquifers). The bulk transmissivity of deep bedrock not affected by faults and fracture zones in the Avoca area would be expected to be significantly lower than 30 m²/day.

Groundwater flow near the top of bedrock in the higher permeability transition zone is also towards the Avoca river valley. Flow gradients would be equally steep (approximating topography) and would also be influenced by the mine shafts and pits. Evidence of shallow groundwater seeps can be seen on the exposed faces of the open pits (e.g., at Cronebane). Chemical weathering and staining above the seeps indicate where historically the water table would have been prior to mining. As hydraulic sinks, the underground mine workings divert groundwater flow, and under present conditions, the mines have a zone of contribution away from their geometric positions. The zone of contribution would be expected to be marginally smaller for the transition zone (in shallow bedrock) than the deeper bedrock zone, as the transition zone mostly occurs above the levels of the mine workings.

Recharge to, and water level fluctuations within, the transition zone would be more rapid than in deep bedrock. Depending on location and climatic conditions, the transition zone of shallow bedrock may be dry for parts of the year, notably on the steeper valley slopes.

Similarly, depending on location and local hydrogeology, it is expected that the transition zone may be hydraulically separated from deeper groundwater, in effect acting as a perched groundwater layer above the main water table in deeper bedrock.

Given the generally low-permeability characteristics of bedrock at Avoca, regional groundwater flow systems have not developed. Flow systems are short and localised, generally less than 1 km in length between recharge (upland) and discharge areas (river/streams).

4.4 Groundwater/Surface Water Interaction

In the Avoca river valley, deep groundwater and flow along the transition zone discharges towards the Avoca River and its tributaries. At several locations along the valley sides, surface seeps and springs occur where groundwater tables intersect topography. Several such seeps and springs have been mapped on both sides of the Avoca River and sampled for chemical analysis (see attached Data Report, Section 2.3). The springs and seeps ultimately discharge to the Avoca River (as overland flow) or re-infiltrate into the ground along the way.

The mining spoil areas represent a particular hydrological setting. A significant proportion of rainfall will run off the spoil heaps to low-lying spots due in part to their low-permeability characteristics. Exposed cross-sections on Mt. Platt show layering of waste materials. Water that infiltrates will accumulate above low-permeability layers and seep laterally outwards, following paths of least resistance. At

the Shelton Abbey Tailings, a water level of 7 metres was measured in April 2007 in one existing piezometer located at the edge and close to the top of the berm. This implies that perched water beneath the dam is seeping out along the face of the dam. Such seeps (which reportedly also occur on Mt. Platt) are lost through evapotranspiration (e.g., uptake by plants), follow surface water drainage courses, or infiltrate further into bedrock.

Deeper groundwater (including interflow) not captured by the underground waorkings discharges directly to alluvial sediments along the river valley. The Avoca River valley consists of alluvial sediments and glacial till overlying bedrock. The alluvium is up to 20 metres thick in East Avoca near the Deep Adit spoils area and up to 30 metres thick in West Avoca near the Emergency Tailings area and downstream from the Ballymurtagh Landfill. At the Shelton Abbey tailings dam, 12 metres of alluvium was encountered during recent drilling, without reaching bedrock. Similar indications of alluvial sediment depth are reported from Ballymurtagh Landfill investigations (RPS, 2006) and trial well drilling near Woodenbridge (White Young Green 2004 and 2005).

The alluvial sediments are of fluvial origin; i.e., they were deposited by the Avoca River and represent floodplain deposits. The width of the alluvial sediments is constrained by the U-shape shape of the Avoca valley, ranging from approximately 100 metres at the Deep Adit to several hundred metres at Woodenbridge.

The alluvial sediments are consistently coarse grained, consisting mainly of coarse, sub-angular sands and gravels with occasional bands or thin layers of fine silts and clays. Large, sub-angular cobbles are lodged throughout the alluvial deposits, at all depths. The alluvium partly represents reworked boulder clay (till). The cobbles comprise shale, slate, rhyolite, and granitic rocks (the latter transported from the Leinster granite in the core of the Wicklow mountains at higher elevation).

Drilling conducted as part of this study suggests that a potentially significant chemical change takes place at a depth of approximately 16-18 metres in the Deep Adit spoil and Emergency Tailings areas. Above these depths, alluvial sediments tend to carry a brown/orange colour, while below this depth, the alluvial sediments are distinctly grey. A silt/clay layer was encountered at both locations at the indicated depth.

In addition to the existing wells drilled for Ballymurtagh Landfill monitoring purposes, six additional wells were installed in the alluvium during this study, as follows:

- Two nested wells in the Emergency Tailings area, downgradient of the West Avoca pit and slightly sidegradient of the Ballymurtagh Landfill (MWET1 and MWET2)

- Two nested wells in the Tigroney West spoil area near the Deep Adit (MWDA1 and MWDA2)

- One shallow well upgradient of the Deep Adit area, near the eastern margin of the alluvial sediments (MWPF1)

- One shallow well immediately adjacent to, and downgradient of, the tailings dam at Shelton Abbey (MWSA2)

The well locations are shown in Figures 4-1b and 4-1c of the attached Data Report. The well construction diagrams are included in Appendix C of the attached Data Report.

The primary purposes of installing the six additional monitoring wells were to:

- Explore the hydraulic relationship between the alluvial aquifer and the river

- Determine the water quality immediately beneath potentially significant groundwater contaminant sources (Deep Adit spoils, Emergency Tailings, Shelton Abbey Tailings Dam)

- Explore the thickness and nature of the alluvial sediments beneath the mentioned potential source areas

The well MWPF1 was installed to test groundwater quality just upgradient of the East Avoca mines area, to try and bracket the northerly extent of potentially contaminated groundwater.

Drilling that penetrated the alluvium encountered weathered schist/slate bedrock. Weathering was apparent from observations of drill cuttings and intervals of "softer rock" reported by the driller and recorded on the drill logs.

No pumping tests were carried out in the new wells installed as part of this study. The alluvial sediments were sufficiently permeable to render falling and rising head tests meaningless. Pumping testing of alluvial trial wells near Woodenbridge and Shelton Abbey (for the Arklow Water Supply Scheme) indicate reported individual "sustainable" well yields ranging from approximately 600 m^3/day to 2,000 m^3/day (White Young Green 2004).

Each of the new wells were fitted with automatic pressure transducers and loggers in late November 2007. Figure 4-6 shows the recorded data between December 17, 2007 and February 20, 2008 for the six wells. There is a significant hydrological (rainfall) event between January 10-20, 2008 which resulted in groundwater levels rising between 0.4–0.8 metres, depending on distance from the river and degree of hydraulic connection to the river. Figure 4-7 shows a corresponding 1.1 metre rise in river stage at the County Wicklow maintenance yard, along with the measured response in wells at the Emergency Tailings (wells closest to the staff gauge). The Avoca River has an immediate and measurable impact on groundwater levels in the alluvial sediments in the mines area. The degree of hydraulic communication between the river and

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groundwater is of primary importance in reviewing potential contaminant loads to the river from diffuse groundwater flow.

Interestingly, from Figure 4-6, the data suggest an upward hydraulic gradient between wells ET1 (shallow alluvium) and ET2 (deep alluvium). The two wells are separated by a fine silt/clay layer at approximately 16 metres depth, which could act as a confining layer to ET2. The hydraulic response to rainfall and river stage is more muted in ET1 than in ET2.

The same relationship between shallow and deep wells does not hold true for another cluster of wells, GW1/05 and GW2/05, which are located just downgradient of the Ballymurtagh landfill, closer to the western alluvial margin, and approximately 95 metres to the northeast of the ET1/ET2 well cluster. The GW1/05 well is the deeper of the two wells and is screened in bedrock (reportedly a dark grey slate), whereas the GW2/05 well is a shallow well screened across the water table in the alluvial aquifer (RPS, 2007). The two wells were installed in the spring of 2005, and Figure 4-8 summarises the measured water levels collected for County Wicklow's landfill monitoring purposes. From Figure 4-8, there is a downward gradient between the alluvial well and top of bedrock at this location, but given the juxtaposition of bedrock against alluvium at the western margin of the alluvial aquifer, flux from bedrock is inferred to discharge into the alluvial aquifer at depth, similar to the situation in the Deep Adit spoil area.

The water level data measured to date from the existing and new wells point to a complex relationship between bedrock, the alluvial aquifer, and the Avoca River. Where a positive hydraulic gradient from the alluvial aquifer to the river predominates (i.e., the head in the aquifer is higher than in the river), the Avoca River is a net gaining river. In this scenario, there is greater probability that diffuse groundwater pollutants will contribute to the contaminant loading of the river.

Conversely, where a negative gradient from the river to the alluvial aquifer predominates (i.e., the head in the aquifer is lower than in the river), the Avoca River is a net losing river. In this scenario, river water will flow into the alluvial sediments, and thereby influence (dilute) groundwater concentrations.

Whether the river gains or loses water is a function of many factors, including:

- Rainfall and river stage (with time)

- Characteristics of river-bed and riverbank sediments (low/high permeability)

- River bank elevation (exposure of river bank along river's edge)

- Presence and/or exposure of (alluvial) flood plain deposits, facilitating groundwater recharge

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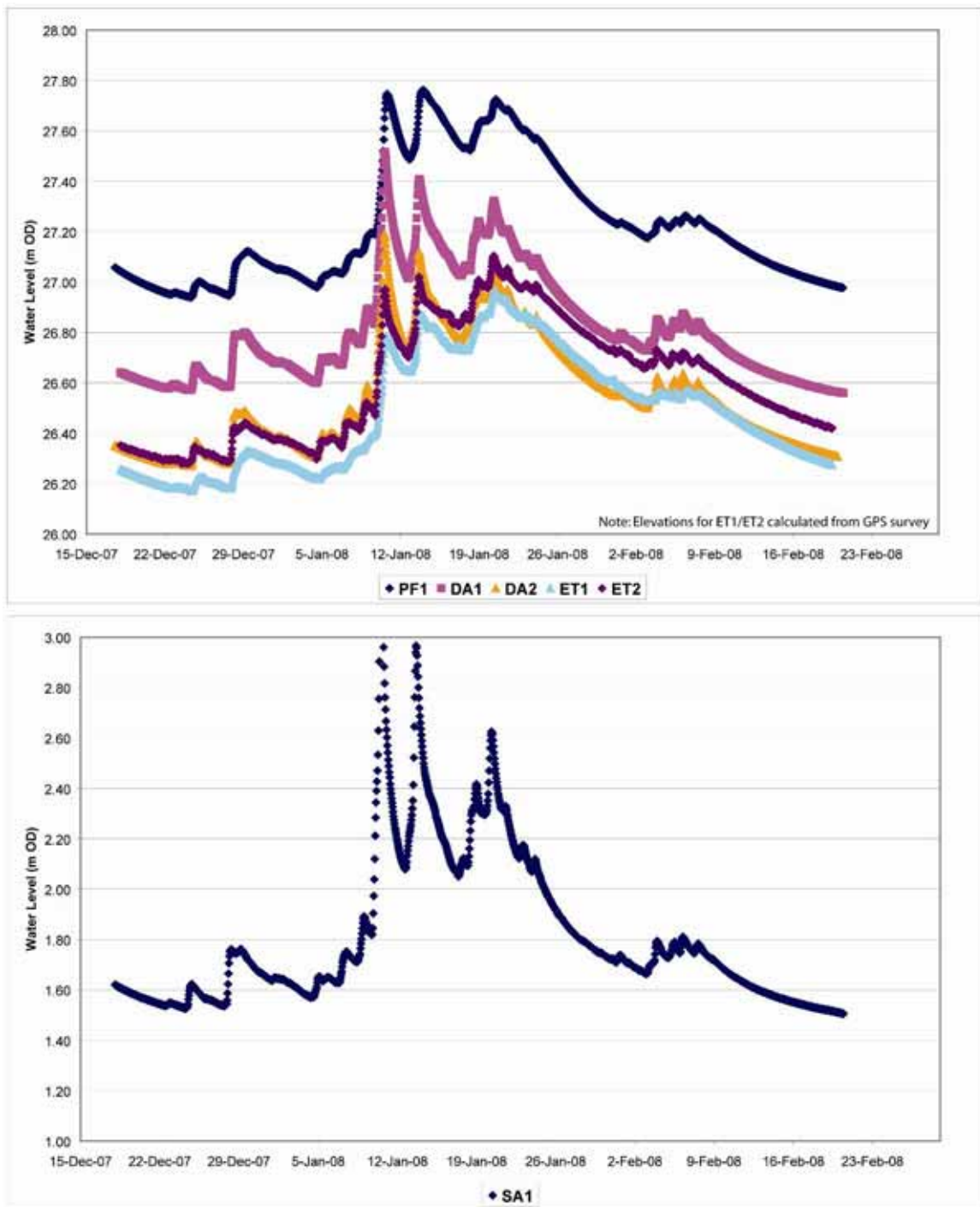
Figure 4-6 Measured Groundwater Levels in Six New Alluvial Wells
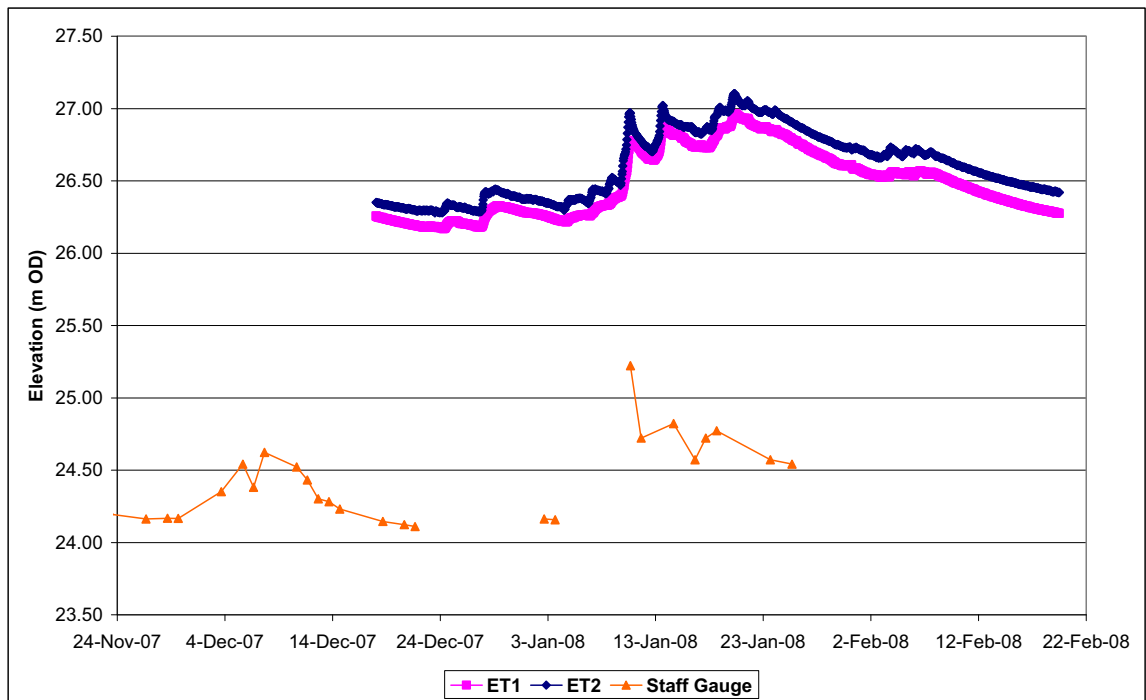
Figure 4-7 Measured Water Levels in the Avoca River and Two Nested Wells in the Emergency Tailings Area
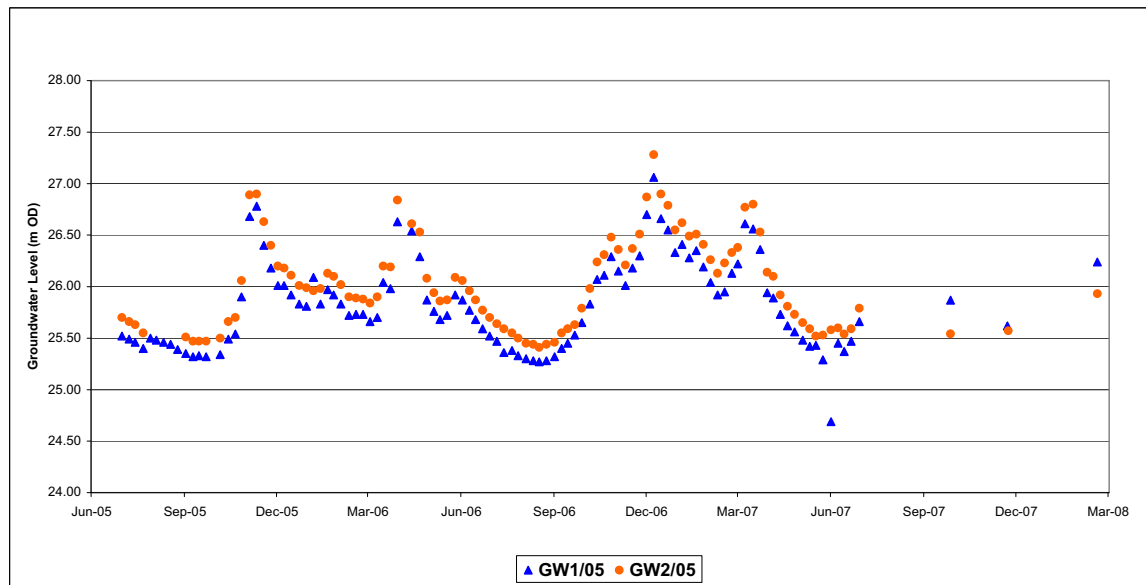
Figure 4-8 Measured Water Levels in Two Nested Wells Near the Ballymurtagh Landfill

There is presently no river stage recorder immediately adjacent to the Deep Adit or Road Adit, which are the two main contaminant sources to the river. The nearest stage recorder is located at the northern end of the County Wicklow maintenance yard where stage is recorded manually once a day, on most days of the year. For the future, it will be important to establish a proper and rated hydrometric gauging station near the mines area, and include staff gauges at one or two locations upgradient and downgradient of the hydrometric station to measure gradient relationships between the river and adjacent groundwater.

Using staff gauge data, groundwater level data from the DA and ET nested wells, and estimated surface water elevation data (from the Lidar survey) at perpendicular river points near the Deep Adit and Emergency Tailings, it is inferred that the Avoca River is a net gaining river along the main mine workings. Table 4-1 summarises resulting hydraulic gradient data between the well clusters and the river, and shows an estimated net positive gradient from the wells to the rivers in September and November 2007.

Whether the river is gaining all throughout the year is not yet proven, without further groundwater and river level monitoring over one or more full hydrological year. Care should also be taken with the gradient calculations since they are based on date-adjusted Lidar survey data rather than actual staff gauge data at the selected river points. However, given the significant vertical resolution achieved by Lidar data, the estimated gradients are believed to represent a useful approximation of site conditions.

The apparent net gain in flow of the Avoca River in the area near the Deep Adit and Emergency Tailings is supported by direct flow measurements and tracer tests that were carried out at different river transects, shown in Figure 4-9, in late July/early August 2007. These flow measurements were summarised in the attached Data Report Section 2.4 and indicated a net increase in flows between Transects 1 and 2, past the Deep Adit area. This was occurring during a time when the river was receding, i.e., flow was decreasing with falling river stage (see Figure 4-4). While Transect 2 is located downstream of the Deep Adit discharge and the Vale View tributary, the flow increase between Transects 1 and 2 cannot be explained by these contributions alone, and it is concluded that, on average, the river is gaining water along this stretch of river.

Table 4-1:
Calculated Groundwater Gradients

Well ID	Date	Water Level Depth (m)	Water Level Elevation (m)	Water Elevation at Perpendicular Stream Point (m)*	Well	Distance to Perpendicular Stream Point (m)	Well ID	Date	Gradient
PF1	9/27/2007	4.62	26.871	26.04	PF1	37	PF1	9/27/2007	0.022
DA1	9/27/2007	6.2	26.589	26.04	DA1	38	DA1	9/27/2007	0.014
DA2	9/27/2007	6.345	26.27	26.04	DA2	38	DA2	9/27/2007	0.006
ET1	9/27/2007	7.26	26.125	25.20	ET1	82	ET1	9/27/2007	0.011
ET2	9/27/2007	7.1	26.265	25.20	ET2	82	ET2	9/27/2007	0.013
SA2	9/27/2007	8.72	1.445	1.50	SA2		SA2	9/27/2007	
G1/05	9/27/2007	5.12	25.869	24.75	G1/05	66	G1/05	9/27/2007	0.017
G2/05	9/27/2007	5.23	25.541	24.75	G2/05	66	G2/05	9/27/2007	0.012
PF1	11/15/2007	4.62	26.871	26.16			PF1	11/15/2007	0.019
DA1	11/15/2007	6.13	26.659	26.16			DA1	11/15/2007	0.013
DA2	11/15/2007	6.29	26.325	26.16			DA2	11/15/2007	0.004
ET1	11/15/2007	7.32	26.065	25.32			ET1	11/15/2007	0.009
ET2	11/15/2007	7.18	26.185	25.32			ET2	11/15/2007	0.011
SA2	11/15/2007	8.72	1.445	1.50			SA2	11/15/2007	
G1/05	11/15/2007	5.37	25.619	24.87			G1/05	11/15/2007	0.011
G2/05	11/15/2007	5.2	25.571	24.87			G2/05	11/15/2007	0.011

* From Lidar survey data

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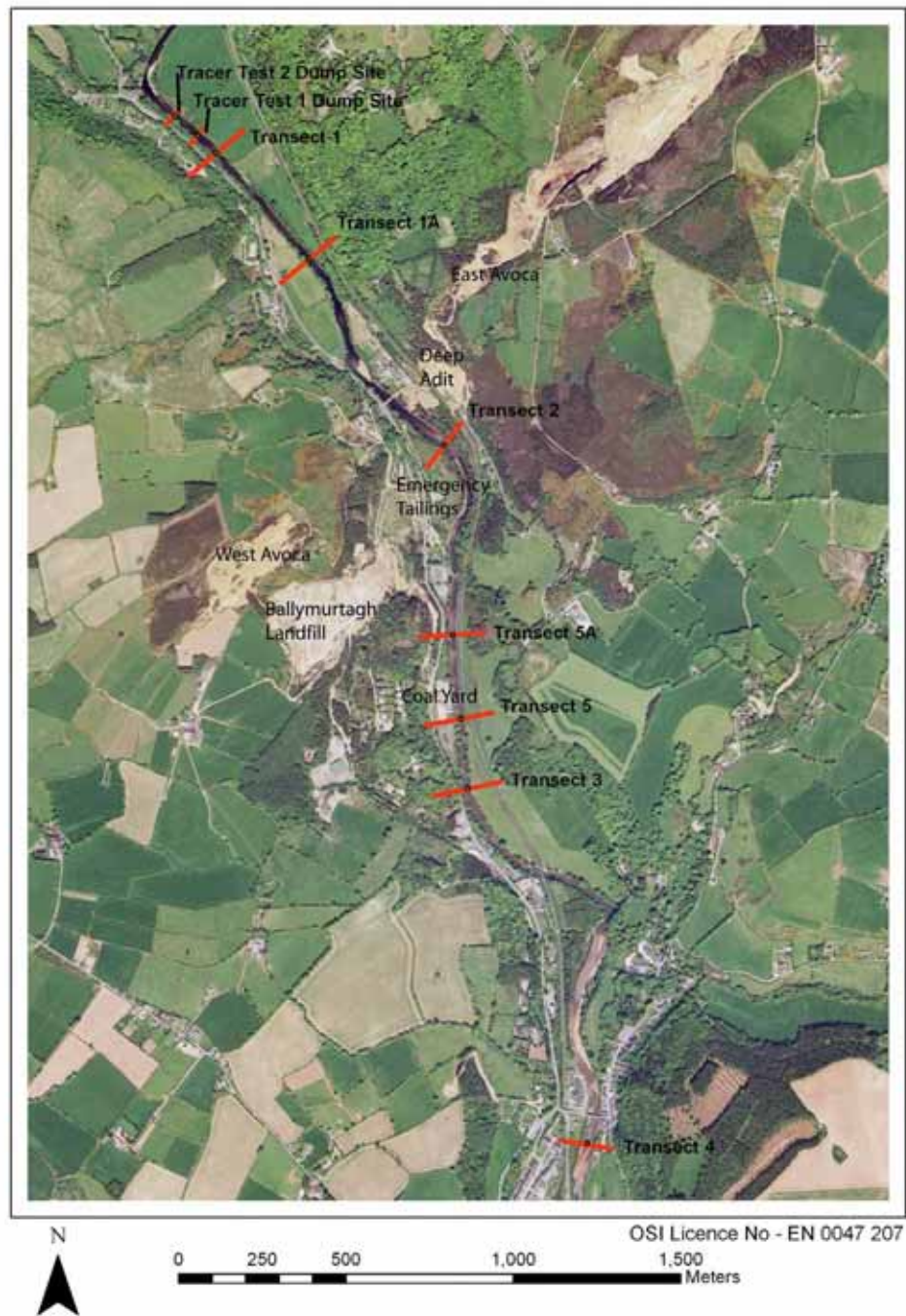
Figure 4-9 River Transect Locations

Conversely, the flow measurements and tracer tests (see attached Data Report) indicated a net loss in river flow between Transects 2 and 3, along the stretch of river that runs past the Road Adit and coal yard. The point where the river starts losing water is not precisely defined, but is inferred to start at a location just downstream of Transect 2. The Avoca River valley and associated alluvial aquifer narrows considerably below the Road Adit, and the river banks steepen. The precise cause for the loss of flow is not precisely known without supporting groundwater elevation data to the south of the Road Adit, but the loss is inferred to be related to riverbed seepage and riverbank storage. There are no river abstractions along this stretch of the river, so there has to be a natural, but as yet unknown, reason for the net loss.

Figure 4-10 shows an elevation profile of the water level of the Avoca River, as derived from the Lidar survey, between Transects 2 and 3, on July 24, 2007. The profile shows a considerable variation in river level gradient which, combined with streambed characteristics and elevations, influence velocities and play a part in defining the measured losses and gains in river flows along certain stretches of the river.
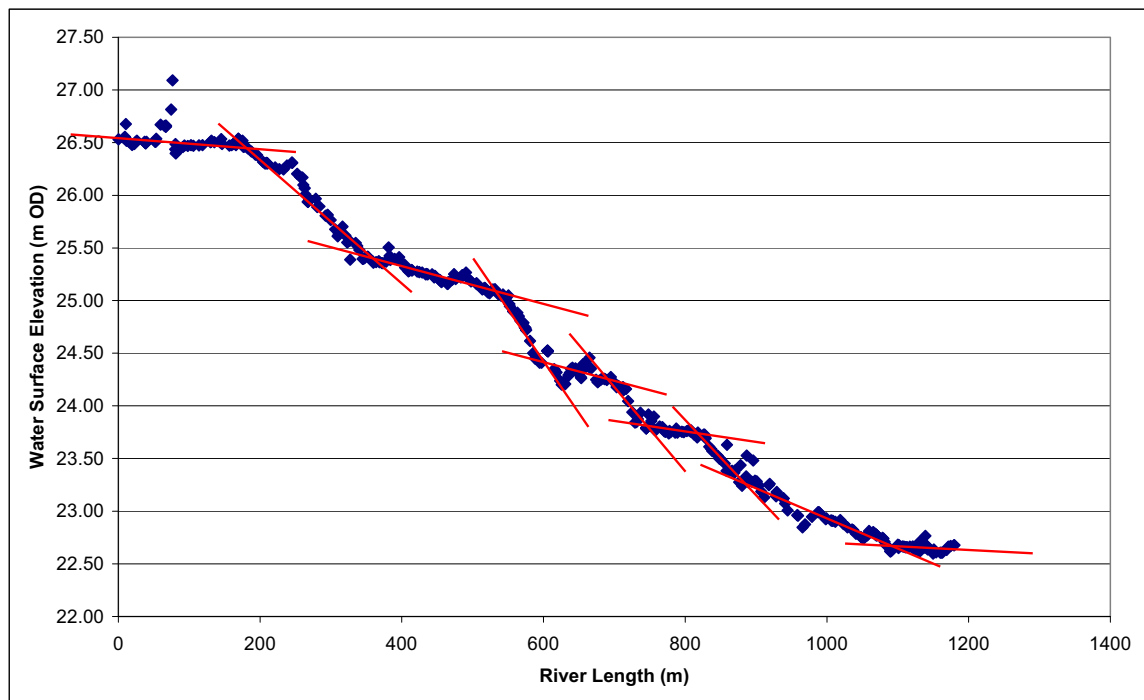
Figure 4-10 River Surface Profile Between Transects 2 and 3 on 24 July 2007

Overall the current and past studies have shown that the Avoca River/groundwater interaction is dynamic. As a result, routine monitoring is recommended. However, the current evaluations are adequate to recommend and evaluate proposed remedial options with the understanding that final designs may require some information refinement.

4.5 Groundwater Zone of Contribution of the Underground Mine System

Surface and groundwater pathways in the Avoca mine area are complex and are controlled by topographic, geologic, and man-made features. The measured discharges from the East and West Avoca adits represent the bulk of the water that moves through the mine system. The average reported discharges from the two main adits (May 1994 to April 1995 reported by Newcastle University) are:

- West Avoca (Road Adit): 17.1 L/s
- East Avoca (Deep Adit): 17.7 L/s

The Eastern Regional Fisheries Board reported average discharge values of 15 and 19 L/s for the Deep Adit and Road Adit, respectively, between October 2004 and June 2006. Measured flows during the 2007 field program (July 31, 2007) were 16.2 L/s (Deep Adit) and 19.2 L/s (Road Adit). GSI measured flows of 13.7 L/sec (Deep Adit) and 13.4 L/sec (Road Adit) on June 13, 2007 and 24.1 L/sec (Deep Adit) and 26.3 L/sec (Road Adit) in February 2, 2007.

The discharges at the Deep and Road Avoca Adits represent water which is collected and discharged by a tiered and complex network of underground mine workings, and which reflects a number of pathways and sources of water:

- Rainfall over the open pit areas which partly infiltrates into the underground drainage system;

- Surface runoff from adjacent areas which flows into the open pits and infiltrates into the underground drainage system;

- Groundwater that flows into the underground drainage system from adjacent areas (via shallow and deep groundwater pathways).

The first two can be estimated with reasonable certainty, but the latter can only be inferred using a water balance approach and estimating a zone of contribution for the mine system. An estimated water balance for long-term average conditions for the East and West Avoca mine system is presented in Table 4-2 and described below.

The long-term (30-year) median precipitation (P) over the Avoca mine area is estimated to be 1,082 mm/yr. The estimated potential evapotranspiration (PET) rate is approximately 540 mm/yr (Met Eireann, 2007). The actual evapotranspiration (AET) is assumed to be about 90 percent of PET, or 486 mm/yr. This leaves 598 mm/yr as potential recharge (PR = P-AET). Due to the steep slopes of the mines area, it is further assumed that about 50 percent of rainfall runs off as overland flow, which leaves approximately 298 mm/yr as available recharge (AR).

Table 4-2 Estimated Water Balance and Zone of Contribution of the Underground Mine System

		mm/yr	Source
Precipitation	P	1082	Met Eireann 1961-1990
Potential Evapotranspiration	PET	540	Met Eireann 1961-1990
Actual Evapotranspiration (90% of PE)	AET	486	
Potential Recharge (P-AE)	PR	596	
Runoff (50% of PR)	R	298	ERBD rainfall runoff modeling
Available Recharge (PR-R)	AR	298	
Deep Groundwater Recharge Cap	CAP	100	National Groundwater Working Group

WEST AVOCA			
Direct Rainfall Into Pits:			
P is used for direct rainfall over open pit areas	1082	mm/yr	
West Pit Areas	33181	m^2	
Volume in Pits from Rainfall	35901.84	m^3/yr	
Surface Runoff Into Pits:			
Surface Area Draining to Pits	101819	m^2	
R that drains to Pits	298	mm/yr	
Volume in Pits from Surface Runoff	30342.06	m^3/yr	
Total Volume Accumulating in Pits from P and R	66243.90	m^3/yr	
	2.10	l/s	
Recharge in Pits from P and R	2.10	l/s	
Contribution from Spoil:			
Area	81690	m^2	
50% of P on spoil runs off into pits	541	mm/yr	
Volume in Pits from Spoil	44194.29	m^3/yr	
	1.40	l/s	
Total Recharge in Pits (Direct Rainfall, Surface Runoff, Spoil)	**3.50**		
Measured Average Flow in Road Adit	17.1	l/s	
Difference (Measured - Contribution from Pits)	13.60	l/s	
Recharge from Other Areas Needed to Make Up Difference	13.60	l/s	
Available Recharge over Other Areas	298	mm/yr	
Zone of Contribution needed to arrive at Measured Adit Flows	1500000	m^2	1000 m x 1500 m
Zone of Contribution needed to arrive at Measured Adit Flows if Recharge Cap Applies	4600000	m^2	2000 m x 2200 m
EAST AVOCA			
Direct Rainfall into Pits:			
P is used for direct rainfall over open pit areas	1082	mm/yr	
East Pit Areas	20500.00	m^2	Tigroney
	62000.00	m^2	Cronebane
Volume in Pits from Rainfall	89265.00	m^2/yr	
Surface Runoff into Pits:			
Surface Area Draining to Pits	41500	m^2	Both pits
R that drains to Pits	298	mm/yr	
Volume in Pits from Surface Runoff	12367.00	m^3/yr	
Total Volume Accumulating in Pits from P and R	101632.00	m^3/yr	
	3.22	l/s	
Recharge in Pits from P and R	3.22	l/s	
Contribution from Spoil:			
Area	183689.00	m^2	
50% of P on spoil runs off into pits	541.00	mm/yr	
Volume in Pits from Spoil	99375.75	m^3/yr	
Total Volume Accumulating in Pits from Spoil	99375.75	m^3/yr	

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Table 4-2 Estimated Water Balance and Zone of Contribution of the Underground Mine System

Total Recharge in Pits (Direct Rainfall, Surface Runoff, Spoil)		
Measured Average Flow in Deep Adit	17.70	l/s
Difference (Measured - Contribution from Pits)	11.33	l/s
Recharge from Other Areas Needed to Make Up Difference	11.33	l/s
Available Recharge over Other Areas	298	mm/yr
Zone of Contribution needed to arrive at Measured Adit Flows	1225000	m^2 350 m x 3500 m
Zone of Contribution needed to arrive at Measured Adit Flows if Recharge Cap Applies	3675000	m^2 1050 m x 3500 m

From Table 4-2, and using the derived available recharge rate of 298 mm/yr, the volume of water that accumulates and infiltrates through the open pit areas is estimated, on average, to be:

- West Avoca: 3.5 L/s
- East Avoca: 6.4 L/s

The difference between these volumes and the measured average discharges from the East (Deep) and West (Road) adits represent groundwater recharge and flow from a larger area adjacent to the mine shaft system – i.e., the zone of contribution (ZOC). From Table 4-2, these areas would cover area of approximately 1.23 km² and 1.50 km² for East and West Avoca, respectively. In the case of East Avoca, the ZOC is expected to be elongated along the axis of the mine workings, covering an area 3.5 km long (along axis of ore bodies) by 350 m wide (perpendicular to the axis). In the case of West Avoca, the ZOC would cover an area that is nearly rectangular, as a function of the layout of mine shafts. The calculated ZOC areas are in addition to the land areas of the open pits.

The available recharge defined above represents recharge to bedrock. As described in Section 4.3, the low-permeability rocks of Avoca have a finite ability to accept the AR, and it is suggested that recharge should be capped at approximately 100 mm/yr for rocks of the Pl and Pu categories (National Working Group on Groundwater, 2005). In this case, the ZOCs would be much larger, 3.68 km² and 4.5 km², respectively for East and West Avoca.

As partial validation of the 100 mm/yr recharge cap, it should be noted that the EPA-reported Q95 flow of hydrometric gauge 10002 at Rathdrum is 0.97 m³/s (970 l/s) for a catchment area of 233 km². This represents the flow that is exceeded at least 95 percent of the time, and is mostly represented by groundwater contributions during the drier, late-summer season. On the assumption that all of the Q95 flow is groundwater, the specific contribution, per km² of catchment area, is 4.16 l/s/km², equivalent to 130 mm of recharge per year. This value is close to the estimated recharge cap of 100 mm/yr for deep groundwater contribution, and less than the estimated total available recharge of 298 mm/yr.

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The actual shapes and sizes of the ZOCs can only be determined by installing monitoring wells and measuring groundwater levels over a period of time. The ZOC could be different in shallow and deep bedrock, and could be further influenced by geological structures, notably the N-S trending faults (which cut across the mine shafts and probably deliver groundwater to the shafts system) and the southeasterly dip direction (i.e., the ZOC may extend further away from the mine system to the NW than SE). The ZOCs would also be influenced by heterogeneities in the underlying shallow and deep bedrock, as well as dynamic (transient) changes in hydrological conditions.

While it is not possible to predict the actual extent of the ZOC without bedrock monitoring wells, the above estimates of areal extents are considered reasonable. What is certain is that the ZOCs of the mine system on either side of the river are localized features, not regional.

Based on the above calculations, the majority of the adit discharges (Deep and Road Adits) results from infiltration and recharge from a limited area. Therefore, remediation techniques that decrease infiltration (caps, covers, liners, etc.) will be effective in reducing adit discharges.

4.6 Groundwater Quality

The bulk of contaminated groundwater associated with the Avoca mines is captured by the underground drainage system that discharges to the main adits on both sides of the river. However, contaminant mass loading of the Avoca River may be contributed from two potential sources of diffuse groundwater flow:

- Contaminated groundwater in bedrock outside the ZOC of the underground drainage system, which discharges to the alluvial aquifer along the margins of the alluvial aquifer, where bedrock and alluvium are juxtaposed.

- Contaminated groundwater that results from spoil materials which overlie the alluvium along the river and along the sides of the Avoca valley, either via direct infiltration or groundwater flowing through and across the spoil materials.

Diffuse groundwater refers to any subsurface groundwater flow that does not discharge to the main adits, whether it flows along the transition zone, in deep bedrock (deep groundwater), or alluvium.

The first potential source, groundwater outside the ZOC of the underground drainage system, cannot be directly measured or evaluated due to a lack of bedrock monitoring wells downgradient of the mine workings. However, a qualitative assessment of potential total contribution (as a discharge rate) can be made by considering the estimated average hydraulic properties of the bedrock. Hydraulic characteristics of the bedrock have been partly quantified from past drilling and basic hydraulic testing in the east Wicklow and Avoca mines area (Flynn 1996; Woods 2003). These studies,

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as well as recent work by the GSI on poorly productive aquifers (GSI 2005), indicate that fracturing is more prevalent in the top 20-30 metres of bedrock, with derived transmissivity values (away from fault zones) ranging from 0.04-11.5 m^2/day. Using reported ranges of transmissivity values and hydraulic gradients in poorly productive bedrock, and assuming most of the groundwater flows in the top 30 metres of bedrock, diffuse discharges from groundwater in bedrock would be expected to range between 100-500 m^3/day per km of river length, or approximately 1-5 litres per second per km of river length. These flows are almost negligible compared to flow rates (and volumes) in the alluvial aquifer, but could nonetheless add mass loading of contaminants (primarily metals) to the alluvial groundwater. Potentially polluted discharges from bedrock into alluvium would also be limited to short stretches of the Avoca River in the immediate vicinity of the open pit systems and spoil/tailing materials.

The second potential source, spoil directly overlying the alluvial aquifer, is considered a more significant input to diffuse contamination of the Avoca River. Drilling of wells in East Avoca near Whitesbridge (Deep Adit Area) indicated that the spoil materials are up to 7-8 metres thick, and therefore in direct contact with the alluvial aquifer. Moreover, measured groundwater levels in the Deep Adit wells (DA1 and DA2) are only 5-6 metres below ground surface, thus within the spoil materials. As the river rises and falls with hydrological conditions, groundwater levels also in the alluvium rise and fall. Therefore there is a constant cycling/leaching effect of the contract area between the spoils and the underlying alluvial groundwater.

Groundwater quality results for metals in wells that were sampled in the Avoca area as part of this study are included in Table 4-3, while Figure 4-11 shows the locations of the sampled wells. Other results for general water quality parameters were presented in the attached Data Report.

Table 4-3: Metals Analytical Data: Groundwater Wells

Sample I.D.	Date	X	Y	Dissolved Mercury Low Level ug/l	Total Mercury mg/l	Dissolved Aluminium Low Level ug/l	Total Aluminium Low Level ug/l	Dissolved Antimony Low Level ug/l	Total Antimony Low Level ug/l
Heffernans Well	03/08/2007 1332	320402	182508	-	1.40	0.05 U	24.00 U	83.00	1.00 U
Cosgrove's Well	04/08/2007 1500	320244	181424	0.05 U	0.05 U	2.00	95.00	1.00 U	1.00 U
G1NSL2	03/08/2007 1925	319575	181625	0.05 U	0.05 U	2154.00	2142.00	1.00 U	1.00 U
GW1/05	03/08/2007 1025	319880	181673	0.05 U	0.05 U	86040.00	62440.00	1.00 U	1.00 U
GW1/05	16/11/2007 1220			0.05 U		73130.00		1.00 U	
GW1/05	19/02/2008 1515	319880	181673	0.05 U	0.05 U	107100.00	75680.00	1.00 U	50.00 U
GW2/05	16/11/2007 1145			0.05 U		57080.00		1.00 U	
GW2/05	19/02/2008 1545	319880	181673	0.05 U	0.05 U	75990.00	56160.00	1.00 U	50.00 U
GW2/05	3/8/2007 1215	319880	181673	0.05 U	0.05 U	48450.00	38300.00	1.00 U	1.00 U
Holy Well	04/08/2007 1530	320120	181468	0.05 U	0.05 U	8.00	1186.00	1.00 U	1.00
Kerins Well	21/02/2008 1330	320158	181657	0.05 U	0.05 U	12.00	50.00 U	1.00 U	50.00 U
Kerins Well	3/8/2007 1220	320158	181657	0.05 U	0.05 U	2147.00	1014.00	1.00	1.00 U
Kerins Well-D	03/08/2007 1914	320158	181657	0.05 U	0.05 U	66.00	122.00	1.00 U	1.00 U
Meehan's Well	04/08/2007 1305	320382	181844	0.05 U	0.05 U	80.00	115.00	1.00 U	1.00 U
MWDA1	15/11/07 1600	319877	182043	0.05 U		66460.00		1.00 U	
MWDA1	20/02/2008 1330	319877	182043	0.05 U	0.05 U	325400.00	213800.00	1.00 U	50.00 U
MWDA2	15/11/07 1620	319879	182039	0.05 U		76200.00		1.00 U	
MWDA2	20/02/2008 1400	319879	182039	0.05 U	0.05 U	102500.00	75390.00	1.00 U	50.00 U
MWET1	15/11/07 1500	319916	181778	0.05 U		125500.00		1.00 U	
MWET1	19/02/2008 1320	319916	181778	0.05 U	0.05 U	154800.00	96020.00	1.00 U	50.00 U
MWET2	15/11/07 1430	319917	181781	0.05 U		103.00		1.00 U	
MWET2	20/02/2008 1600	319917	181781	0.05 U	0.05 U	392.00	1660.00	1.00 U	70.00
MWPF1	16/11/2007 1045	319678	182296	0.05 U		154.00		1.00 U	
MWPF1	20/02/2008 1220	319678	182296	0.05 U	0.05 U	2.00 U	50.00 U	1.00 U	50.00 U
MWSA2	15/11/07 1200	321566	175292	0.05 U		57750.00		1.00 U	
MWSA2	20/02/2008 1100	321566	175292	0.05 U	0.05 U	44300.00	65510.00	1.00 U	50.00
Richards Well	03/08/2007 1809	320067	181817	0.05 U	0.05 U	5.00	177.00	1.00 U	1.00 U
SG104	03/08/2007 1500	319806	181523	0.05 U	-	1300000.00	-	1.00 U	-
SG104	21/02/2008 1230	319806	181523	0.05 U	0.05 U	1506000.00	965500.00	1.00 U	60.00

Table 4-3: Metals Analytical Data: Groundwater Wells

Sample I.D.	Date	Dissolved Chromium Low Level (ug/l)	Total Chromium Low Level (ug/l)	Dissolved Cobalt Low Level (ug/l)	Total Cobalt Low Level (ug/l)	Dissolved Copper Low Level (ug/l)	Total Copper Low Level (ug/l)	Dissolved Iron Low Level (ug/l)	Total Iron Low Level (ug/l)
Heffernans Well	03/08/2007 1332	1.00 U	4.00 U	1.00 U	1.00 U	7.00	31.00	2.00 U	296.00
Cosgrove's Well	04/08/2007 1500	1.00 U	3.00 U	1.00 U	1.00 U	17.00	43.00	2.00 U	331.00
G1NSL2	03/08/2007 1925	1.00 U	4.00 U	13.00	11.00	598.00	602.00	31.00	1058.00
GW1/05	03/08/2007 1025	2.00	2.00	135.00	116.00	9664.00	8028.00	731.00	452.00
GW1/05	16/11/2007 1220	1.00 U		130.00		10010.00		186.00	
GW1/05	19/02/2008 1515	2.00	50.00 U	140.00	120.00	9880.00	9330.00	182.00	50.00 U
GW2/05	16/11/2007 1145	1.00 U		97.00		8736.00		156.00	
GW2/05	19/02/2008 1545	1.00 U	50.00 U	101.00	90.00	7083.00	7010.00	46.00	50.00 U
GW2/05	3/8/2007 1215	1.00 U	2.00	78.00	67.00	6047.00	5336.00	92.00	630.00
Holy Well	04/08/2007 1530	1.00 U	4.00	1.00 U	1.00 U	2.00	27.00	2.00 U	324.00
Kerins Well	21/02/2008 1330	1.00 U	50.00 U	1.00 U	50.00 U	56.00	150.00	15.00	50.00 U
Kerins Well	3/8/2007 1220	1.00 U	4.00	4.00	1.00 U	326.00	81.00	2.00 U	400.00
Kerins Well-D	03/08/2007 1914	1.00 U	3.00	1.00 U	1.00 U	52.00	78.00	2.00 U	371.00
Meehan's Well	04/08/2007 1305	1.00 U	4.00	1.00 U	1.00 U	31.00	63.00	2.00 U	413.00
MWDA1	15/11/07 1600	7.00		79.00		8821.00		16090.00	
MWDA1	20/02/2008 1330	44.00	50.00 U	220.00	190.00	19630.00	18030.00	56330.00	49980.00
MWDA2	15/11/07 1620	1.00 U		169.00		7746.00		38690.00	
MWDA2	20/02/2008 1400	1.00 U	50.00 U	132.00	130.00	6250.00	6520.00	6080.00	5480.00
MWET1	15/11/07 1500	1.00 U		125.00		358.00		87260.00	
MWET1	19/02/2008 1320	3.00	50.00 U	207.00	180.00	9556.00	8370.00	47130.00	38380.00
MWET2	15/11/07 1430	1.00 U		2.00		15.00		477.00	
MWET2	20/02/2008 1600	1.00 U	50.00 U	178.00	140.00	26.00	50.00 U	1808.00	1020.00
MWPF1	16/11/2007 1045	1.00 U		1.00 U		95.00		64.00	
MWPF1	20/02/2008 1220	1.00 U	50.00 U	1.00	50.00 U	56.00	60.00	2.00 U	50.00 U
MWSA2	15/11/07 1200	1.00 U		160.00		158.00		65310.00	
MWSA2	20/02/2008 1100	1.00	50.00 U	135.00	130.00	206.00	150.00	8022.00	7830.00
Richards Well	03/08/2007 1809	1.00 U	4.00	1.00 U	1.00 U	2.00	27.00	2.00 U	502.00
SG-104	03/08/2007 1500	370.00	-	1087.00	-	85460.00	-	136000.00	-
SG-104	21/02/2008 1230	207.00	170.00	1083.00	1150.00	128300.00	160700.00	73410.00	72770.00

Table 4-3: Metals Analytical Data: Groundwater Wells

Sample I.D.	Date	Dissolved Lead Low Level ug/l		Total Lead Low Level ug/l		Dissolved Magnesium Low Level ug/l	Total Magnesium Low Level ug/l	Dissolved Manganese Low Level ug/l	Total Manganese Low Level ug/l	Dissolved Nickel Low Level ug/l		Total Nickel Low Level ug/l
Heffernans Well	03/08/2007 1332	1.00	U	1.00		2308.00	4733.00	2.00	6.00	1.00	U	5.00
Cosgrove's Well	04/08/2007 1500	1.00	U	2.00		7681.00	9883.00	1.00	7.00	1.00	U	5.00
G1NSL2	03/08/2007 1925	6.00		10.00		13140.00	15700.00	544.00	464.00	5.00		8.00
GW1/05	03/08/2007 1025	2.00		4.00		114500.00	97580.00	6593.00	5537.00	68.00		58.00
GW1/05	16/11/2007 1220	1.00	U			94130.00		6704.00		63.00		
GW1/05	19/02/2008 1515	4.00		50.00	U	112700.00	101900.00	7068.00	5930.00	73.00		80.00
GW2/05	16/11/2007 1145	1.00	U			72140.00		5507.00		51.00		
GW2/05	19/02/2008 1545	1.00		50.00	U	81830.00	76890.00	5127.00	4440.00	51.00		70.00
GW2/05	3/8/2007 1215	1.00	U	3.00		61960.00	59150.00	3904.00	3354.00	42.00		41.00
Holy Well	04/08/2007 1530	1.00	U	1.00		7585.00	9848.00	6.00	8.00	1.00	U	4.00
Kerins Well	21/02/2008 1330	1.00	U	50.00	U	2896.00	2470.00	80.00	70.00	4.00		50.00 U
Kerins Well	3/8/2007 1220	1.00	U	2.00		5677.00	5630.00	199.00	23.00	2.00		7.00
Kerins Well-D	03/08/2007 1914	1.00	U	3.00		2835.00	5323.00	23.00	25.00	1.00		8.00
Meehan's Well	04/08/2007 1305	1.00	U	3.00		3193.00	5893.00	6.00	8.00	1.00	U	8.00
MWDA1	15/11/07 1600	231.00				67430.00		5427.00		60.00		
MWDA1	20/02/2008 1330	88.00		160.00		242000.00	200100.00	18620.00	15070.00	145.00		130.00
MWDA2	15/11/07 1620	203.00				109500.00		13810.00		109.00		
MWDA2	20/02/2008 1400	91.00		60.00		106300.00	99860.00	9506.00	8370.00	89.00		110.00
MWET1	15/11/07 1500	1.00				60980.00		9920.00		143.00		
MWET1	19/02/2008 1320	11.00		50.00	U	116700.00	93800.00	10350.00	7810.00	100.00		80.00
MWET2	15/11/07 1430	29.00				3920.00		157.00		2.00		
MWET2	20/02/2008 1600	75.00		50.00	U	303900.00	234100.00	46080.00	36600.00	36.00		50.00 U
MWPF1	16/11/2007 1045	1.00	U			2887.00		67.00		1.00		
MWPF1	20/02/2008 1220	1.00	U	50.00	U	2644.00	2950.00	77.00	80.00	2.00		50.00 U
MWSA2	15/11/07 1200	1.00	U			85020.00		23890.00		138.00		
MWSA2	20/02/2008 1100	21.00		50.00	U	81300.00	80070.00	18520.00	17380.00	117.00		130.00
Richards Well	03/08/2007 1809	1.00	U	3.00		2979.00	5095.00	35.00	20.00	1.00	U	5.00
SG104	03/08/2007 1500	107.00		-		1216000.00	-	51310.00	-	575.00		-
SG104	21/02/2008 1230	116.00		620.00		1143000.00	792200.00	50810.00	45560.00	503.00		580.00

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Table 4-3: Metals Analytical Data: Groundwater Wells

Sample I.D.	Date	Total Phosphorous Low Level (ug/l)	Dissolved Selenium Low Level (ug/l)	Total Selenium Low Level (ug/l)	Dissolved Silver Low Level (ug/l)	Total Silver Low Level (ug/l)	Dissolved Thallium Low Level (ug/l)	Total Thallium Low Level (ug/l)	Dissolved Tin Low Level (ug/l)
Heffernans Well	03/08/2007 1332	413.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Cosgrove's Well	04/08/2007 1500	447.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
G1NSL2	03/08/2007 1925	389.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
GW1/05	03/08/2007 1025	404.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
GW1/05	16/11/2007 1220		2.00		2.00		1.00		1.00
GW1/05	19/02/2008 1515		1.00 U	50.00 U	2.00 U	2.00 U	1.00 U	1.00 U	5.00 U
GW2/05	16/11/2007 1145		2.00		2.00		1.00		1.00 U
GW2/05	19/02/2008 1545		1.00 U	140.00	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
GW2/05	3/8/2007 1215	399.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Holy Well	04/08/2007 1530	527.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Kerins Well	21/02/2008 1330		1.00 U	70.00	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Kerins Well	3/8/2007 1220	501.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Kerins Well-D	03/08/2007 1914	425.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Meehan's Well	04/08/2007 1305	426.00	1.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
MWDA1	15/11/07 1600		1.00 U		2.00 U		1.00 U		1.00 U
MWDA1	20/02/2008 1330		1.00 U	60.00	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
MWDA2	15/11/07 1620		1.00 U		2.00 U		1.00 U		1.00 U
MWDA2	20/02/2008 1400		1.00 U	50.00 U	2.00 U	2.00 U	2.00 U	1.00 U	1.00 U
MWET1	15/11/07 1500		3.00		2.00 U		1.00 U		1.00 U
MWET1	19/02/2008 1320		1.00 U	140.00	2.00 U	2.00 U	3.00 U	2.00	1.00 U
MWET2	15/11/07 1430		1.00 U		2.00 U		1.00 U		1.00 U
MWET2	20/02/2008 1600		1.00 U	50.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
MWPF1	16/11/2007 1045		2.00		2.00		1.00		1.00 U
MWPF1	20/02/2008 1220		1.00 U	80.00	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
MWSA2	15/11/07 1200		2.00		2.00		1.00		1.00 U
MWSA2	20/02/2008 1100		1.00 U	50.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
Richards Well	03/08/2007 1809	508.00	3.00 U	1.00 U	2.00 U	2.00 U	1.00 U	1.00 U	1.00 U
SG104	03/08/2007 1500	-	1.00 U	-	2.00 U	-	1.00 U	-	1.00 U
SG104	21/02/2008 1230		9.00	80.00	2.00 U		1.00 U		1.00 U

Table 4-3: Metals Analytical Data: Groundwater Wells

Sample I.D.	Date	Total Tin Low Level (ug/l)	Dissolved Titanium Low Level (ug/l)	Total Titanium Low Level (ug/l)	Dissolved Uranium Low Level (ug/l)	Total Uranium Low Level (ug/l)	Dissolved Vanadium Low Level (ug/l)	Total Vanadium Low Level (ug/l)	Dissolved Zinc Low Level (ug/l)	Total Zinc Low Level (ug/l)
Heffernans Well	03/08/2007 1332	1.00	1.00 U	4.00 U	1.00 U	3.00 U	1.00 U	2.00	35.00	81.00
Cosgrove's Well	04/08/2007 1500	2.00	1.00	3.00 U	1.00 U	3.00 U	1.00 U	1.00 U	10.00 U	91.00
G1NSL2	03/08/2007 1925	2.00	1.00 U	21.00 U	1.00 U	4.00 U	1.00 U	4.00	746.00	533.00
GW1/05	03/08/2007 1025	3.00	4.00	6.00	5.00	7.00	1.00 U	1.00	12190.00	9855.00
GW1/05	16/11/2007 1220		3.00		5.00		1.00 U		13830.00	
GW1/05	19/02/2008 1515	1.00 U	4.00	5.00	6.00	5.00	1.00 U	280.00	12710.00	
GW2/05	16/11/2007 1145		4.00		5.00		1.00 U	1.00 U	10450.00 U	
GW2/05	19/02/2008 1545	3.00	3.00	3.00	4.00	4.00	1.00 U	220.00	8601.00	5863.00
GW2/05	3/8/2007 1215	4.00	3.00	8.00	4.00	6.00	1.00 U	1.00 U	6651.00 U	
Holy Well	04/08/2007 1530	1.00	2.00	4.00	1.00 U	3.00	1.00 U	1.00 U	22.00 U	47.00
Kerins Well	21/02/2008 1330	1.00 U	3.00	4.00	1.00 U	1.00 U	1.00 U	50.00 U	65.00 U	
Kerins Well	3/8/2007 1220	2.00	1.00 U	3.00 U	1.00 U	4.00	1.00 U	2.00	403.00	117.00
Kerins Well-D	03/08/2007 1914	1.00	1.00 U	3.00 U	1.00 U	3.00	1.00 U	1.00 U	70.00 U	113.00
Meehan's Well	04/08/2007 1305	1.00	1.00 U	4.00 U	4.00	4.00	1.00 U	1.00 U	68.00 U	108.00
MWDA1	15/11/07 1600	6.00	6.00		4.00		2.00		21990.00	
MWDA1	20/02/2008 1330	1.00 U	11.00 U	14.00	15.00	12.00	1.00 U	510.00	59960.00	
MWDA2	15/11/07 1620	3.00	3.00		6.00		1.00 U		42120.00	
MWDA2	20/02/2008 1400	1.00 U	4.00 U	6.00	7.00	7.00	1.00 U	240.00	27300.00	
MWET1	15/11/07 1500	1.00	1.00		2.00		1.00 U		15240.00	
MWET1	19/02/2008 1320	1.00 U	7.00 U	6.00	10.00	8.00	1.00 U	1000.00 U	12310.00 U	
MWET2	15/11/07 1430	1.00 U	1.00 U		1.00 U		1.00 U		161.00	
MWET2	20/02/2008 1600	1.00 U	1.00 U	1.00 U	1.00 U	1.00 U	1.00 U	490.00	4899.00	
MWPF1	16/11/2007 1045	1.00 U	1.00 U		1.00 U		1.00 U		95.00	
MWPF1	20/02/2008 1220	1.00 U	1.00 U	1.00 U	1.00 U	1.00 U	1.00 U	50.00 U	85.00 U	
MWSA2	15/11/07 1200	3.00	3.00		5.00		1.00 U		4475.00	
MWSA2	20/02/2008 1100	1.00 U	2.00 U	4.00	3.00	3.00	1.00 U	230.00	3680.00	
Richards Well	03/08/2007 1809	1.00	1.00 U	5.00 U	1.00 U	2.00	1.00 U	2.00	206.00	234.00
SG104	03/08/2007 1500	-	9.00	-	93.00	-	1.00 U	-	137700.00	-
SG104	21/02/2008 1230	1.00 U	10.00 U	11.00	101.00	84.00	1.00 U	2590.00	136800.00	
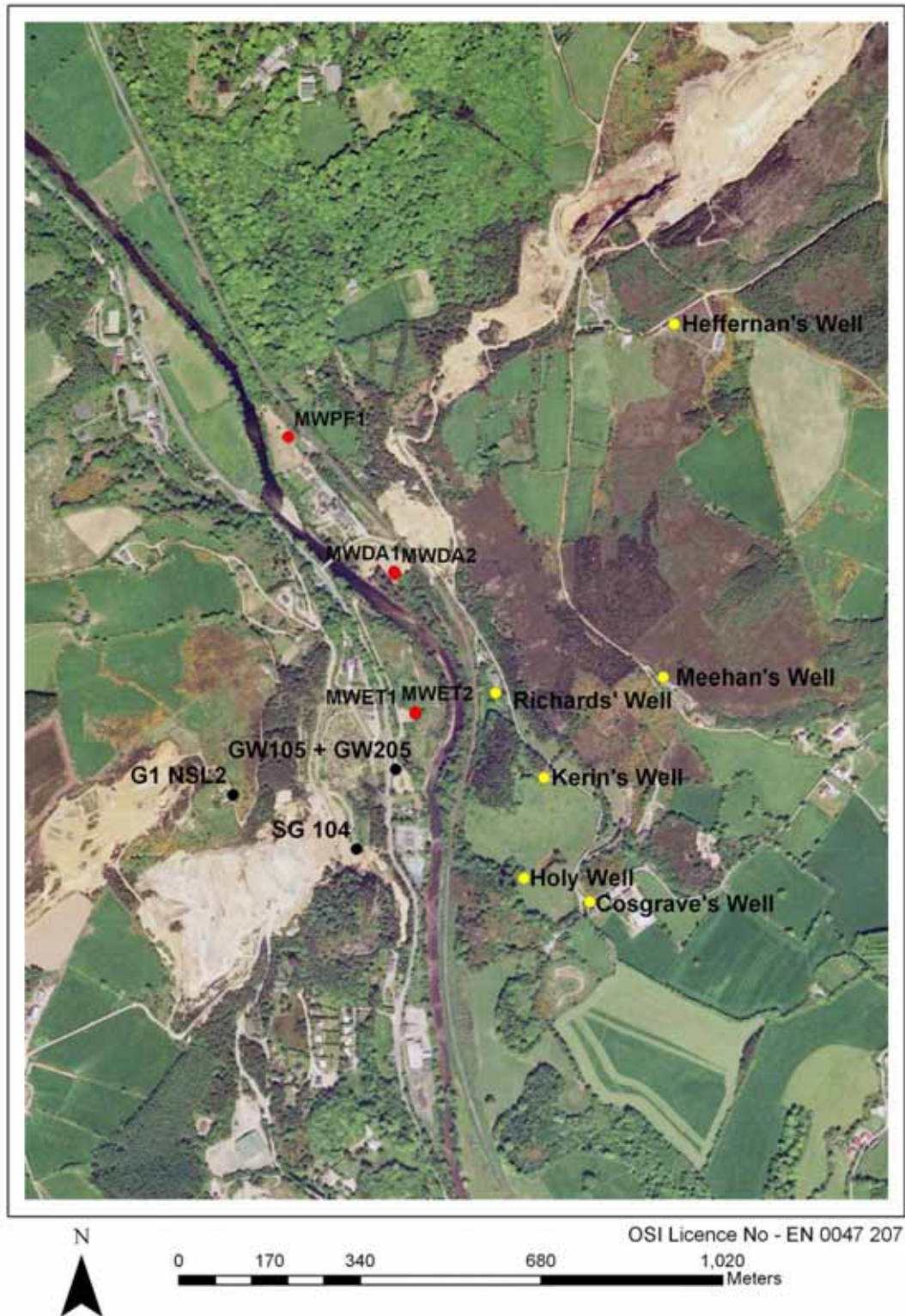
Figure 4-11 Well Locations

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Compared to existing drinking water and indicator parameter thresholds, groundwater quality in the Deep Adit wells DA1 and DA2 are significantly degraded, notably with very high concentrations of dissolved and total metals – aluminium, cadmium, copper, iron, manganese, nickel, and zinc. Of general water quality parameters, the wells show elevated concentrations of sulphate.

On the western side of the river, downgradient of the Ballymurtagh landfill and the West Avoca open pits, alluvial wells show similar high concentrations of metals and sulphate, notably in wells ET1 and ET2, as well as SG104, GW1/05 and GW2/05. Wells DA1, ET1, ET2, and SG104 also have elevated concentrations of total (but not dissolved) arsenic.

For wells such as ET2 and DA1, metal concentrations are higher in February 2008 than in November 2007, which may be attributed to higher flow rates and increased loading of contaminants to the alluvial aquifer from bedrock, expected during the wetter winter conditions. The bedrock well GW1/05 shows marginally higher metal concentrations than its nested, shallow alluvial well GW2/05.

It should also be noted that metal concentrations at ET2 are lower than at ET1, which could be explained by the apparent confined nature of ET2 (heads in ET2 are higher than in ET1) and also because ET1 is screened directly beneath the Emergency Tailings deposits.

While most of the wells on the western side of the Avoca River are located downgradient of the Ballymurtagh landfill (itself a source of historic groundwater contamination), the elevated metal concentrations are most likely related to the mines, rather than the landfill. This conclusion is based on the observation that most municipal landfills do not contain large quantities of leachable metals and do not generate the observed low pH values. The observed metal and low pH values are consistent with oxidation of sulfide minerals.

The shallow (water table) well downgradient of the tailings impoundment near Shelton Abbey also shows some elevated metals, notably (dissolved) arsenic, antimony, iron, lead, manganese, nickel, and zinc. However, copper was not detected at levels of concern. Concentrations of zinc are lower at Shelton Abbey than near the Deep Adit and Emergency Tailings.

The well located upgradient of the Deep Adit and at the eastern margin of the alluvial aquifer, PF1, is effectively free of metal concentrations of concern. PF1 measures groundwater quality in the shallow alluvial aquifer upgradient of the mine workings, including any discharge from bedrock in this part of the valley. Given its upgradient location of the East Avoca mine area, the results from PF1 suggest the northern extent of diffuse groundwater pollution is limited to the upstream (northern) boundary of the Deep Adit and Tigroney West (ore bins) spoil area.

A total of six private wells in the Avoca mines area were sampled once in August 2007. With the exception of iron and manganese (which are inferred to be naturally occurring in bedrock), groundwater quality is good, with low metal concentrations, below EPA's drinking and indicator water quality thresholds.

The elevated metals concentrations in groundwater (Table 4-3) imply that groundwater contributes to the mass loading of metals to the Avoca River, along those stretches of the river where the river is gaining water from the underlying and adjacent alluvial aquifer. As discussed in Section 4.4, the available field data indicate that the river was gaining in the stretch of river that flows past the Deep Adit and Emergency Tailings in late July and early August, but that it was losing water in the stretch flowing past the Road Adit and coal yard. Mass loading estimates to the river from diffuse sources, including groundwater, is discussed in Section 5 below.

Section 5
Loading Analysis

5.1 Methodology

Mass loads were calculated for the Avoca River, the adits, and tributaries using flow and concentration data, as follows:

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

Where,

C = the concentration of the parameter in the water

F = the flow rate of the input

Flow and concentrations were measured directly in the field or from laboratory analyses, and therefore represent known inputs. However, the loading to the Avoca River also includes several "unknown" inputs which cannot be measured directly or easily in the field:

- Overland flow in contact with spoils (only during rain events)

- Seepage from spoils and tailings adjacent to the river (which can occur for long periods following a rain event)

- Seepage from "losing" adit ditches near the river (which may partly soak into ground before reaching the river)

- Diffuse flow (groundwater inflow)

- Desorption from or dissolution of metal-bearing coatings on river sediment

These potential source terms (not including overland flow, as the analysis was done following a "dry" period) were therefore lumped together as a single, lumped loading term, and calculated by difference, as follows.

$$\text{Load}_{\text{Lumped}}\ (\text{kg/day}) = \text{Load}_{\text{Transect}} - (\Sigma \text{Load}_{\text{Adits}} - \Sigma \text{Load}_{\text{Tributaries}})$$

The lumped input represents the sum total of all of the unknown gains and losses. Distinguishing between the lumped inputs is difficult at best, requiring a vast amount of field data, and is further complicated by the fact that losses of water and/or mass in the system may also be occurring as a result of:

- Loss of river water to groundwater in certain stretches of the river
- Indirect pathways
- Evaporation (minimal)
- Attenuation (adsorption/co-precipitation onto river sediments)

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The overall effect (loss or gain) depends on the relative importance of each loss or gain component, recognizing that for any given chemical parameter, multiple processes apply (e.g., groundwater attenuation, seepage/recharge, etc.).

Once the lumped loading term was determined for each chemical parameter under study, a theoretical input concentration for each parameter was back-calculated using the volume of water gained within a particular segment of river.

Therefore, in order to simplify the analysis, the mass and flow evaluations were divided into segments or river, as defined by the transect locations along the Avoca River where flow and concentrations were determined. The segments are defined as follows:

- Segment A (T1 – T2)
- Segment B (T2 – T5)
- Segment C (T5 – T3)
- Segment D (T3 – T4)
- Segment E (Shelton Abbey)

A description of each segment, including the known mass and flow inputs/outputs and the calculated lumped loading terms are presented in the following sections.

5.2 Segment A (Transect 1 to Transect 2)

Segment A extends from Transect 1, approximately 900 m upstream of Whitesbridge to Transect 2, a location just downstream of the Deep Adit discharge (see Figure 4-11), a total length of approximately 1,100 m. The segment includes the following water/mass inputs into the Avoca River:

- Vale View Tributary

- Seepage Inputs from the Tigroney West spoil piles (SP1, SP2A, SP2, SP3, and SP4)

- Overland flow in contact with the Tigroney West spoil piles

- Seepage losses through the sides and bottom of the Deep Adit Ditch

- Direct discharge of the Deep Adit into the Avoca

- Diffuse groundwater flow

A schematic illustrating flow and potential mass loading components into/out of the Avoca River is presented in Figure 5-1, while a more detailed illustration representing a location just upgradient of the Deep Adit discharge is shown in Figure 5-2.
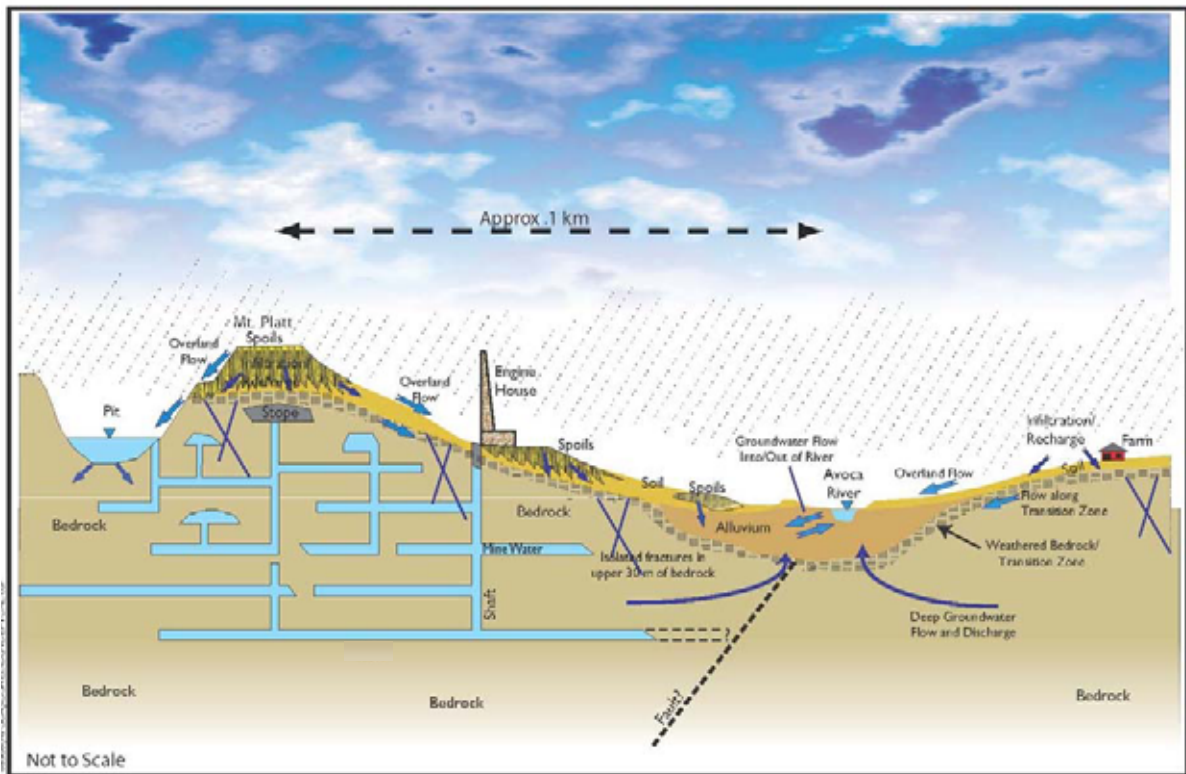
Figure 5-1 Schematic Cross-Section of Flow Components Influencing the Avoca River
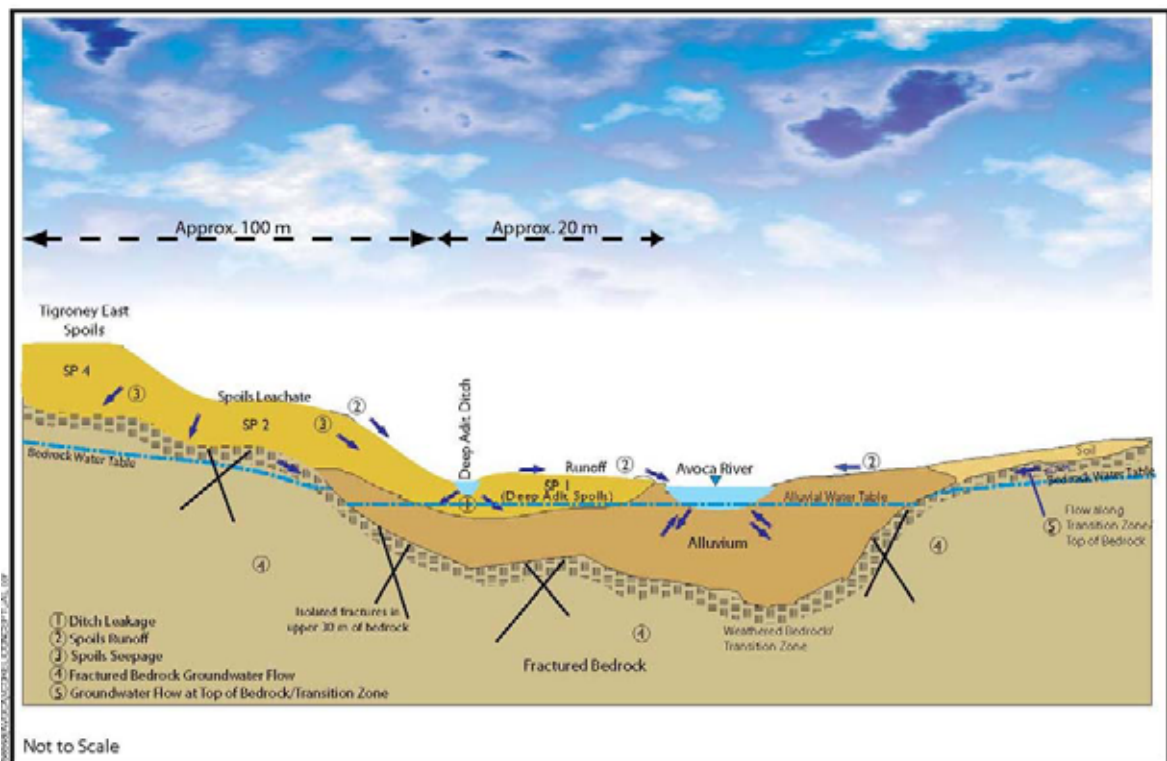
Figure 5-2 Schematic Cross-Section of the East Avoca Area Upgradient of the Deep Adit

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The interflow component shown above represents flow that primarily takes place in the transition zone between subsoils and bedrock, which was described in Section 4. The alluvium also underlies the river along the Avoca River valley, and spoil materials partly overlie the alluvium at both West East Avoca.

The mass loadings for each source and the impact on the loads of copper, zinc, iron, and sulfate are shown in Table 5-1a and Figure 5-3a. The load (kg/day) of copper, zinc, iron, and sulfate were calculated for each location. The amount attributed to diffuse contamination (spoils leachate, ditch leakage, and diffuse flow) was back-calculated to arrive at the estimated load.

For example the load at T2 equals the sum of the loads at T1, Vale View, Deep Adit Confluence, and the "diffuse" component. The results are somewhat misleading because the loads were calculated using analytical results from the Deep Adit Confluence sample. This sample was collected where the deep adit discharge flows into Avoca River. Between the exit from the adit and the discharge to the Avoca River, the concentrations of metal decrease significant and precipitation occurs (i.e., large quantities of orange ferric oxyhydroxides are observed in the ditch). As a result, the loads calculated for the "diffuse" load include metals removed in the ditch. The mass balance was also performed using a sample collected nearer the active adit (see next paragraphs).

Segment A is a gaining reach as indicated by the increase in flow between T1 and T2 which cannot be accounted for by tributary or adit flows. Zinc is the most mobile of the parameters listed and has the highest contribution from the Deep Adit discharge (yellow band in Figure 5-3a). Iron and copper are much less mobile and tend to be attenuated within the ditch sediments. Sulfate, while usually considered fairly mobile, is not conservative within the ditch due to the formation of jarosite and iron-aluminum hydroxysulfates at low pH.

Table 5-1a Water and Mass Balance Summary for Segment A (T1 - T2)

Sample I.D.	Flow (L/day)	Copper Diss. Conc. (µg/L)	Load (kg/day)	Zinc Diss. Conc. (µg/L)	Load (kg/day)	Iron Diss. Conc. (µg/L)	Load (kg/day)	Sulfate Conc. (µg/L)	Load (kg/day)
T1	505958400	8.00	4	29	14.7	99	50	5.00	2530
Vale View	1814400	2.00	0.004	3	0.005	7	0.01	16.00	29
Deep Adit Confluence	1390090	0.50	0.001	43090	60	293	0.41	1362	1893
Spoils Leachate, Ditch Leakage, and Diffuse Flow	91749110	34.43[2]	3[1]	124	11	510	47	10.42	956
T2	600912000	12.00	7	143	86	162	97	9.00	5408

[1] Determined by difference (Load$_{T2}$ – (Load$_{T1}$ + Load$_{VV}$ + Load$_{DAC}$))
[2] Back-calculated from the load and flow

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Loading (kg/day)
Segment A (T1 through T2)
Confluence
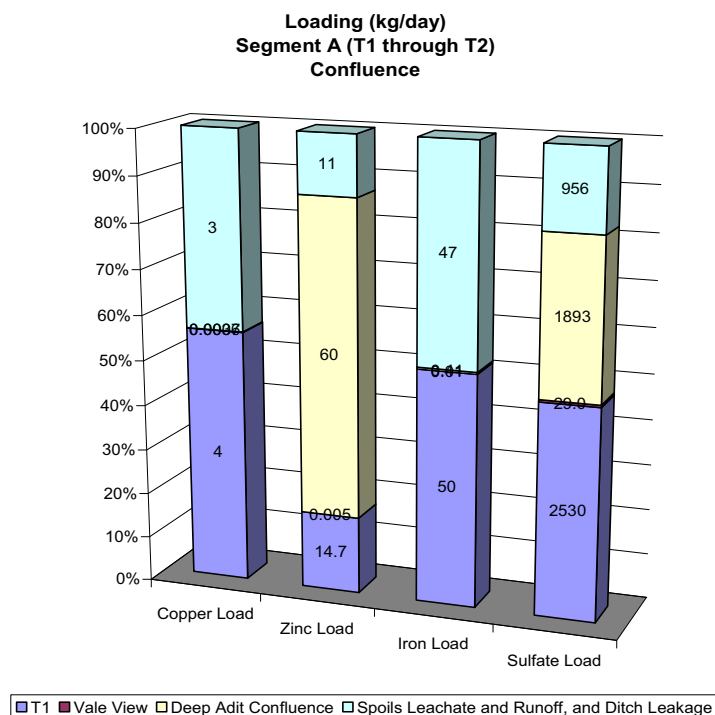
Figure 5-3a: Mass loading summary for Segment A (T1-T2) using the
Deep Adit Confluence sample results.

The input required to achieve the mass of metals and flow of water measured at T2 (the "lumped" load) would have a copper concentration of about 34 µg/L, a zinc concentration of 124 µg/L, an iron concentration of 510 µg/L, a sulfate concentration of 10 µg/L, and a flow of 1062 L/s.

When the Deep Adit sample from nearer the portal is used in the analyses, the resultant loads are presented Table 5-1b and Figure 5-3b.

Table 5-1b Water and Mass Balance Summary for Segment A (T1 - T2) – Adit

| Sample I.D. | Flow (L/day) | Copper | | Zinc | | Iron | | Sulfate | |
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T1	505958400	8.00	4	29	14.7	99	50	N/A[1]	N/A
Vale View	1814400	2.00	0.004	3	0.005	7	0.0	N/A	N/A
Deep Adit	1390090	845.00	1.175	47620	66	72340	101	N/A	N/A
Spoils Leachate, Ditch Leakage, and Diffuse Flow	91749110	20.91	2	53	5	-561	-53	N/A	N/A
T2	600912000	12.00	7	143	86	162	97	N/A	N/A

[1] N/A = Not Analyzed (data not available)

Loading (kg/day)
Segment A (T1 through T2)
Adit
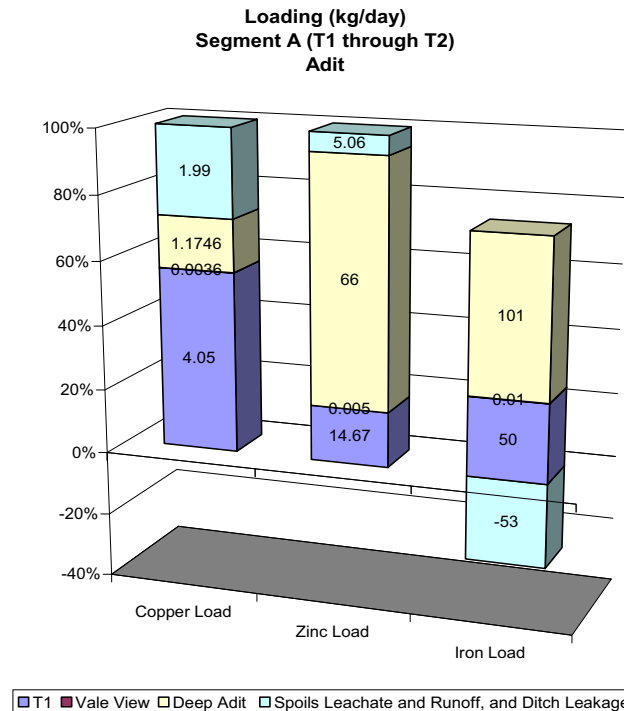
Figure 5-3b: Mass loading summary for Segment A (T1-T2) using
the Deep Adit sample results.

In the latter case, the adit contribution is much greater and the "diffuse" load is reduced. In fact, the adit contribution is over 100 percent for iron. The iron load at T2 is 97 kg/day while the Deep Adit alone contributes 101 kg/day. The reason for the greater, apparent iron contribution by the adit is attenuation reactions (oxidation and precipitation) occurring within the ditch, as discussed in section 5.2.2 below (Deep Adit discharge). Due to leakage from the ditch, the actual contribution of the Deep Adit is likely to lie between the resulting values obtained using the Deep Adit and Deep Adit Confluence samples.

The contributions of the diffuse flow component at transect T2 for copper, zinc, iron, and sulfate were 42.9 percent, 12.8 percent, 48.4 percent, and 17.7 percent, respectively (calculated from the loads in Table 5-1a; for example for copper, the diffuse load is 3 kg/day and the load at T2 is 7 kg/day, and the diffuse contributions is 3 kg/day/7 kg/day x 100 percent = 42.9 percent). The "diffuse" load in these calculations includes the losses in the ditch. Using values from Table 5-1b, the "diffuse" component at T2 for copper and zinc are 28.6 percent and 5.8 percent, respectively.

5.2.1 Vale View Tributary

The Vale View Tributary crosses the Rathdrum Road via a culvert in front of the Avoca Methodist Church. In front of the church, the stream makes a 90 degree bend and is routed southeast along a ditch running in front of the Saint Patrick's Football Club and parallel to Rathdrum Road (see Figure 5-4). The tributary makes another 90 degree bend where the football pitch meets a farm field, running along the southeast border of the football club and into the Avoca.

Figure 5-4 Vale View Tributary along Rathdrum Road (July 2007)

The flow of the Vale View tributary in July 2007 was only 21 L/s, compared to a flow of 5,856 L/s in the Avoca River at T1, which represents only 0.4 percent of the river flow. As the metals concentrations are low as well (less than at T1), the mass loading of the Vale View tributary is deemed insignificant, as illustrated by the very thin bands of red (representing the load of the Vale View Tributary) on the bar charts in Figures 5-3a and 5-3b.

5.2.2 Deep Adit Discharge

The Deep Adit discharge has historically been sampled fairly close to the portal, before significant changes to the water quality occur. However, the water that is actually entering the Avoca River has been influenced by precipitation reactions, as evidenced by the fluffy red-brown precipitate within the channel (see Figure 5-5).

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Figure 5-5 Red-brown precipitate in the channel which conveys the Deep Adit discharge from the portal to the Avoca River (April 2007).

The deep adit was sampled at two locations during the August 2007 field event, one at the portal (sample called "Deep Adit") and the other at the confluence just before entering the river (sample called "Deep Adit Confluence"). The results are shown in Table 5-2.

Table 5-2 Comparison of Dissolved Metals Concentrations in the Deep Adit vs. Deep Adit Confluence Samples (July 31, 2007)[1]

Parameter	Deep Adit (µg/L)	Deep Adit Confluence (µg/L)
Aluminum	102,600	9
Arsenic	2	1
Calcium	10,770	8,188
Cadmium	115.6	0.4
Copper	845	0.5
Iron	72,340	293
Lead	1,717	0.5
Manganese	4,100	961
Zinc	47,620	43,090
pH (su)	3.55	3.47
DO (mg/L)	2.9	8.6

[1]   Units are µg/L unless noted otherwise.

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The large difference in the concentrations is due to precipitation of iron-aluminum oxyhydroxides with coprecipitation of metals such as copper, cadmium, and lead. Zinc is the only metal that appears to be relatively conservative, with only a 9.5 percent decrease in concentration. The significant increase in DO concentrations from 2.9 at the portal to 8.6 at the confluence suggests that iron is oxidizing within the ditch. The slight decrease in the pH from the portal to the confluence is due to the production of protons during the precipitation of iron oxyhydroxide (see Conceptual Site Model Phase 1 Report).

The results of precipitation are also observed when comparing the results of the total metals, which includes both the dissolved and the particulate forms, to the dissolved analyses. Figures 5-6 and 5-7 show the dominance of the particulate form in the Deep Adit Confluence discharge (determined by subtracting the dissolved concentration from the total concentration).

The result of the attenuation of most of the metals within the ditch is that the adits appear to contribute very little metals loading (with the exception of zinc) to the Avoca River when using the Deep Adit Confluence sample, as shown in Table 5-1a and Figure 5-3a. However, as mentioned previously, the adit contribution may be understated by using the confluence analyses, as some of the ditch flow likely leaks through the bottom and sides of the channel, contributing metals to the Avoca via seepage through the spoil piles (see Figure 5-2). Treatment of the Deep Adit discharge would require collecting of the adit discharge into a pipe, which would eliminate the ditch leakage. Therefore, treatment of the Deep Adit discharge water would not only remove the Deep Adit Confluence water, but the ditch leakage component of the "lumped" input as well.

Deep Adit Confluence
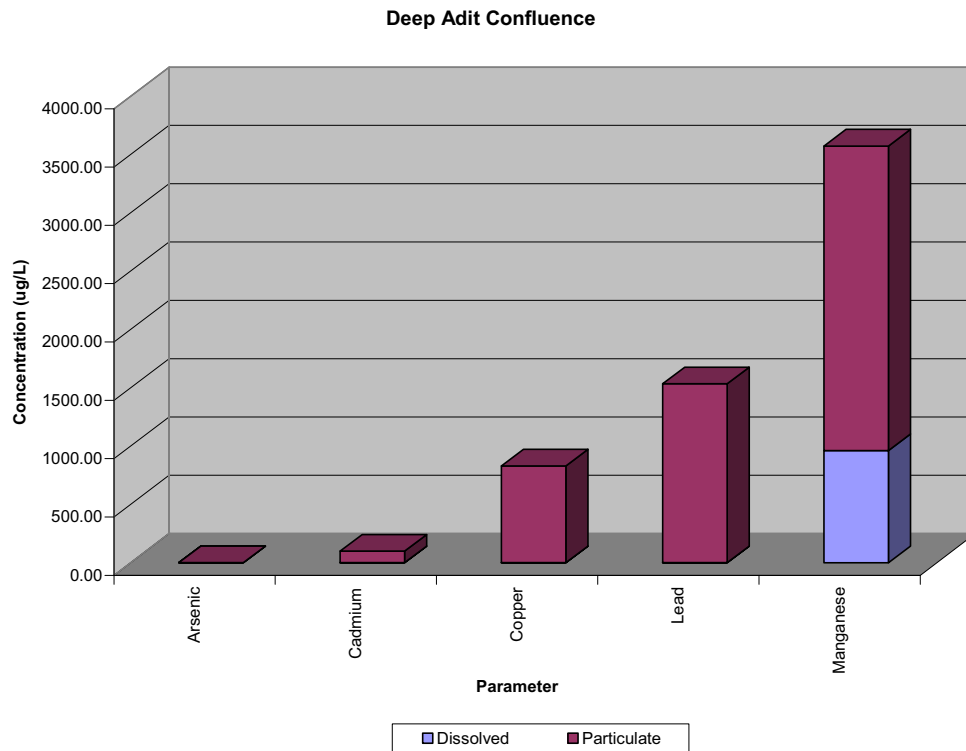
Figure 5-6 Relative Proportion of particulate phase metals (red) as compared with the dissolved
phase (blue) for the Deep Adit Confluence Sample (July 2007).

Deep Adit Confluence
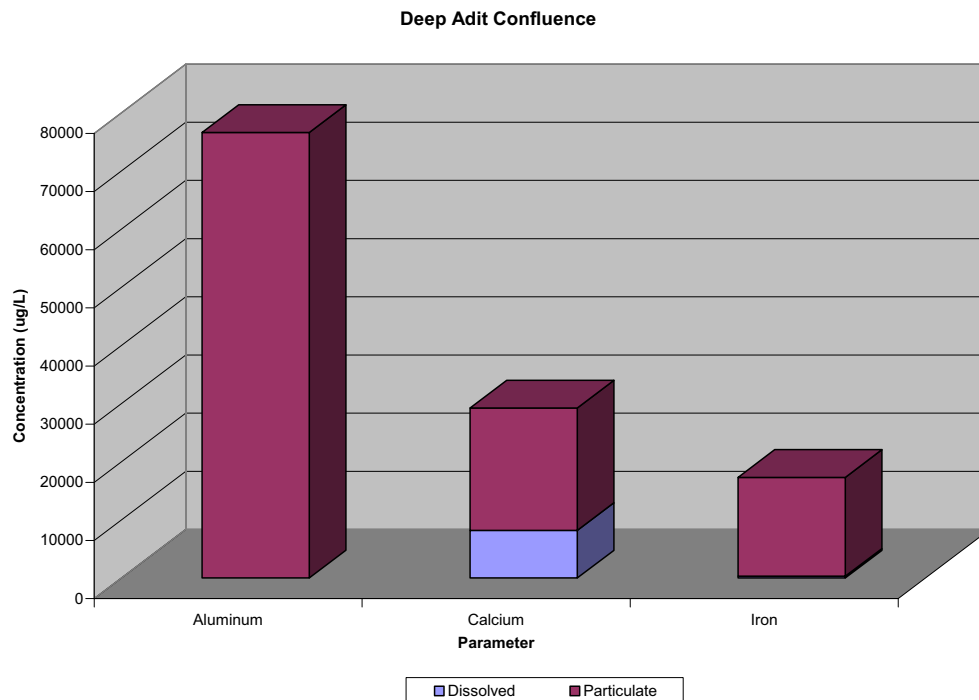
Figure 5-7 Relative Proportion of particulate phase metals (red) as compared with the dissolved
phase (blue) for the Deep Adit Confluence Sample (July 2007).

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5.2.3 Spoil Piles Seepage

As part of the August 2007 sampling event, samples of Avoca River water on the river banks were collected to determine if or where seepage is taking place (see Figure 2-4a in the Data Report for locations). The results for Segment A are shown in Table 5-3.

Table 5-3 Segment A Bank Sampling Results (July-August 2007)

Sample ID	Location	pH (su)	Eh-SHE (mv)	Conductivity at 25 ºC (µS/cm)	Copper (µg/L)	Zinc (µg/L)
CDM-BS1[1]	East Bank Avoca near Whites Bridge	6.14	378	77	17	80
CDM-BS2	South of Whites Bridge and upstream of BS1	6.34	376	76	8	56
CDM-BS3	75m N of Whites Bridge - E Bank	6.58	365	72	16	59
CDM-BS4	N. of Whites Bridge, 30m N of Island	6.74	336	71	4	22
CDM-BS5	E. Bank directly across from BS4	6.82	354	72	<1	20
CDM-BS6	E. Bank under Whites Bridge	7.05	319	72	-	-
CDM-BS7	S. end of St. Patrick's Football Pitch - W. Bank	7.58	305	71	11	23
CDM-BS16	E. Bank - 15m N. of Deep Adit Discharge	5.38	471	121	71	1423
CDM-BS17	E. Bank - 30m N. of Deep Adit Discharge	5.12	507	142	68	1315
CDM-BS18	Upstream of BS17	5.52	490	106	-	-
CDM-BS19	5 m Upstream of BS18	5.19	519	156	-	-
CDM-BS20	5 m Upstream of BS19	5.35	500	131	-	-
CDM-BS21	5 m Upstream of BS20 (near BS1 but closer to the bank)	5.93	446	93	-	-

[1]   Red indicates the sample was collected South of Whites Bridge adjacent to the Tigroney West (Deep Adit) Spoil Piles, and upstream of the Deep Adit discharge.

The results indicate that low pH, metals-bearing water is entering the Avoca River upstream of the Deep Adit discharge point and adjacent to the Tigroney West (Deep Adit) spoil piles. The seepage from the spoil piles is believed to originate as one or more of the following potential sources:

- Direct seepage of leachate from the spoils

- Discharge of impacted, alluvial groundwater (including leakage from the unlined ditch at the Deep Adit discharge, via groundwater)

- Runoff from the spoil surface (only during rainfall events)

Seepage of spoils leachate is likely to be low pH and high in metals, based on the analysis of the spoil crust (formed when the leachate evaporates), which contained 7,253 mg/kg copper, 827 mg/kg zinc, and 95,463 mg/kg iron (see sample SA-26S in Table 2-13 of Conceptual Site Model Phase 1 Report). In addition, unsaturated spoils

pile SP2 had the two most acid-generating ABA results of any spoils or tailings at the site.

The groundwater beneath the Tigroney West area is partly recharged by spoils leachate. Analyses of the groundwater for wells DA1 and DA2 are provided in Table 5-4.

Table 5-4 Summary of Deep Adit Area Groundwater Concentrations for Selected Parameters (November 2007)

Well ID	Water Level bgs[1] (m)	Screen Interval bgs (m)	pH (su)	DO (mg/L)	Eh[2] (mv)	SC (µmhos/ cm)	Copper[3] (µg/L)	Zinc[3] (µg/L)	Iron[3] (µg/L)	Sulfate (mg/L)
MWDA1	6.13	9.0 - 12	3.41	2.43	625	1,050	8,821	21,990	16,090	784
MWDA2	6.29	21.9 - 24.9	4.22	2.24	503	1,227	7,746	42,120	38,690	1,240

[1]   bgs = Below Ground Surface
[2]   Corrected to Eh-SHE (standard hydrogen electrode) by adding 224-T to the field ORP, where T is the temperature in degrees C.
[3]   Dissolved concentrations

The pH is similar, but groundwater concentrations of copper, zinc, and iron are higher than in the Deep Adit Confluence water. The groundwater concentrations are also higher than the water quality that would be predicted for the "diffuse" or seep input (i.e., copper of 34 µg/L, zinc of 124 µg/L, etc.) in the mass balance. This implies that the seeps are influenced by dilution or chemical processes prior to discharge, or that the area over which groundwater is significantly contaminated is smaller than would be predicted based on the DA groundwater monitoring well samples alone. Because groundwater is of considerably higher quality upgradient of the Tigroney West (Deep Adit) spoils area, as evidenced by the sample from the well MWPF1 (see Table 4-3), inflow and mixing with relatively "clean" water from areas upgradient of Whitesbridge are probably contributing to the lower-than-expected loading from the riverbank seeps in the spoils area. The "dilution effect" of the Avoca River would also be expected to influence riverbank seeps, as river water enters and flows back from the adjacent alluvial aquifer in tune with the rise and fall of river stage.

Combined with groundwater and direct seepage from spoils adjacent to the river, leakage from the ditch which conveys the Deep Adit discharge is considered a likely contributor to riverbank mass loading. The leakage would not influence the riverbank seeps directly, but would infiltrate into the underlying groundwater (i.e., an indirect pathway). The sides and bottom of the ditch are completed in coarse spoils, and while buildup of precipitates may partially seal the channel, downward and lateral leakage probably occurs. The base of the ditch is at a higher elevation than the groundwater table beneath the spoils (as measured in well MWDA1), and there is an expected falling head gradient from the location of the ditch to the river (except potentially during extreme river flood events). As shown in Figure 2-4a in the Data Report, the ditch (the brown linear feature north of samples BS16 through BS21) follows a southeast coarse which is semi-parallel to the Avoca before turning due south to the discharge point. The expected quality of the ditch water would be somewhere

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between the analyses for the Deep Adit discharge and Deep Adit Confluence samples (summarised in Figure 5-2).

Overland flow is an unlikely source to account for the metals load at T2 because the loadings were measured on July 30, 2007 and no rain was recorded for the previous days that would result in overland runoff. However, loading via overland flow may be an important process during storm events, as discussed below.

5.2.4 Runoff (Overland Flow)

On August 5, 2007, CDM sampling personnel observed significant overland flow across the SP1 spoils pile (see Figure 5-8). The spoils tend to develop a surface crust (possibly a precipitate) which spatially affects (impedes) rapid infiltration of rain water. The runoff on August 5 was sampled just before entering the Avoca River from a low area which had begun to channel the runoff. GSI also observed runoff in the area on November 20, 2006 and collected a sample. The analytical results for both samples are shown in Table 5-5.

Figure 5-8 Runoff from the Tigroney West Area Spoils Piles (August 5, 2007)

Table 5-5 Water Quality of a Runoff Collected from the Surface of Spoil Pile SP1

Parameter	Result[1] (Collected by CDM August 5, 2007)	Result (Collected by GSI November 20, 2006)
Copper	4,549	1,563
Zinc	2,806	45,190
Iron	39,930	23,840
Aluminum	22,980	98,200
Lead	108	2,009
pH (su)	2.93	3.12
SC (µmhos/cm)	1,051	1,670
Eh-SHE (mv)	751	—

[1]µg/L unless noted otherwise, dissolved concentrations

Although metal concentrations in the runoff are lower than groundwater (and presumably the spoils leachate), the impact on the Avoca River could be significant during the storm events.

5.2.5 Diffuse Groundwater Flow

As mentioned previously, the potential sources of pollutant loading in the riverbank samples include diffuse groundwater flow, discharging to the river through the alluvial aquifer which underlies the spoils area and the river. The low pH and elevated metals concentrations in groundwater have three potential sources:

- Infiltration of leachates in the spoils area

- Influx of groundwater from bedrock along the eastern margin of the alluvial aquifer (via deep groundwater and the transition zone – see Section 4)

- Infiltration of ditch water associated with the Deep Adit flow channel

Of these, infiltration of spoils leachate is considered to be the main source, followed by infiltration of ditch water and influx of water from bedrock (the latter is expected to be very small, as described in Section 4). Leachates from spoils therefore affect the quality of riverbank seeps indirectly via groundwater discharges to the river.

The mass loading of the riverbank seeps in the Tigroney West (Deep Adit) spoils area is also expected to be influenced by influx of higher quality groundwater from the area to the north of Whitesbridge, which would tend to dilute groundwater beneath the spoils area through mixing. Finally, the seeps would also be influenced by dilution of river water by flushing as the river rises and falls in tune with flood events, which in turn affects groundwater levels immediately adjacent to the river.

5.2.6 Avoca Water Quality – Minus Deep Adit Discharge

The effect of removing the Deep Adit discharge was calculated by subtracting out the flow and load of the Deep Adit Confluence water from the cumulative load. The input from the spoils leachate, runoff, diffuse flow, and ditch leakage was assumed to be the

same. The predicted concentrations of copper, zinc, iron, and sulfate at T2 were calculated from the load and flow. The results are presented in Table 5-6a.

Table 5-6a Avoca Water Quality Minus the Deep Adit Discharge for Segment A (T1 - T2) - Confluence

Sample I.D.	Flow (L/day)	Copper Diss. Conc. (µg/L)	Copper Load (kg/day)	Zinc Diss. Conc. (µg/L)	Zinc Load (kg/day)	Iron Diss. Conc. (µg/L)	Iron Load (kg/day)	Sulfate Conc. (µg/L)	Sulfate Load (kg/day)
T1	505958400	8.00	4	29	14.7	99	50	5.00	2,530
Vale View	1814400	0.00	0.004	3	0.005	7	0.01	16.00	29
Deep Adit	1390090	0.00	0.000	0	0	0	0	0.00	0.00
Spoils Leachate, Ditch Leakage, and Diffuse Flow	91749110	34.43	3	124	11	510	47	10.42	956
T2	600912000	**12**	7	**43**	26	**161**	97	**5.85**	3,515

As the ditch leakage would not be present under an adit treatment scenario (as mentioned previously), the actual concentrations could be somewhat lower. However, desorption from the bed sediments could offset the benefit of treating the ditch water. The predicted concentrations in the Avoca River using the sample nearer the Deep Adit are presented in Table 5-6b.

Table 5-6b Avoca Water Quality Minus the Deep Adit Discharge for Segment A (T1 - T2) - Adit

Sample I.D.	Flow (L/day)	Copper Diss. Conc. (µg/L)	Copper Corrected Load (kg/day)	Zinc Diss. Conc. (µg/L)	Zinc Load (kg/day)	Iron Diss. Conc. (µg/L)	Iron Corrected Load (kg/day)	Sulfate Conc. (µg/L)	Sulfate Corrected Load (kg/day)
T1	505958400	8.00	4	29	14.7	99	50	N/A[1]	N/A
Vale View	1814400	0.00	0.004	3	0.005	7	0.01	N/A	N/A
Deep Adit	1390090	0.00	0.000	0	0	0	0	N/A	N/A
Spoils Leachate, Ditch Leakage, and Diffuse Flow	91749110	20.91	2	53	5	-561	-53	N/A	N/A
T2	600912000	**10.05**[2]	6	**33**	20	**-5**	-3	N/A	N/A

[1] N/A = Not Analyzed
[2] Conc (µg/L) = (Corrected Load (kg/day)/Flow (L/day))*1,000,000,000 µg/kg

Again, the predicted iron concentration is negative due to attenuation of iron within the ditch (before reaching the Avoca River). The negative concentration for iron suggests that the copper concentration is also overly optimistic. Note that for the purposes of this evaluation, the treated water was assumed to contain no iron, copper, sulfate, or zinc. The assumption is conservative in that it provides a best-case scenario. However, in reality the effect will be minor due to the low flow of the Deep Adit compared to the Avoca River (the Deep Adit represents about 0.2 percent of the flow at T2). The predicted Cu concentration (10 µg/L) is greater than the value of 5 µg/L given in the Water Quality (Dangerous Substances) Regulations, SI No. 12 of 2001. Based on these results, the Tigroney West (Deep Adit) spoil seeps would need to be addressed in order to meet water quality standards in the Avoca River.

5.2.7 Avoca River Water Quality – Minus Deep Adit Discharge and Tigroney West Seepage

The water quality in the Avoca assuming that both the adits and the diffuse flows are contributing no metals or sulfate is shown in Table 5-7.

Table 5-7 Avoca Water Quality Minus the Deep Adit Discharge for Segment A (T1 - T2) - Confluence

		Copper		Zinc		Iron		Sulfate	
Sample I.D.	Flow (L/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T1	505958400	8.00	4	29	14.7	99	50	5.00	2,530
Vale View	1814400	0.00	0.004	3	0.005	7	0.01	16.00	29
Deep Adit	0	0.00	0.000	0	0	0	0	0.00	0.00
Spoils Leachate and Runoff, Ditch Leakage, and Diffuse Flow	91749110	0.00	0	0	0	0	0	0.00	0
T2	599521910	**6.76**	4	**24.48**	15	**83.57**	50	**4.3**	2,559

Under this scenario, all of the loading is contributed from upgradient of the mine site. The results show that the predicted Cu concentration is very near the water quality standard of 5 µg/L.

5.3 Segment B (Transect 2 to Transect 5)

Segment B extends from Transect 2 to Transect 5, a distance of approximately 940 metres. Transect 5 is located just south of the Wicklow County Yard across from the abandoned coal yard. The mass/water sources for Segment B could include the following:

- Seepage from the West Avoca pit and Emergency Tailings areas
- Ballygahan Adit Discharge
- Road Adit Discharge
- Diffuse Flow (Groundwater)
- Runoff from the West Avoca Spoil Piles

Losses of water can occur as well, such as in losing portions of the river. At the time of the flow measurements taken in July 2007, overall Segment B was a losing stretch. The point where the river starts losing water is not precisely defined, but is inferred to start at a location just downstream of Transect 2. The Avoca River valley and associated alluvial aquifer narrows considerably below the Road Adit, and the river banks steepen. The cause for the loss of flow is not precisely known without supporting groundwater elevation data to the south of the Road Adit, but the loss is inferred to be related to riverbed seepage and riverbank storage. There are no river abstractions along this stretch of the river, so there has to be a natural, but not yet fully defined , reason for the net loss in flow.

The loading analysis for Segment B using the Road Adit Confluence sample in the calculations is shown in Table 5-8a and Figure 5-9a.

Table 5-8a Water and Mass Balance Summary for Segment B (T2 - T5) - Confluence

Sample I.D.	Flow (L/day)	Copper		Zinc		Iron		Sulfate	
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T2	600912000	12.00	7	143	85.9	162	97	9.00	5408
Ballygahan Adit	5443	5237	0.029	21680	0.118	10800	0.06	2072.00	11
Road Adit Confluence	1670890	2.00	0.003	10600	18	30.00	0.05	1539	2571
Seeps/GW Loss	- 169983533	- 18.47	3	-69	12	-452	77	-32	5420
T5	432604800	24.00	10	267	116	403	174	31	13411
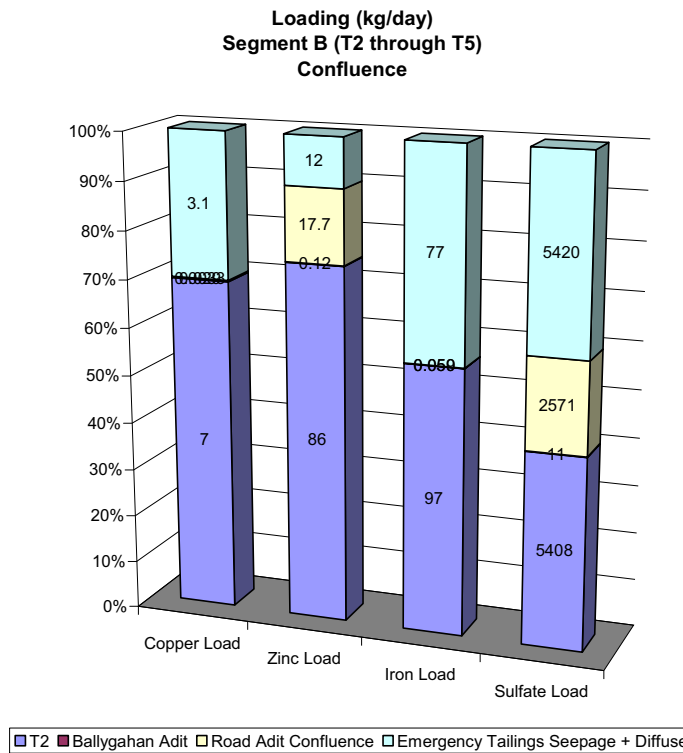
Figure 5-9a: Mass loading summary for Segment B (T2-T5) using the Road Adit Confluence sample results.

The results for copper, zinc, iron, and sulfate indicate a net gain of mass through Segment B, despite the fact that the river was losing flow within the segment during late July and early August 2007. One possibility is that groundwater seepage in the area of the Emergency Tailings area adds metals load, while groundwater loss occurs simultaneously or within lower portions of the segment. The negative concentration predicted for the lost water reflects the apparent contradiction where mass is gained while flow is lost.

The loading calculations performed using the Road Adit sample from near the portal are presented in Table 5-8b and Figure 5-9b.

Table 5-8b Water and Mass Balance Summary for Segment B (T2 - T5) - Adit

Sample I.D.	Flow (L/day)	Copper		Zinc		Iron		Sulfate	
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T2	600912000	12.00	7	143	85.9	162	97	N/A	N/A
Ballygahan Adit	5443.2	5237	0	21680	0.118	10800	0.06	N/A	N/A
Road Adit	1670890	268	0.448	10950	18	150700	252	N/A	N/A
Seeps/GW Loss	-169983533	-15.86	3	-66	11	1029	-175	N/A	N/A
T5	432604800	24.00	10	267	116	403	174	N/A	N/A

[1]   N/A = Not Analyzed

The analysis using the Road Adit sample again shows a greater than 100 percent contribution of iron, suggested that attenuation is occurring within the Road Adit ditch.

The contribution of the diffuse flow component at transect T5 for copper, zinc, iron, and sulfate was 30.0 percent, 10.3 percent, 44.3 percent, and 40.4 percent, respectively (calculated from the loads in Table 5-8a; for example for copper, the diffuse load is 3 kg/day and the load at T5 is 10 kg/day, and the diffuse contributions is 3kg/day / 10 kg/day x 100 percent = 30.0 percent). When data from Table 5-8b are used, the diffuse flow component at T5 for copper and zinc is 33 percent and 9.5 percent, respectively.

5.3.1 Emergency Tailings Seepage

The test pits and ET1 and ET2 borings in the Emergency Tailings showed that within these locations, the tailings are mainly dry, with almost no detectable moisture content, suggesting little or no infiltration of rainwater takes place (i.e., the tailings are naturally impermeable). Unlike the Tigroney West (Deep Adit) spoils area, the Emergency Tailings are not believed to be a significant contributor of leachates to underlying groundwater or riverbank seepage. Because the emergency tailings materials are in direct contact with the underlying alluvial aquifer, it cannot be ruled out that physical-chemical processes in the contact area may result in some metals loading of groundwater, as suggested by the water quality of the well located at the toe of the Shelton Abbey tailings impoundment (see Table 4-3).

5.3.2 Ballygahan Adit

Following closure of the Avoca Mine, the Ballygahan Adit discharged through a subsurface pipe into Seamus Heffernan's yard.

Upon excavation, Mr. Heffernan discovered that the pipe was plugged. After cleaning out the pipe, the discharge traveled a little further into his neighbor's garden. Discharge of the adit in the subsurface may have been responsible for the sinkhole present in this yard (see Figure 5-10). The County Wicklow was contacted and a 4-inch pipe from the garden to the Avoca River was installed which now discharges over a steep bank.

Metals concentrations within the discharge are fairly high (copper = 5,237 µg/L and zinc = 21,680 µg/L). However, the flow was very low in late July 2007, amounting to approximately 0.063 L/s, or 5,443 L/day (flow measurements were difficult to achieve due to difficult access on the steep slope leading down to the river). Overall, the metals loading of the Ballygahan pipe is relatively insignificant.

Figure 5-10 Sinkhole likely caused by prior subsurface discharge of the Ballygahan Adit.

5.3.3 Road Adit Discharge

The Road Adit, like the Deep Adit, was also sampled at two locations; one near the portal, and the other at the confluence, just before entering the Avoca River. A comparison of the results is provided in Table 5-8.

Table 5-9 Comparison of Dissolved Metals Concentrations (µg/L) in the Road Adit vs. Road Adit Confluence Samples

Parameter	Road Adit Confluence (µg/L)	Road Adit (µg/L)
Aluminum	984	20930
Arsenic	3	6
Calcium	219,100	227,600
Cadmium	0.4	12.3
Copper	2	268
Iron	30	150,700
Lead	1	308
Manganese	42	13,240
Zinc	10,600	10,950

Like the Deep Adit, significant attenuation is occurring within the Road Adit ditch before it discharges into the Avoca River. Comparisons of the dissolved vs. particulate concentrations in the Confluence discharge are provided in Figures 5-11 and 5-12.
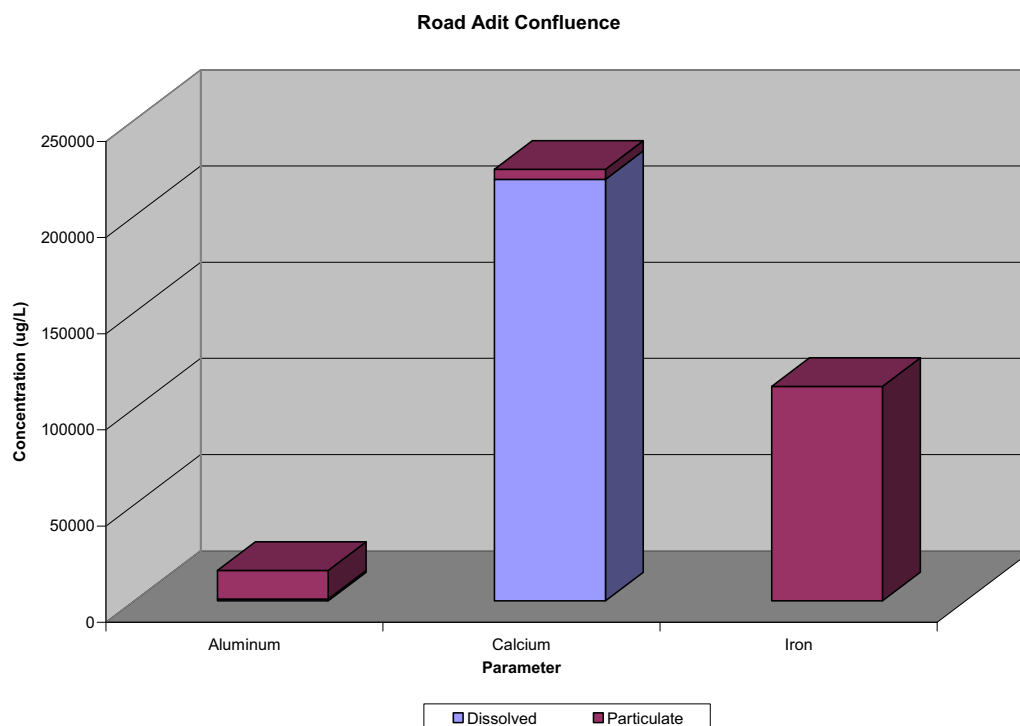
Figure 5-11 Relative Proportion of particulate phase metals (red) as compared with the dissolved phase (blue) for the Road Adit Confluence Sample (July 2007).

Road Adit Confluence
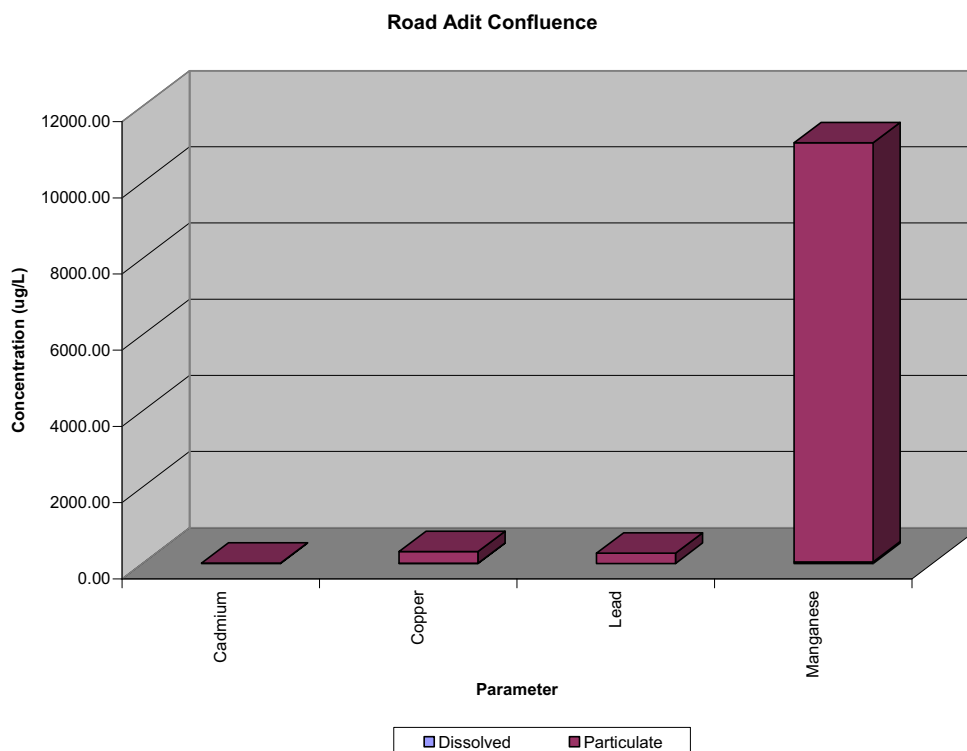
Figure 5-12 Relative Proportion of particulate phase metals (red) as compared with the dissolved phase (blue) for the Road Adit Confluence Sample (July 2007).

Essentially all of the iron, copper, cadmium, lead, and aluminum are present in the particulate form, while the calcium and zinc (not shown) are present mainly in the dissolved form. The result is that the Road Adit has a low contribution of copper (0.3 percent) and iron (0.3 percent) at transect T5. The lower attenuation of zinc and sulfate result in larger contributions by the Road Adit, at 67 percent and 33 percent, respectively.

5.3.4 Diffuse Flow

Table 5-10 presents the results of riverbank samples collected on the west bank of Segment B (see Figure 2-4b in the Data Report for the sample locations). The west bank samples collected adjacent to the Emergency Tailings had pH values less than 6 su, Eh in excess of 400 mv, and elevated copper and zinc concentrations indicating a direct contribution from groundwater seepage.

These impacted riverbank seeps originate as groundwater which discharges from the alluvial aquifer which underlies the Emergency Tailings area. As discussed in Section 5.3.1, the Emergency Tailings are not believed to be a source of leachate (from infiltrating rainwater), and the primary source of the impacted riverbank seeps is believed to be polluted groundwater flowing from upgradient areas in the west

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towards the river in the east. Upgradient areas include most of the spoils, pits and underground mine workings in West Avoca.

Table 5-10 Segment B Bank Sampling Results (July-August 2007)

Sample ID	Location	pH (su)	Eh-SHE (mv)	Conductivity at 25 ºC (uS/cm)	Copper (ug/L)	Zinc (ug/L)
CDM-BS8	W. of RR and S. of Whites Bridge (flowing water)	6.9	307	86	14	341
CDM-BS9	W. Bank directly across from BS8 (stagnant water)	5.67	445	126	65	300
CDM-BS10	50m N. of BS-9	5.61	428	106	90	375
CDM-BS11	W. Bank	5.34	453	127	66	413
CDM-BS12	W. Bank	5.95	429	89	83	482
CDM-BS13	W. Bank - Near T2 S. of Whites Bridge	6.56	380	74	8	61
CDM-BS14	W. Bank, S. of BS9	6.57	354	79	49	274
CDM-BS15	W. Bank - Beside black pipe	6.59	349	82	24	141

1. Red indicates the sample was collected from adjacent to the Emergency Tailings on the west bank of the Avoca.

Groundwater quality of wells sampled as part of this study were presented in full in Table 4-3, and selected results for August 3, 2007 in monitoring wells located immediately downgradient of the Ballymurtagh landfill and within the Emergency Tailings are presented in Table 5-11 below.

Table 5-11 Summary of Road Adit Area Groundwater Concentrations for Selected Parameters (August 3, 2007)

Well ID	Water Level bgs[1] (m)	Screened Interval bgs (m)	pH (su)	Eh-SHE (mv)	Dissolved Copper (µg/L)	Dissolved Zinc (µg/L)	Dissolved Iron (µg/L)	Sulfate (mg/L)
GW1/05	5.37	25-31[2]	4.07	638.6	9,664	12,190	731	1,121
GW2/05	4.94	4-10	4.00	443.5	6,047	6,651	92	753
MWET1[3]	7.32	7.8-10.6	4.08	533	358	15,240	87,260	1636
MWET2[3]	7.18	17-20	6.35	323	15	161	477	26
MWET1[4]		7.8-10.6			9,556	12,310	47,130	1,426
MWET2[4]		17-20			26	4,899	1,808	2,515

[1] bgs = Below Ground Surface
[2] County Wicklow Records
[3] November 2007
[4] February 2008

The concentrations of copper and zinc in groundwater are sufficiently high to explain the copper and zinc concentrations measured in the western riverbank samples, and it is inferred that contaminated groundwater from West Avoca is the primary source of metals loading to the Avoca River in the Emergency Tailings area.

Although there is a net loss of river flow within Segment B, the losses are believed to start downstream from the Emergency Tailings on account of the positive measured hydraulic gradients described in Section 4.4.

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As described in Section 4.6, the groundwater quality of the shallow well (MWET1) completed beneath the Emergency Tailings is considerably different from the deeper well (MWET2) at the same location for samples collected in November 2007 and February 2008. The shallow well is consistent with GW2/05, another shallow alluvial well located downgradient of the landfill. The deep well MWET2 has much lower metals and sulfate concentrations, and a near-neutral pH. This may partly be explained by the fact that a (partial) confining layer is protecting MWET2 at depth, and an upward hydraulic gradient was consistently measured between the wells over the study period to date.

The February 2008 results (Table 5-11) indicate that metal concentration in MWET2 increased when compared to the November 2007, possibly as a result of increased flow contribution from bedrock at depth in winter.

5.3.5 Runoff from the West Avoca Spoils

The spoils in West Avoca are located at a much greater distance from the Avoca River than the spoils in the Tigroney West area. Although less likely, this does not imply that a direct contribution of runoff to the Avoca River can be ruled out. The runoff is more likely to infiltrate into the ground and travel as groundwater to the river, or be intercepted by open ditches and flow indirectly as runoff to the river. No tributaries to the Avoca River are present within Segment B.

5.3.6 Avoca Water Quality – Minus Road Adit and Ballygahan Adit Discharges

The water quality predictions assuming no adit discharges for either Segment A or Segment B is provided for the analysis using the Road Adit Confluence sample in Table 5-12a.

Table 5-12a Avoca Water Quality Minus the Road Adit Discharge for Segment B (T2 - T5) - Confluence

Sample I.D.	Flow (L/day)	Copper		Zinc		Iron		Sulfate	
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T2	600912000	12.00	7	43	26	161	97	5.85	3515
Ballygahan Adit	5443.2	0.00	0.000	0	0.000	0.00	0.00	0.00	0
Road Adit Confluence	1670890	0.00	0.000	0	0	0.00	0.00	0	0
Emergency Tailings Seeps/GW Loss	-169983533	-18.47	3	-69	12	-452	77	-32	5420
T5	432604800	23.92	10	87	38	402	174	21	8935

Again, treatment of the adits alone appears to be insufficient to meet water quality standards for copper within the Avoca River of 5 µg/L and also do not meet the calculated, site specific values for survival, growth and reproduction of salmonid (11 µg/L). The predicted value for zinc is also above the Water Quality (Dangerous

Substances) Regulations of 50 µg/L. A similar analysis using the Road Adit sample is provided in Table 5-12b.

Table 5-12b Avoca Water Quality Minus the Road Adit Discharge for Segment B (T2 - T5) - Adit

Sample I.D.	Flow (L/day)	Copper		Zinc		Iron		Sulfate	
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T2	600912000	**10.05**	6	**33**	19.7	**-5**	-3	N/A	N/A
Ballygahan Adit	5443.2	0	0	0	0.000	0	0.00	N/A	N/A
Road Adit	1670890	0	0.000	0	0	0	0	N/A	N/A
Emergency Tailings Seeps/GW Loss	-169983533	-15.86	3	-66	11	1029	-175	N/A	N/A
T5	432604800	**20.18**	9	**71**	31	**-412**	-178	N/A	N/A

1. N/A = Not Analyzed

Iron loadings are negative due to attenuation of iron within both ditches (Road and Deep Adit). Even assuming the greater copper removals, water quality standards for copper and zinc are still not met without addressing the diffuse flow.

5.3.7 Avoca Water Quality – Adit Discharges and Diffuse Loading

The predicted concentrations in the Avoca assuming no adit or diffuse flow is presented in Table 5-13.

Table 5-13 Avoca Water Quality Minus the Adit Discharges and Diffuse Loading for Segment B (T2 - T5)

Sample I.D.	Flow (L/day)	Copper		Zinc		Iron		Sulfate	
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T2	600912000	**6.76**	4	**24**	15	**84**	50	**4.27**	2559
Ballygahan Adit	5443.2	0.00	0.000	0	0.000	0.00	0.00	0.00	0
Road Adit Confluence	1670890	0.00	0.000	0	0	0.00	0.00	0	0
Emergency Tailings Seeps/GW Loss	-169983533	0.00	0	0	0	0	0	0	0
T5	432604800	**9.36**	4	**87**	15	**402**	50	**21**	2559

Note that the concentrations are slightly higher due to the loss of 28 percent of the flow within Segment B. The predicted concentration for copper is still elevated above the Water Quality Regulation of 5 µg/L but below the site-specific value of 11 µg/L.

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5.4 Segment C (Transect 5 to Transect 3)

Segment C extends from Transect 5 to Transect 3, a distance of only about 200 m. No tributaries or adit flows are present within the segment. The segment was a gaining reach based on initial flow measurements; however, the tracer test (performed later at a lower flow) suggests that the segment was a losing reach at the time of testing. Using the initial flow measures, the metals loads decreased as shown in Table 5-14 and Figure 5-13.

Table 5-14 Water and Mass Balance Summary for Segment C (T5 - T3)

Sample I.D.	Flow (L/day)	Copper		Zinc		Iron		Sulfate	
		Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Diss. Conc. (µg/L)	Load (kg/day)	Conc. (µg/L)	Load (kg/day)
T5	432604800	24.00	10	267	116	403	174	31	13411
Attenuation	62294400	-39.56	-2.46	-75	-4.65	-399	-25	-120	-7472
T3	494899200	16.00	8	224	111	302	149	12	5939

**Loading (kg/day)
Segment C (T5 through T3)**
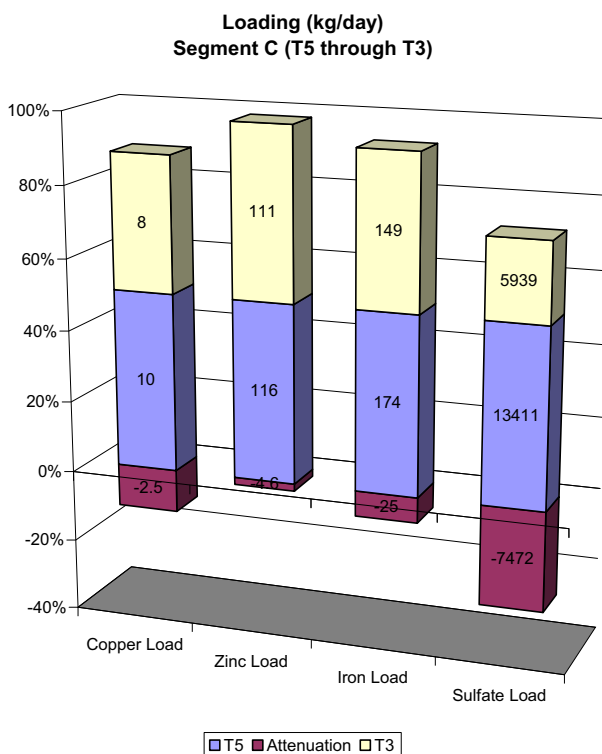
Figure 5-13 Mass loading summary for Segment C (T5-T3)

The decrease in loads can best be explained by attenuation within the bed sediments. Attenuation is clearly taking place within the Avoca, as evidenced by the red coating present on the river sediments and cobbles. The fact that the metals and sulfate concentrations decrease could also indicate influence of an influx of relatively clean groundwater, though given the short length of Segment C and the narrow extent of alluvial aquifer materials, this is not considered to be the primary cause for the decrease in loads.

The apparent contradiction between net flow and load measurements in Segments B and C may warrant additional field study.

5.5 Segment D (Transect 3 to Transect 4)

Segment D extends from Transect 3 to Transect 4, a distance of about 1,300 m. Segment D includes the following tributaries (sources of flow):

- Red Road Tributary
- Sulfur Brook
- Unknown Tributary

Segment D shows a net gain in measured flow, whereas the mass analysis (Table 5-15 and Figure 5-14) shows a decrease in copper and iron mass, and an increase in zinc and sulfur mass.

Table 5-15 Water and Mass Balance Summary for Segment D (T3 - T4) – Confluence

		Copper		Zinc		Iron		Sulfate	
Sample I.D.	**Flow (L/day)**	**Diss. Conc. (µg/L)**	**Load (kg/day)**	**Diss. Conc. (µg/L)**	**Load (kg/day)**	**Diss. Conc. (µg/L)**	**Load (kg/day)**	**Conc. (µg/L)**	**Load (kg/day)**
T3	494899200	16.00	8	224	110.9	302	149	12	5939
Red Road	1702080	0.50[1]	0.001	206	0.351	1.00	0.00	29	49
Sulfur Brook	9901440	0.50[1]	0.005	190	2	1.00	0.01	14	139
Unknown Trib	10272960	1.00	0.010	1	0.005	31.00	0.32	9	92
Desorption/Attenuation	-9521280	34.20	-0.33	-855	8	2413	-23	-93	882
T4	507254400	15.00	8	239	121	250	127	14	7102

1. One-half the analytical detection limit was used for ND values.

Loading (kg/day)
Segment D (T3 through T4)
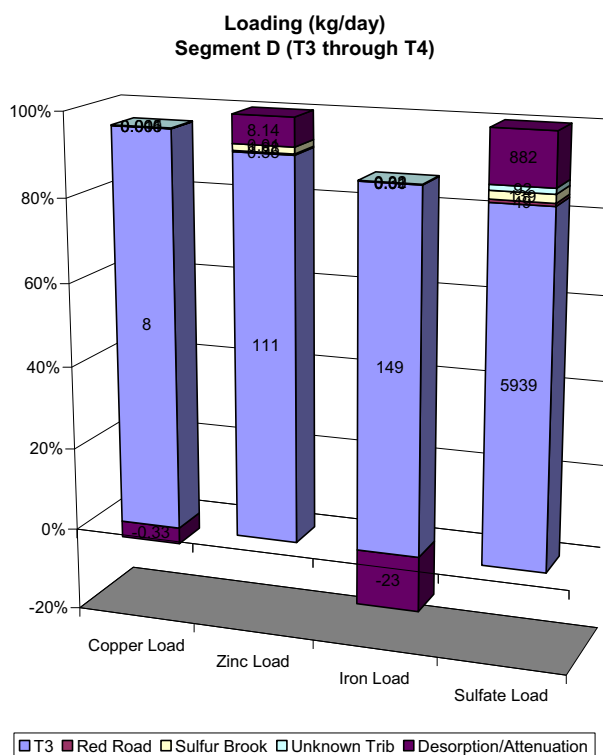
Figure 5-14 Mass loading summary for Segment D (T3-T4).

The loss of copper and iron mass is likely due to attenuation as these metals tend to have low mobility within a near-neutral pH and oxidizing environment. However, under the same conditions, zinc and sulfate tend to be mobile, and the increase in loadings of these elements is likely due to desorption from bed sediments. The bed sediments likely contain higher concentrations of sulfate and zinc than the equilibrium value due to improvements in the water quality of the Avoca within the segment. Such improvements are related to the decreased metal loads from the tributaries over time, as will be discussed in more detail in the following sections.

5.5.1 Red Road Tributary

The Red Road tributary drains the West Avoca spoils area and enters the Avoca near the beginning of the segment (just north of the Toyota dealership on Rathdrum Road). As discussed in the Conceptual Site Model Phase 1 Report, the Red Road tributary was once used to convey mine water pumped from the workings. Evidence of the former use of the tributary can be seen as a red-brown coating on the cobbles and sediments within the channel.

The loads of copper, zinc, iron, and sulfate are negligible due to both the low concentrations and flow. For example the copper load of the Red Road tributary was 0.001 kg/day, compared to a load of 8 kg/day at T4, which represents only 0.01 percent of the load (0.001/8 *100 percent = 0.013 percent). The concentrations of

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metals and sulfate have been low and stable since at least 1995, as was discussed in the Conceptual Site Model Phase 1 Report.

5.5.2 Sulfur Brook

Sulfur Brook drains the south slope of the East Avoca area. At one time, Madam Butler's adit, discharged into Sulfur Brook, which adversely impacted the water quality. However, in recent times, the Madam Butler adit discharge has been diverted away from the Sulfur Brook drainage, which has significantly improved the water quality. Table 5-16 shows the water quality of Sulfur Brook in 1993, and 1995, compared to the most recent analysis in July 2007.

Table 5-16 Comparison of Sulfur Brook Water Quality from November 1993 through July 2007

Date	Collected By	pH (su)	EC (µmho/cm)	Dissolved Copper (µg/L)	Dissolved Zinc (µg/L)	Dissolved Iron (µg/L)	Sulfate (mg/L)
November 1993	GSI[2]	5.9	154	53	279	0[1]	16
August 23,1995	GSI[3]	6.37	190	384	875	89	20.5
September 5, 1995	GSI[3]	6.24	210	394	978	105	21.3
October 4, 1995	GSI[3]	6.26	270	445	1,656	221	37.9
October 19, 1995	GSI[3]	6.33	190	365	1,352	75	23.3
July 31, 2007	CDM	7.18	146	<2	190	<1	14

1. Detection limit not provided
2. Reported in Flynn, 1994
3. Reported in Gallagher and O'Connor, 1997

The results show that the water quality of Sulfur Brook has significantly improved since 1993. Attenuation of metals and sulfate onto sediments of the Avoca River during times when aqueous concentrations were much higher has resulted in sediment concentrations that are not in equilibrium with respect to the lower aqueous concentrations of today. For the more mobile elements, such as zinc and sulfate, the result has been a transfer of zinc and sulfate from the sediment to the aqueous phase, given the increased loadings in the Avoca shown in Table 5-15.

Due to the low flow and concentrations, the load of Sulfur Brook to the Avoca is negligible (<2 percent for all parameters).

5.5.3 Unknown Tributary

The unknown tributary drains the area directly east of the Avoca Hand Weavers in an area that is presumably unimpacted by mining activities. The concentrations of copper, zinc, iron, and sulfate in the unknown tributary are very low and likely represent area background. Due to the low concentrations and flow, the load of the unknown tributary to the Avoca River is negligible.

5.5.4 Attenuation

Attenuation of metals and sulfate onto sediments of the Avoca River during times when aqueous concentrations were much higher (due to higher concentrations in Sulfur Brook, Red Road Tributary and with the Deep and Road adit discharges) has

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resulted in sediment concentrations that are not in equilibrium with respect to the lower aqueous concentrations of today. For the more mobile elements, such as zinc and sulfate, the result has been a transfer of zinc and sulfate from the sediment to the aqueous phase, given the increased loadings in the Avoca shown in Table 5-15.

5.6 Segment E (Adjacent to the Shelton Abbey Tailings)

Due to the significantly higher flows in Segment E compared to the segments further upstream, flows could not be safely measured using the available equipment (i.e. Marsh McBirney flow meter) because the river could not be waded by the field personnel.

The bank sampling results shown in Table 5-17 suggest that the Shelton Abbey Tailings are having a minimal impact on the Avoca River (see Figure 2-4d in the Data Report for locations).

Table 5-17 Segment C Bank Sampling Results (July-August 2007)

Sample ID	Location	pH (su)	Eh-SHE (mv)	Conductivity at 25 ºC (uS/cm)	Copper (ug/L)	Zinc (ug/L)
CDM-BS25	Avoca E. Bank - above Shelton Abbey	6.56	322	118	7	123
CDM-BS26	Tributary up-gradient of SA Tailings	6.63	329	177	2	<1
CDM-BS26B	E. Bank - 50m down-gradient from BS25	6.78	303	118	-	-
CDM-BS27	Small pond on E. Bank below tailings	4.04	569	602	108	831
CDM-BS28		6.71	318	118	7	133
CDM-BS29	River adjacent to BS27	6.57	327	117	-	-
CDM-BS30		6.78	305	117	9	119
CDM-BS31		6.79	311	123	10	134
CDM-BS32	Duck Pond	6.31	239	279	-	-
CDM-BS33	E. Bank - Down-gradient of SA Tailings (adjacent to detention facility)	6.86	301	121	-	-

The sample collected from upstream of Shelton Abbey (BS-25) is virtually identical to the downstream locations. The only sample that was obviously impacted by the tailings was sample BS-27, which was collected within a small pond at the base of the tailings dam. In April 2007, the pond was observed flowing into the Avoca River, as shown in Figure 5-15. However, the load was apparently not great enough to significantly effect the quality of the Avoca River due to the very low flow of the pond into the river and the very high flow of the Avoca River.

Figure 5-15 Avoca River Adjacent to the Shelton Abbey Tailings. Low pH and Metals-Bearing Water from a Small Pond at the Base of the Tailings Dam can be Seen Entering on the Left (April 2007).

Section 6
Summary and Conclusions

The conclusions of the CSM addendum are as follows:

- The forms of copper, zinc, arsenic, and lead in the spoils and tailings are determined by the type of the original ore (i.e. supergene vs. sulfide or East Avoca vs. West Avoca), the type of waste (spoils vs. tailings), the depth of burial and age of the waste.

- Cronebane supergene ore (Mt. Platt) contained more iron oxyhydroxides than other wastes (due to gossan cap) as well as supergene copper minerals.

- Buried spoils derived from sulfide zone ore contains copper, lead, zinc, and arsenic as primary sulfide minerals with some degree of oxidation/weathering.

- In surface spoils, primary sulfide minerals are rare, with secondary minerals such as plumbojarosite predominating.

- In general, the tailings are less oxidized than the spoils and contain metals and arsenic as primary sulfides.

- Copper, lead, arsenic, and zinc are abundant in the primary phases, but only lead and arsenic are abundant within the secondary phases (plumbojarosite), due to leaching of copper and zinc.

- The Intermediate Adit contributes a major proportion of the flow and metals and arsenic loads to the Deep Adit. Concentrations within the adit appear to be seasonal, with peak concentrations an order of magnitude higher than other times of the year.

- The Kilmacoo, Cronebane Shallow, Ballygahan, Spa, and Madam Butler adits are of minor importance in terms of metals and arsenic loading to the Avoca, either because of low loads or absence of surface flow to the river.

- The Deep Adit and Road Adit metal concentrations appear to have decreased slightly between 1993/94 and 2007, but paucity of data prevents a specific trend analysis to be carried out. Large seasonal variations in metal concentrations are apparent from existing data.

- The Deep Adit area spoils and/or groundwater are an important diffuse flow input of metals to the Avoca River, while surface runoff may be important following storm events.

- The Emergency Tailings are not believed to be an important source of metals to the Avoca as they are unsaturated, unreacted, and have a soil cap that holds water (is relatively impermeable). The observed low pH and elevated metals concentrations

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in the bank samples adjacent to the tailings are likely due to groundwater discharging to the river. The source of the low pH and elevated metals are believed to be the upgradient West Avoca spoil and pit areas.

- Treatment of the adits which directly discharge to the Avoca (Deep Adit, Road Adit, and Ballygahan) would not provide a sufficient loading reduction to attain Water Quality (Dangerous Substances) Regulations.

- Treatment of both the direct adit discharges and control of diffuse flow could potentially achieve Water Quality Regulations at selected times of the year assuming that significant metals exchange does not occur between the river sediments and the overlying river water (or assuming that selected sediments are removed).

- Despite some observed inputs of low pH, metal-bearing water to the Avoca River from the base of the Shelton Abbey Tailings, the loads are low enough compared to the flow of the river within that segment that the pH and metals concentrations within the near-bank samples are indistinguishable between the upstream sample and those adjacent to or downstream of the tailings.

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Appendix A
Electron Microprobe Analysis

Methodology
Overview

Analyses on a single grain of soil or a single crystal of a precipitate were accomplished using an EMP. Not only can analyses be made on particles as small as 1 micron, but the EMP also provides a visual picture of the soil at magnifications ranging from 40 to 90,000 times. The visual mode is referred to as the "backscatter mode." Information about the relative atomic number of the compounds can be obtained in the backscatter mode due to the contrast in brightness between the low atomic number compounds and the compounds with high atomic numbers. For example, arsenic and iron compounds, which have high mean atomic numbers, tend to be bright white in backscatter mode, while silica compounds, with lower mean atomic numbers, are gray and organic carbon is nearly black. Direct visual inspection of the soil also provides information on the associations, morphology, and any reaction rims on the particles, all of which provide insight into the geochemical history of the sample. Soil samples were analyzed on a JEOL 8600 Superprobe located in the Department of Geological Sciences, University of Colorado, Boulder, Colorado.

Sample Preparation

A 1 gram split of each unground homogenized sample was used to prepare epoxy grain mounts. The procedure for preparing the mounts included pouring the sample into a 1-inch diameter mold and covering with a thin layer of air-cured epoxy. The grains were then blended with the epoxy using a disposable wood stirring rod and additional epoxy was added. After curing at room temperature, the mount was ground flat, forming a cross sectional cut through the grains. Polishing of the mount was performed using successively finer grades of oil-based diamond paste. The final step in the preparation of the grain mounts was

to apply a thin carbon coating to the surface of the mount or "puck" in order to allow proper conduction during microprobe analysis.

Operating Conditions

Operating conditions included a 15 KeV accelerating voltage, 17 NanoAmp cup current, and a 1 to 2 micron beam size. Certified pure element standards were used to determine phase compositions. Wavelength spectrometer crystals TAP for arsenic, PET for iron and sulfur and LDE1 for oxygen were used for the WDS analyses.

Analytical Procedure

Sample pucks were scanned for arsenic-containing minerals using backscattered electron images. The scanning was done manually by systematically traversing from left to right until the edge of the mount was reached. The puck was then moved up one field of view and scanned from right to left. This process was repeated until the whole mount was scanned.

Typically, the magnification used for scanning samples was 40-100X and 300-600X, depending on the individual sample's grain size distribution. The last setting allowed the smallest identifiable (1 to 2 µm) phases to be found. Once a candidate particle was identified, then the backscatter image was optimized to discriminate any different phases within the particle or its association. Identification of the arsenic-bearing phases was done using both energy-dispersive and wavelength-dispersive spectrometers set for analyses of arsenic, sulfur, iron, and oxygen.

Samples Analyzed

A summary of the samples collected for EMP analyses are summarized in **Table A-1.**

Table A-1 – Summary of Samples Analyzed by Electron Microprobe

Sample ID	Location	Depth (m)	Type	Collection Method	Depth Classification
SA-17S	Mt Platt (SP20)[1]	0.15	Spoils	Grab	Surface
SA-7A	Shelton Abbey	0.15	Tailings	Grab	Surface
SA-9	West Avoca (SP34B)	0.15	Spoils	Grab	Surface
SA-12	Connary (SP22)	0.15	Spoils	Grab	Surface
BH-WA1 2.55	West Avoca (SP34B)	2.55	Spoils	Borehole	Subsurface
BH-MP1 8	Mt Platt (SP20)	8	Spoils	Borehole	Subsurface
BH-SA1 17.5	Shelton Abbey	17.5	Tailings	Borehole	Subsurface
BH-ET1 2	Emergency Tailings	2	Tailings	Borehole	Subsurface
BH-MP2 16	Mt Platt (SP20)	16	Spoils	Borehole	Subsurface
BH-ET1 7.5	Emergency Tailings	7.5	Tailings	Borehole	Subsurface
TP-CO4 0.3-0.4	Connary (SP31)	0.3	Spoils	Test Pit	Subsurface
TP-CO3 0.9-1.35	Connary (SP31)	0.9	Spoils	Test Pit	Subsurface

1. The spoil pile ID as defined by Gallagher et al., 1997 are provided in parentheses.

The "SA" series of samples (surface grab samples) were collected in April 2007, while the "BH" and "TP" series of samples (borehole and test pit subsurface samples, respectively) were collected in August 2007.

Results

Surface Tailings

The surface tailings were characterized by the following:

- Primary sulfides (pyrite, sphalerite, galena, etc.) were rare, and when present were remnants of larger grains and showed signs of dissolution (embayments, pitting, etc.) and weathering products (oxides and sulfates).

- Lead was present in high concentrations within plumbojarosite (16.7-23.0%).

- Arsenic was present in high concentrations within plumbojarosite (6.8%) and relatively low concentrations in iron oxyhydroxides (0.64%).

- Copper was present in relatively low concentrations in plumbojarosite (0.3%), schwertmannite (0.15%), and within iron oxyhydroxides (0.23-0.27%).

- Zinc was found in relatively low concentrations in plumbojarosite (0.16%) and near the analytical detection limit in a single grain of iron oxyhydroxide (0.003%).

- Native bismuth was identified in the sample, but was not common.

Shelton Abbey (SA-7A)

Sample SA-7A was characterized by secondary phases, as opposed to the primary sulfides found in the ore, as shown in photomicrographs 1 through 4.

Photomicrograph 1 – Alternating bands of iron oxyhydroxide (FeO) and FePbMgO(S)

Photomicrograph 2 – Alternating bands of As-Bearing Plumbojarosite (white) and Iron Oxyhydroxide (gray).

Photomicrograph 3 – Iron Oxyhydroxide Containing Copper, Zinc, Lead, and Possibly Arsenic. Note that the ND Value Reported for Arsenic was Due to a Malfunction of the WDS.
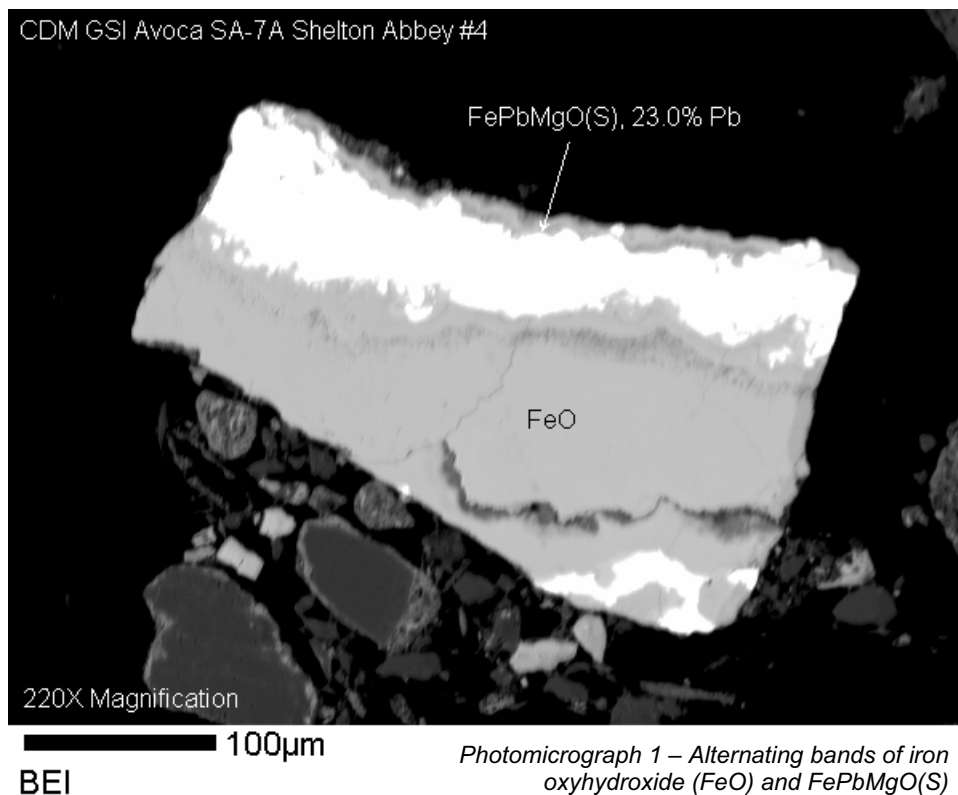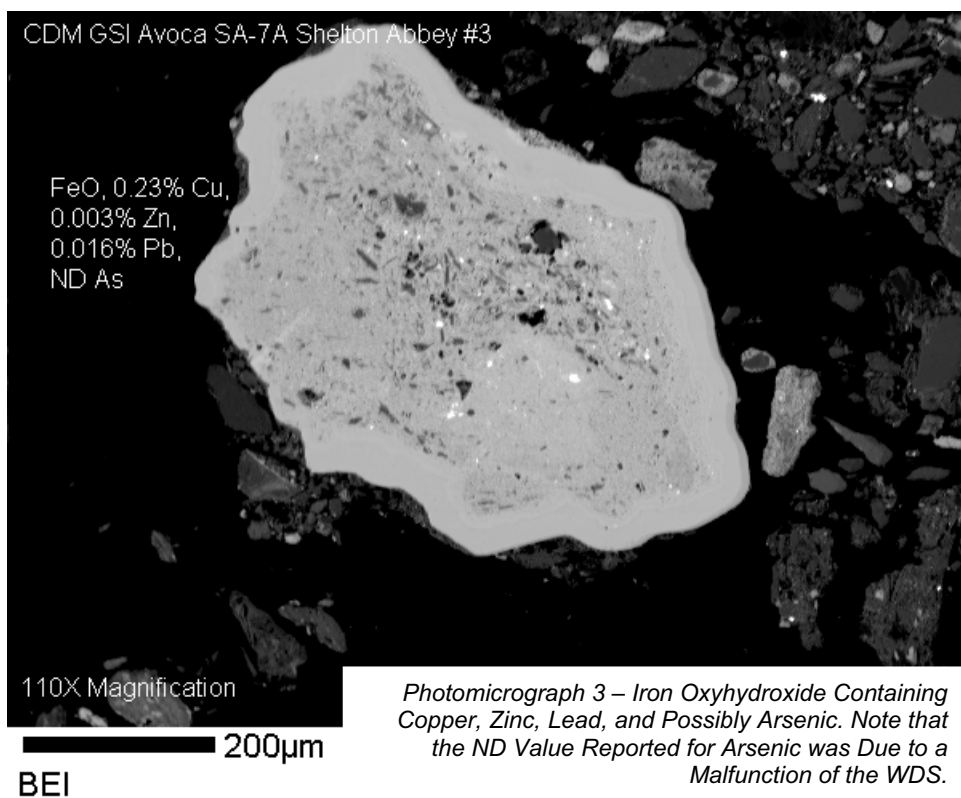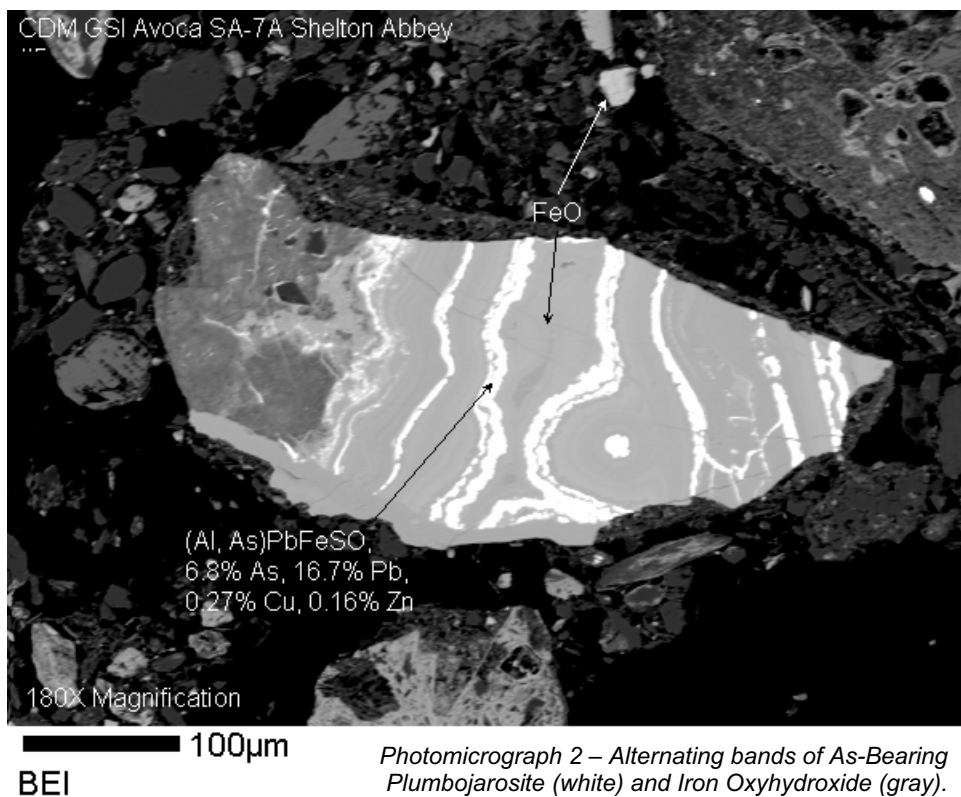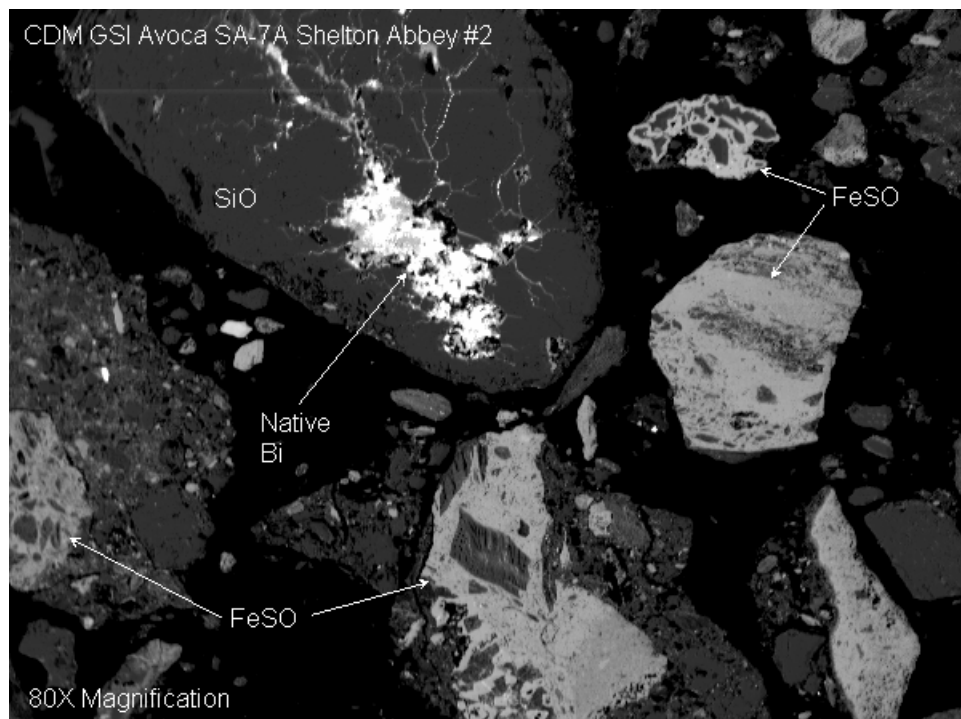
Photomicrograph 4 – Native Bismuth in a Quartz Matrix (white) and secondary jarosite (gray).
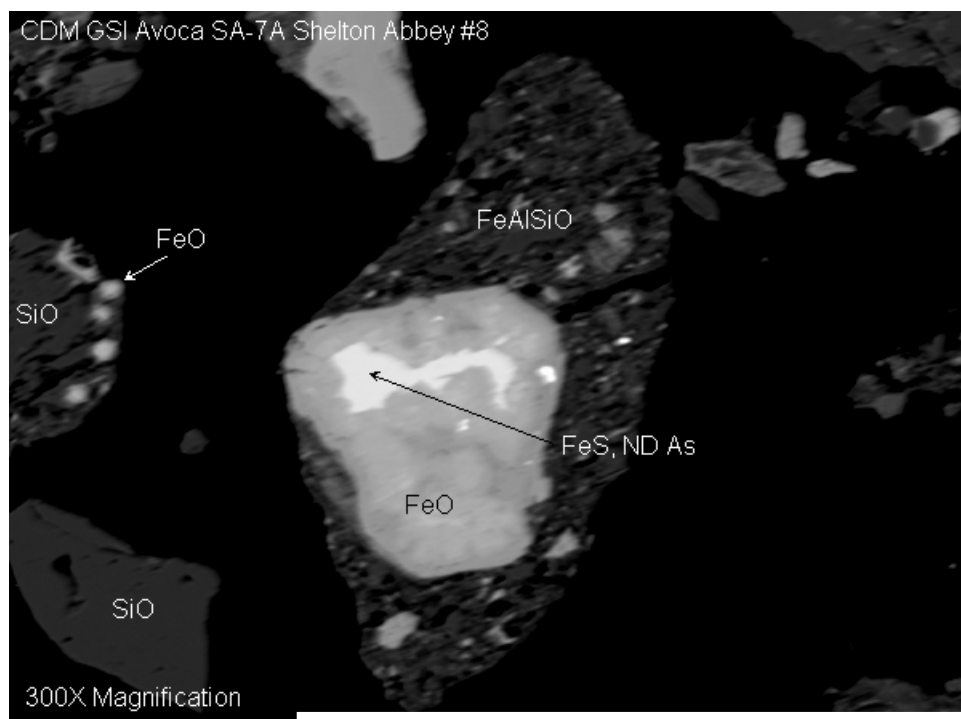
Photomicrograph 5 – Pyrite Grain (FeS) Which Has Been Almost Completely Weathered to Iron Oxyhydroxide (FeO).

When primary sulfides were present, the grains showed signs of weathering, such as pitted grains and embayments where part of the grain had been dissolved away. In some cases, grains of secondary minerals showing the relic crystal structure of the original sulfide mineral were present. An example is shown in photomicrograph 5, where a subhedral pyrite grain has been weathered to iron oxyhydroxide (labeled FeO in photo), retaining only a small core of the original pyrite (labeled FeS in photo).

The secondary minerals contain high concentrations of lead and arsenic. The mineral plumbojarosite, which is a lead-bearing iron hydroxysulfate mineral ($PbFe_6(SO_4)_4(OH)_{12}$), which contains 18% lead when pure, contained not only significant lead (16.7-23%), but high arsenic concentrations as well (6.8%). Concentrations of copper (0.27%) and zinc (0.16%) were much lower, but still significant. Photomicrographs 1 and 2 show examples of plumbojarosite grains.

Iron oxyhydroxide was also present (see photomicrograph 3), but generally contained three orders of magnitude lower concentrations of lead (0.016%), two orders of magnitude lower concentrations of zinc (0.003%), and an order of magnitude lower arsenic (0.64% on reanalysis). Copper concentrations (0.23%) were similar.

An example of an uncommon but interesting mineral found in the sample, was native bismuth, as shown in Photomicrograph 4. In the example shown in the photo, the bismuth is enclosed within a grain of quartz.

Buried Tailings

The buried tailings were characterized by the following:

- Primary sulfides (pyrite, sphalerite and iron-copper sulfide) were abundant and generally unoxidized, with euhedral grains and sharp edges.

- Lead was present as a sulfate mineral consistent with anglesite ($PbSO_4$, 68.3% Pb) and less commonly as galena (PbS, 86.6% Pb).

- Arsenic was present as an impurity within pyrite, with concentrations ranging from 0.2% up to 1.7%. The distribution of arsenic was extremely variable, with only about 10% of the pyrite grains containing detectable levels of arsenic. The variability was evident even within a single grain, with concentrations ranging from non-detect (ND) up to 1.0%.

- Copper was present as iron-copper sulfide, consistent with chalcopyrite (FeCuS, 34.6% Cu) or bornite (Cu_5FeS_4, 63.3% Cu).

- Zinc was present as zinc sulfide, consistent with the mineral sphalerite (ZnS, 64.1% Zn).

- Thallium and arsenic (0.79%) were present within an iron silicate mineral.

Shelton Abbey (BH-SA1 17.5)

The buried tailings contained abundant primary sulfide minerals which showed little or no evidence of weathering (see photomicrographs 6 through 8).

Photomicrograph 6 – Arsenic-Bearing Pyrite Grains (white)

CDM GSI Avoca BH-SA1 17.5 #4

CuFeS

FeS

600X Magnification

30μm

BEI

Photomicrograph 7 – Iron-Copper Sulfide Grain Consistent With Chalcopyrite

CDM GSI Avoca BH-SA1 17.5 #5

PbS

FeS

ZnS

1400X Magnification

10μm

BEI

Photomicrograph 8 – Pyrite (FeS) with Inclusions of Galena (PbS), Surrounded by Sphalerite (ZnS).
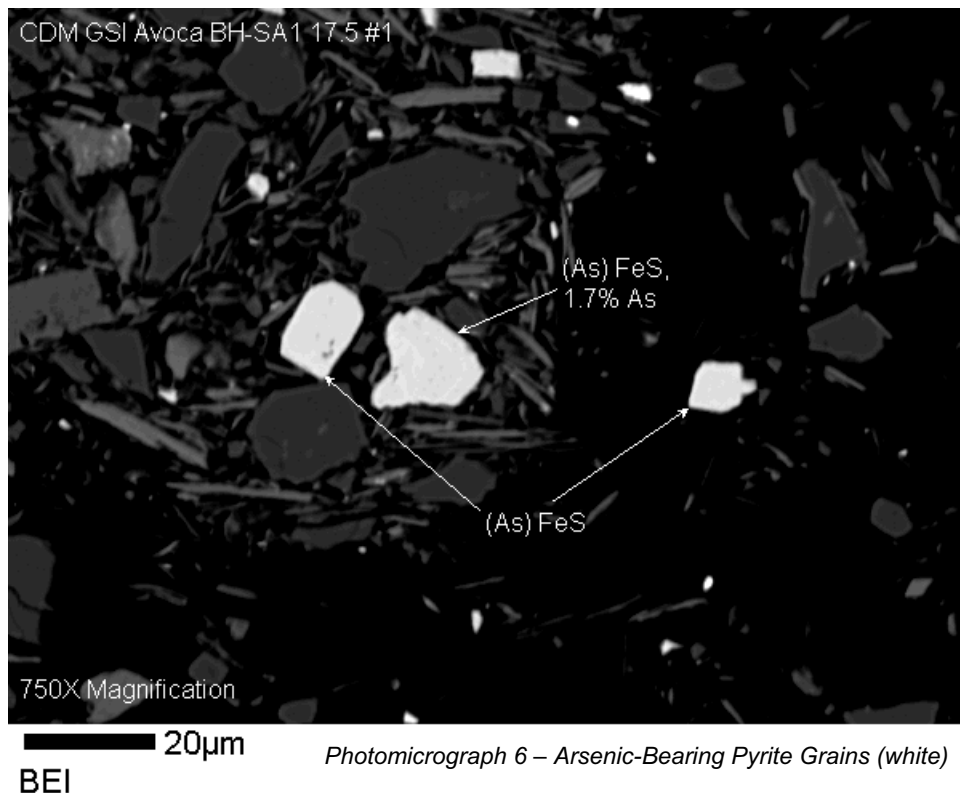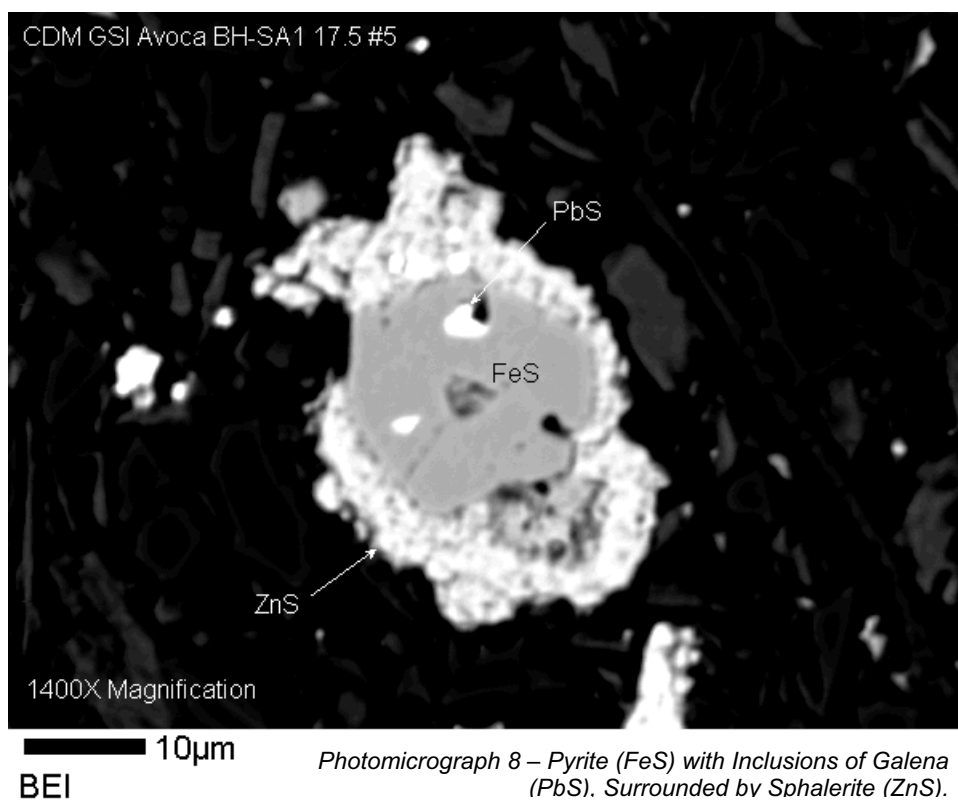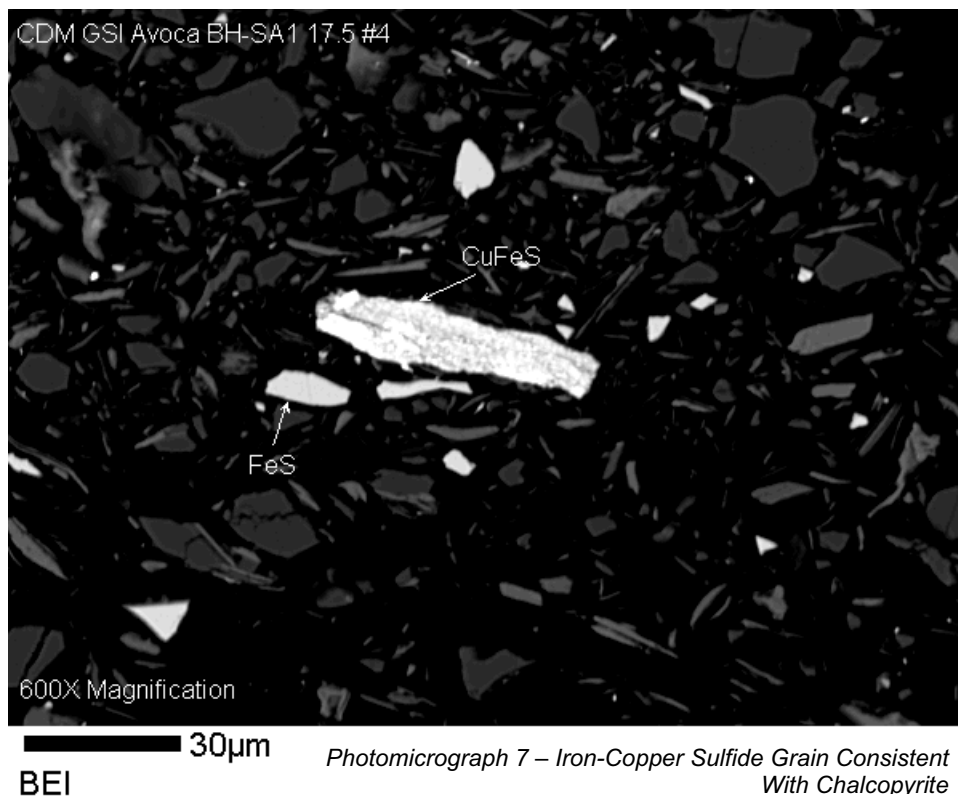
Photomicrograph 6 shows three grains of arsenic-bearing pyrite. The edges of the grains are sharp and the grains are not pitted of embayed, and there is no evidence of secondary reaction rims, all indicating a lack of oxidation (weathering). The presence of arsenic in the pyrite was not obvious, as only about 10% of the grains were arsenic-bearing. Arsenic was present in these grains at concentrations up to 1.7%, although most detections were on the order of 0.3-0.5%.

Copper was present in the form of iron-copper sulfide grains, most likely chalcopyrite ($FeCuS_2$) as this was the main ore mineral (see photomicrograph 7). Lead was present mostly as sulfates, consistent with the mineral anglesite ($PbSO_4$). In cases where the grains were aligned in the right way, a hexagonal cross section of the phase could be seen. The crystallinity of the lead sulfate grains suggest that the mineral is primary anglesite from the more oxidized portion of the ore body as opposed to secondary lead sulfate created due to oxidation of the tailings in place or of the EMP samples following collection. Lead was also present as a sulfide consistent with galena (PbS), as shown in photomicrograph 8. Zinc was present as a sulfide, consistent with the mineral sphalerite (ZnS). Iron was present within the mineral, as shown in the EDXRF spectra. The substitution of iron for zinc is common in sphalerite.

EDXRF Spectra for an Iron-Zinc Sulfide Mineral Consistent with Sphalerite (Zn, Fe)S.
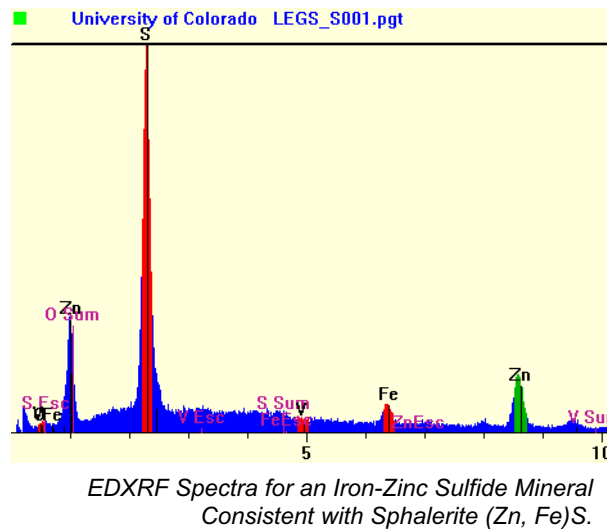
Emergency Tailings (BH-ET1 2)

The emergency tailings were very similar to the tailings at Shelton Abbey, in that they were characterized by primary sulfide minerals with little or no evidence of weathering. Arsenic-bearing pyrite was found at about the same frequency as for Shelton Abbey as well (about 1 grain in 10 was As-bearing). Photomicrograph 9 shows a pyrite grain in which the arsenic concentration varied from non-detect to 1.00%, depending on where within the grain the analysis was performed. Photomicrograh 10 is a "dot map" that shows the distribution of arsenic within the grain. The white dots represent arsenic, such that the greater the density of dots, the higher the arsenic concentration. The dot map shows that the arsenic concentration is significantly higher in the right-hand and lower portion of the grain.

CDM GSI Avoca BH-ET1 2 #1

ND As

FeS

1.00% As

0.51% As

2500X Magnification

8μm

BEI

Photomicrograph 9 – Pyrite Grain With Varying Concentrations of Arsenic.

CDM GSI Avoca BH-ET1 2 #1

2500X Magnification

Arsenic

8μm

As

Photomicrograph 10 – Dot Map Image of the Same Frame as in Photomicrograph 9 Showing the Distribution of Arsenic.

Photomicrograph 11 – Arsenic-Bearing Thallium-Iron Silicate Coating Quartz Grains.

Photomicrograph 11 shows a thallium-iron silicate mineral coating a large grain of quartz. The phase was not commonly found in the sample, but the thallium content was at the percent level (see EDXRF spectra) suggesting that this phase is likely a major form of thallium in the tailings. The morphology suggests that the phase is secondary.
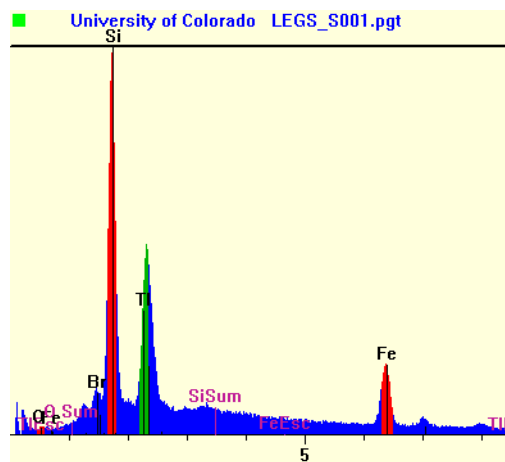
EDXRF Spectra of the Thallium-Iron Silicate Phase Shown in Photomicrograph 11

Emergency Tailings (BH-ET1 7.5)

The deeper sample from the emergency tailings was essentially the same as the shallower sample (discussed above). Primary sulfide minerals were abundant and generally unoxidized except for lead, which was a sulfate (Photomicrographs 12 through 14).

Photomicrograph 12 – Abundant Unweathered Pyrite Grains (white).

Photomicrograph 13 – Lead Sulfate Grain Consistent with Anglesite (white).
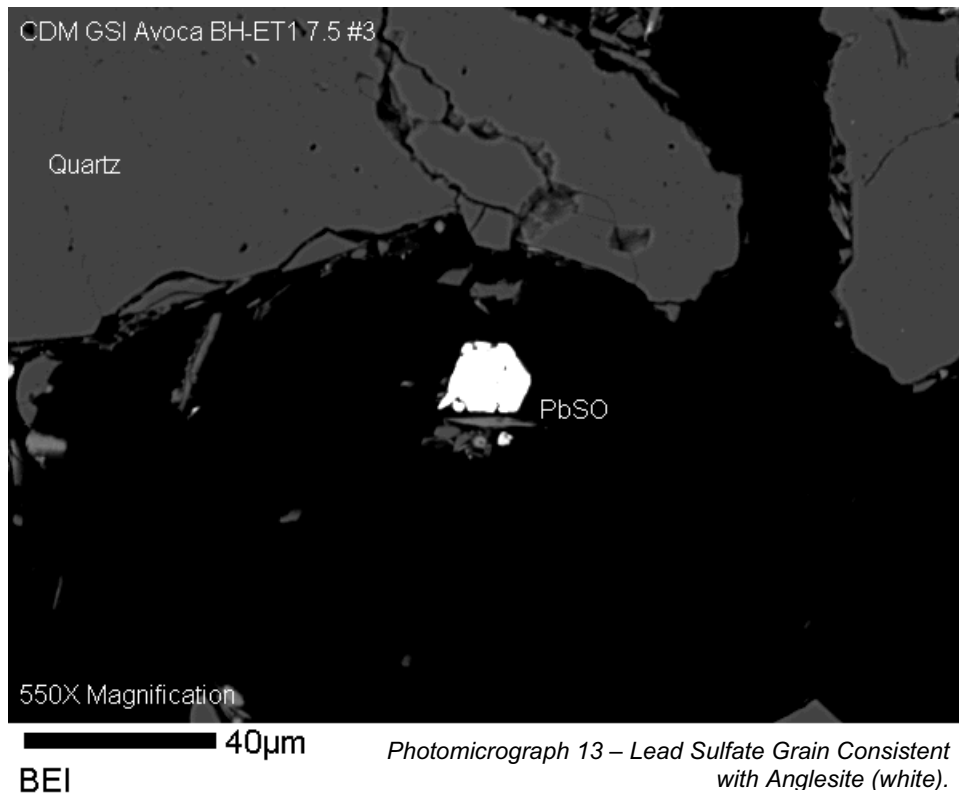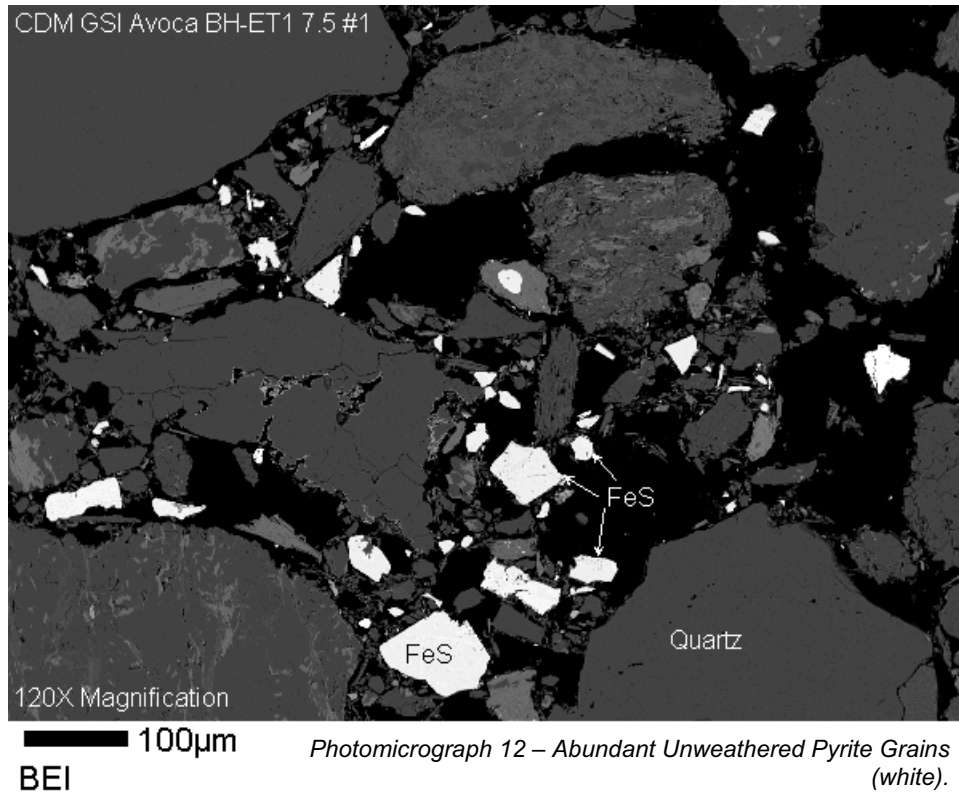
Photomicrograph 13 shows a lead sulfate grain oriented to show the hexagonal cross-section consistent with the mineral anglesite.

CDM GSI Avoca BH-ET1 7.5 #4
FeMgAlSiO
KAlSiO
Quartz
Quartz
CuFeS
FeS
359X Magnification
40µm
BEI

Photomicrograph 14 – Iron-Copper Sulfide Mineral Consistent with Chalcopyrite (white).
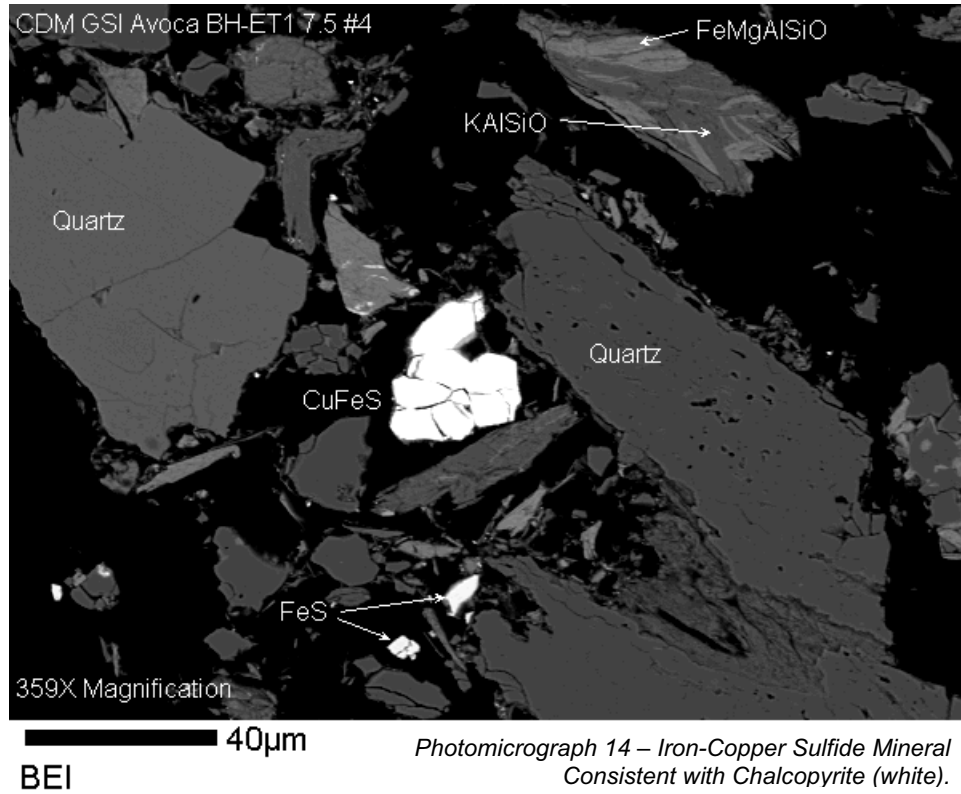
Photomicrograph 14 shows a grain of iron-copper sulfide, presumably chalcopyrite, exhibiting minor weathering (slightly darker material on some of the edges). Other minerals identified in the sample included a potassium-aluminum silicate consistent with sericite, and an iron-magnesium aluminum silicate consistent with the mineral pyroxene.

Surface Spoils

The surface spoils were characterized by the following:

- Primary sulfides (pyrite, sphalerite, galena, etc.) were rare, and when present were remnants of larger grains and showed signs of dissolution (embayments, pitting, etc.) and weathering products (oxides and sulfates).

- Lead was present in high concentrations within plumbojarosite (4.7-21.4%), Pb-schwertmannite (16.5%), and Pb-Al phosphates (17.4-25.9%).

- Arsenic was present in high concentrations within plumbojarosite (0.03-6.7%), iron oxyhydroxides (0.25-0.74%) and Pb-Al phosphates (0.58%).

- Copper was present in relatively low concentrations within plumbojarosite (0.4-2.4%), and iron oxyhydroxides (0.19%).

- Zinc was detected in low concentrations within plumbojarosite (0.06-0.16%).

- Quartz grains were generally very pitted.

Note that a concentration of 1% corresponds to 10,000 mg/kg, so that the lead concentration within the plumbojarosites ranged from 47,000 to 214,000 mg/kg.

Mount Platt – SP20 (SA-17S)

The surface sample from Mount Platt contained lead, arsenic, copper, and zinc within secondary phases. Secondary phases consisted of phosphates, hydroxysulfates (jarosites and schwertmannite), and iron oxyhydroxides. No primary sulfide minerals were identified in the sample.

Photomicrograph 15 shows an iron-lead sulfate or hydroxysulfate phase containing 21.4% lead and 6.7% arsenic. The image also shows an iron oxyhydroxide grain containing much lower concentrations of lead and arsenic. The quartz grains shown in the image are pitted, which was typical of the sample (see also Photomicrograph 18).

Photomicrograph 16 shows a large sulfate or hydroxysulfate grain containing 0.27% arsenic. The phase may be a partially oxidized pyrite grain.

Photomicrograph 17 shows a grain of iron-bearing lead-aluminum phosphate containing 25.9% lead and 0.58% arsenic. Based on the uniform appearance of the grain, the phase may be crystalline.

CDM GSI Avoca SA-17S #1

Quartz

FeO(S)

FeO(S), 0.05% Pb, 75.5% Fe, 0.28% As

FeAsPbSO, 21.4% Pb, 30.0% Fe, 6.7% As

Quartz

90X Magnification

200μm

BEI
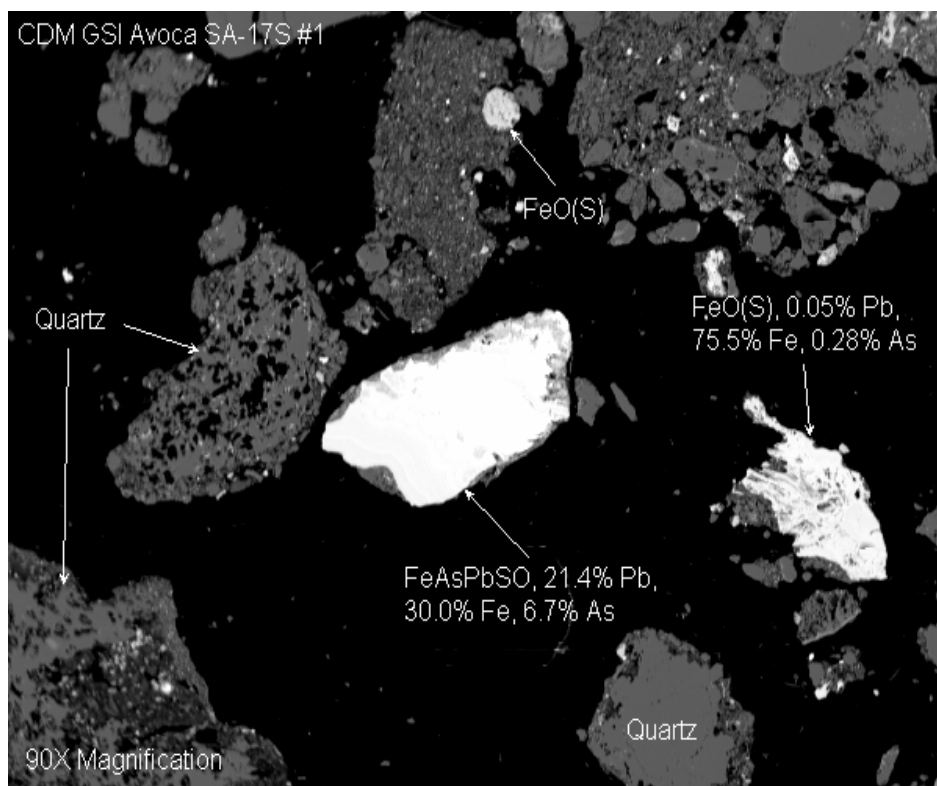
Photomicrograph 15 - Arsenic-Bearing Plumbojarosite and Schwertmannite (white) Along with Extensively Pitted Quartz (gray).

CDM GSI Avoca SA17S #3

Quartz

TiO

Quartz

FePO(Si)

FeS(O), 0.27% As, 48.5% Fe

Quartz

180X Magnification

100μm

BEI
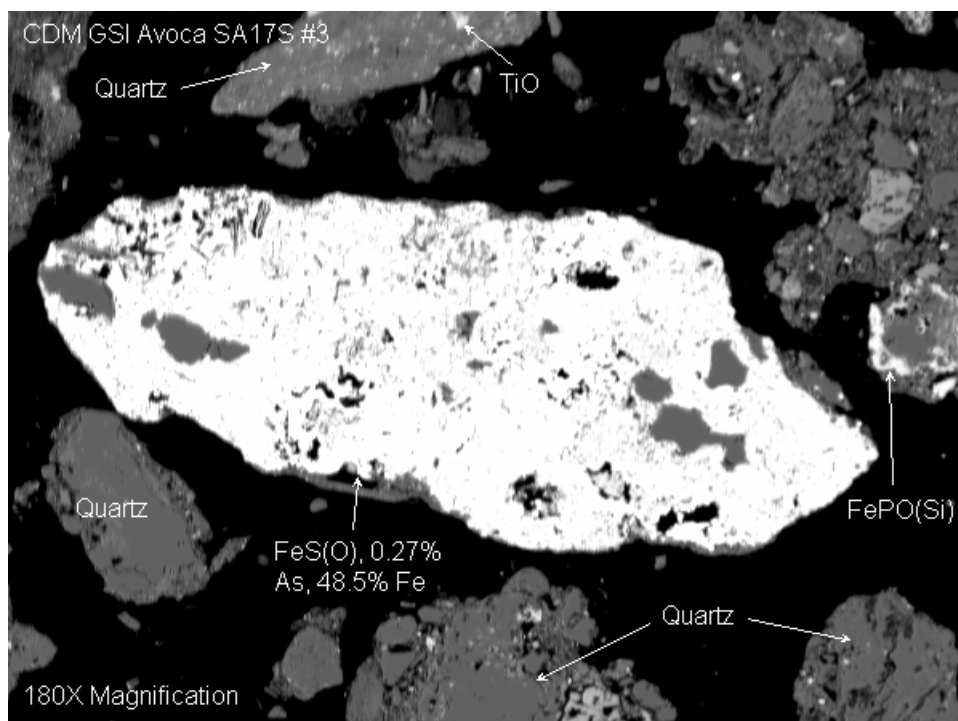
Photomicrograph 16 – Iron Sulfate Phase Containing 2700 mg/kg Arsenic.

CDM GSI Avoca SA17S #7

(Fe)PbAlPO,
25.9% Pb,
0.58% As

Quartz

250X Magnification

80µm

BEI

*Photomicrograph 17 – Lead-Aluminum Phosphate
Containing 25.9% Lead and 5800 mg/kg Arsenic.*

CDM GSI Avoca SA-17S #5

Quartz

70X Magnification

300µm

BEI

Photomicrograph 18 – Pitted Quartz.
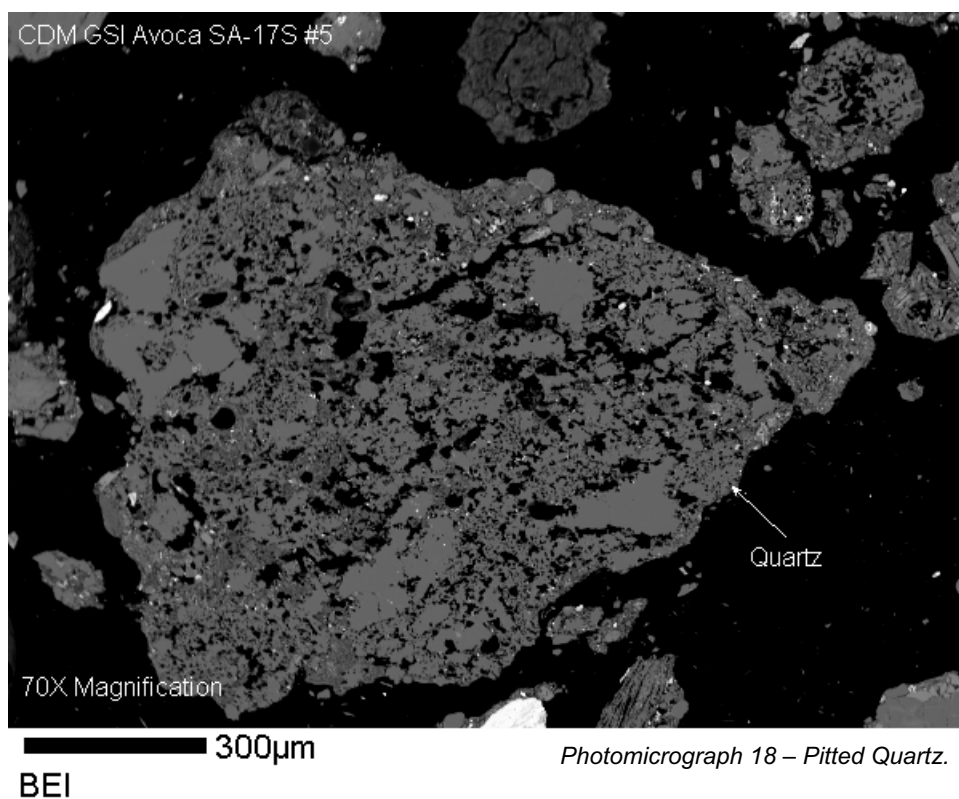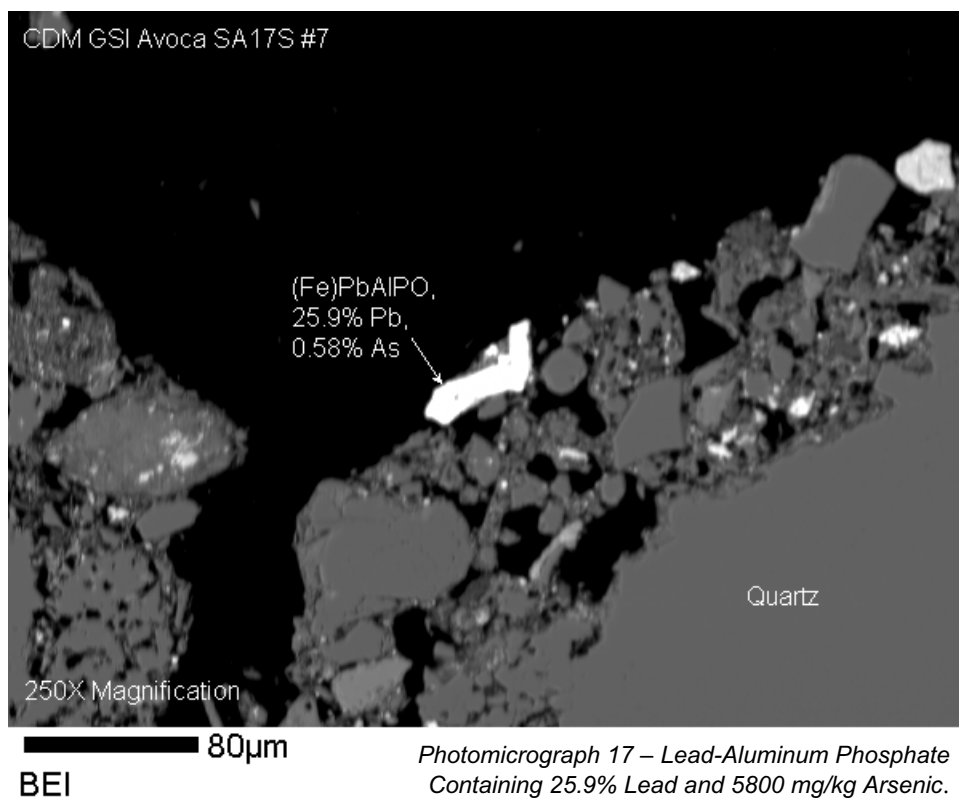
Connary – SP22 (SA-12)

The surface spoils from Connary, in general, were less oxidized than for Mount Platt. Secondary phases were still the dominant form of metals and arsenic in the sample (see Photomicrographs 19, 21, and 22). However, partially oxidized sulfides, such as zinc sulfide were found. Photomicrograph 20 shows a grain of zinc sulfide containing 2.97% oxygen. The edges of the grain have a hackly texture consistent with dissolution. In addition, a secondary phase (gray) is coating the grain.

The secondary phases were similar to those found in the Mount Platt sample. The jarosite mineral shown in Photomicrograph 21 had the composition shown in **Table A-2** below.

Table A-2 Analysis of the Jarosite Grain Shown in Photomicrograph 21

Parameter[1]	Concentration (%)
Zinc	0.06
Copper	0.40
Lead	4.65
Iron	34.32
Sulfur	7.18
Oxygen	12.26

1. An arsenic analysis was performed, but the result was rejected due to a problem with the crystal within the diffractometer of the WDS.

Photomicrograph 19- Lead-Aluminum Phosphate Containing 18.3% Lead.

CDM GSI Avoca SA-12 Connary (SP22) #2

ZnS(O)

250X Magnification

80μm

BEI
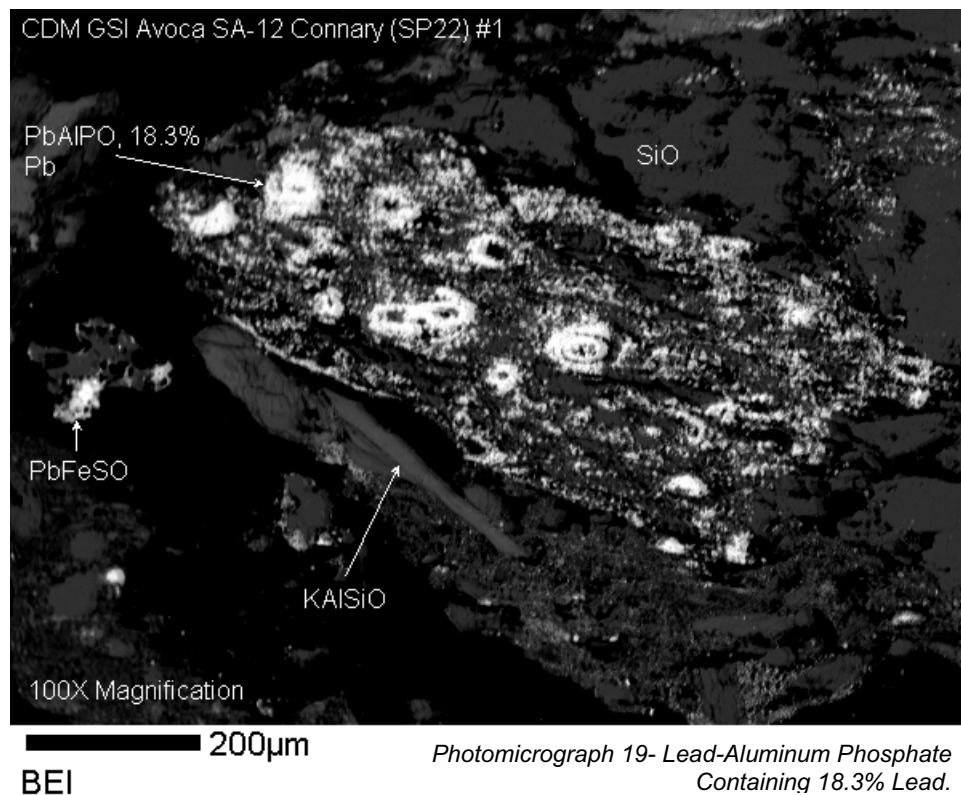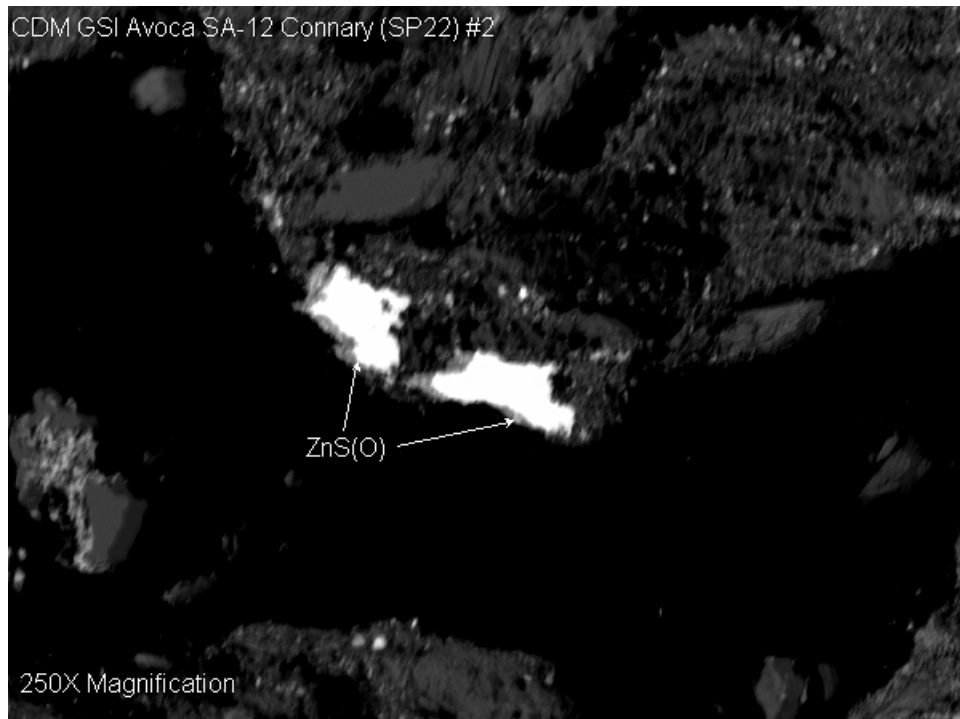
Photomicrograph 20 – Partially Oxidized Zinc Sulfide.

CDM GSI Avoca SA-12 Connary (SP22) #3

(Pb)FeSO, 0.06% Zn, 0.40% Cu, 4.6% Pb

220X Magnification

100μm

BEI
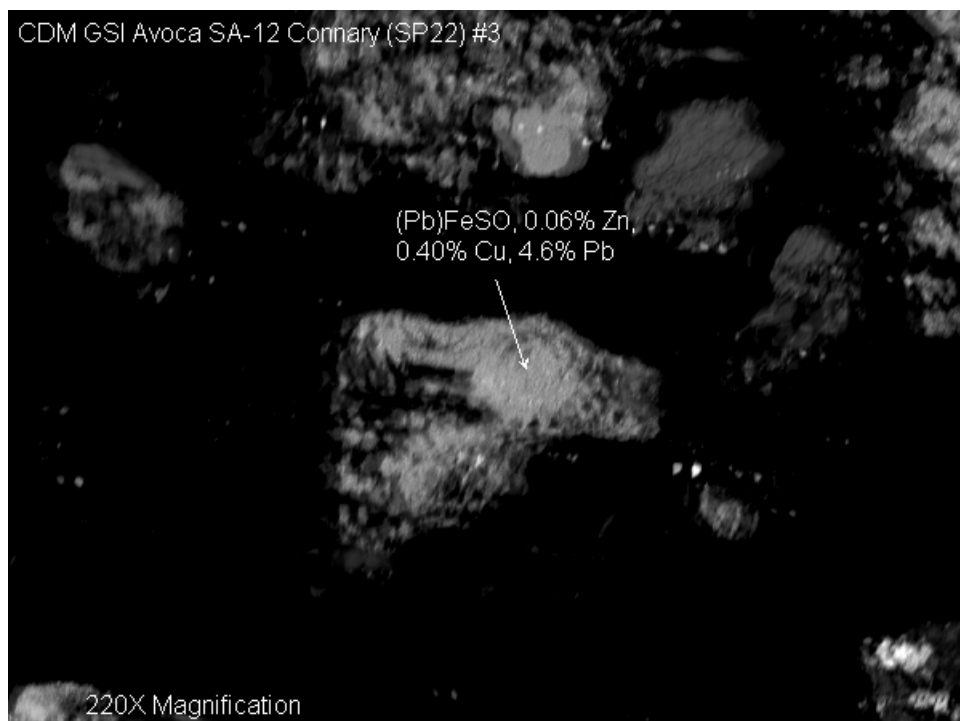
Photomicrograph 21 – Lead-Bearing Iron Sulfate Phase Consistent with the Mineral Schwertmannite.

Photomicrograph 22 – Lead-Bearing Iron Sulfate, Lead Sulfate, Sericite, and Pitted Quartz.
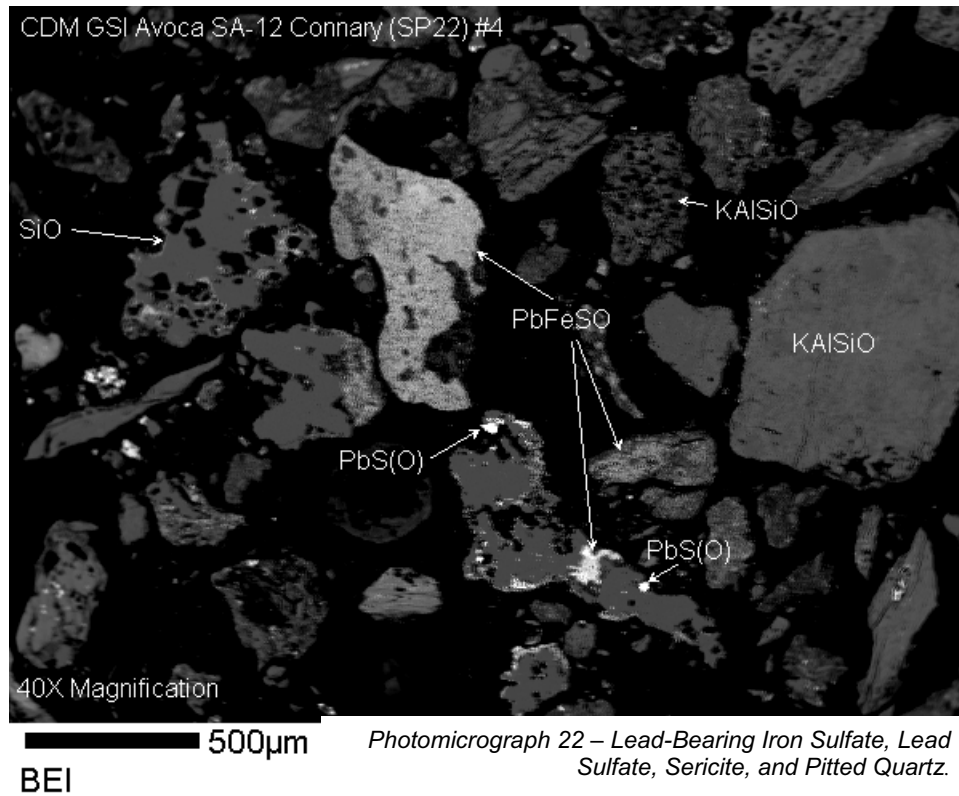
Like the Mount Platt sample, the Connary sample had pitted quartz grains, but the pitting was not as extensive (see Photomicrograph 22).

West Avoca – SP34B (SA-9)

The sample from West Avoca, like the other samples, was characterized by secondary phases. However, significant primary sulfides were also present. Photomicrograph 23 shows a hydroxysulfate phase containing 16.5% lead. Unlike the other jarosite phases described for other samples, this sample contained magnesium-bearing plumbojarosites. The phase was part of a composite grain consisting of iron sulfate or iron hydroxysulfate, quartz, and sericite.

Photomicrographs 24 and 25 show remnant iron and lead sulfide grains. Photomicrograph 24 in particular shows grains which have been partially dissolved, as evidenced by the embayments and holes within the grains.

Photomicrograph 23 – Lead-Iron-Magnesium Oxide encased within Iron Sulfate.
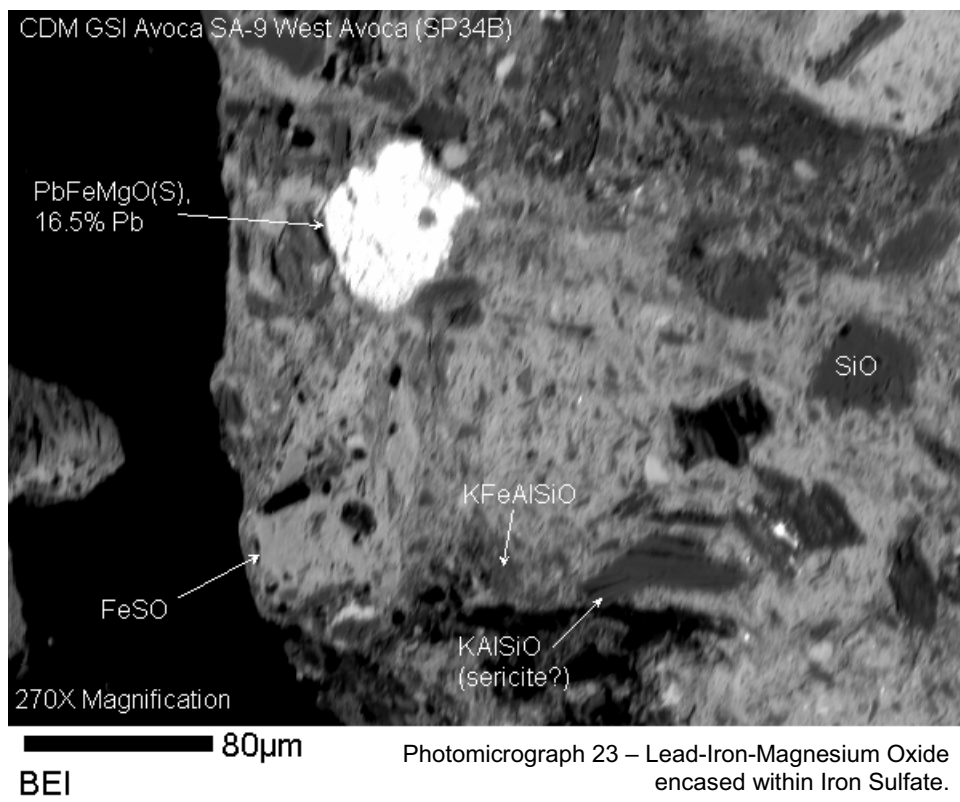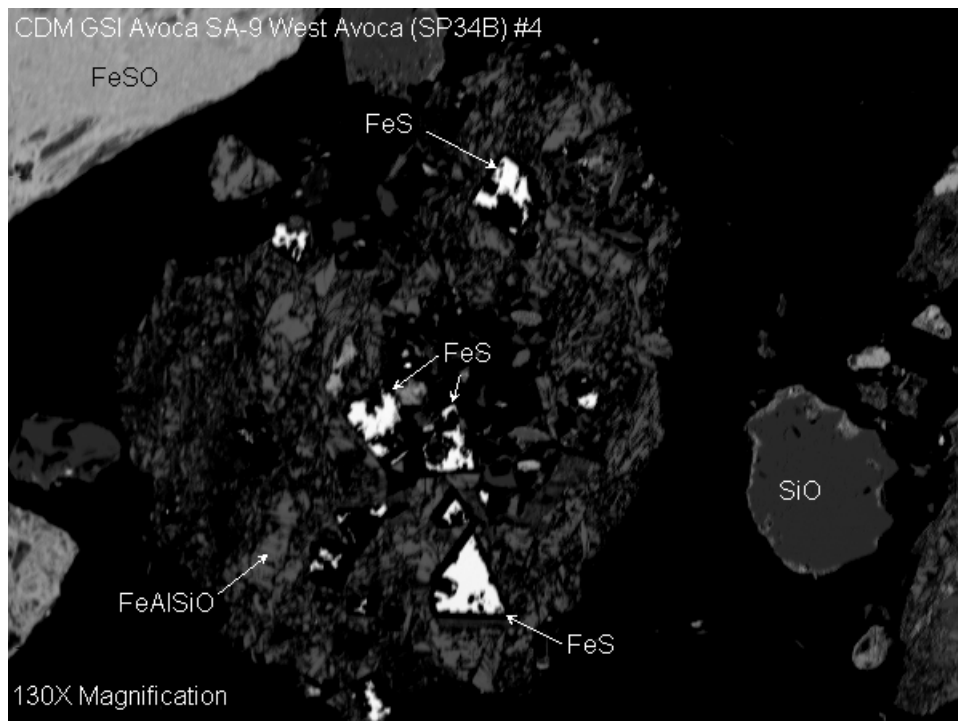
Photomicrograph 24 – Partially Oxidized Pyrite within a matrix of pyroxene.
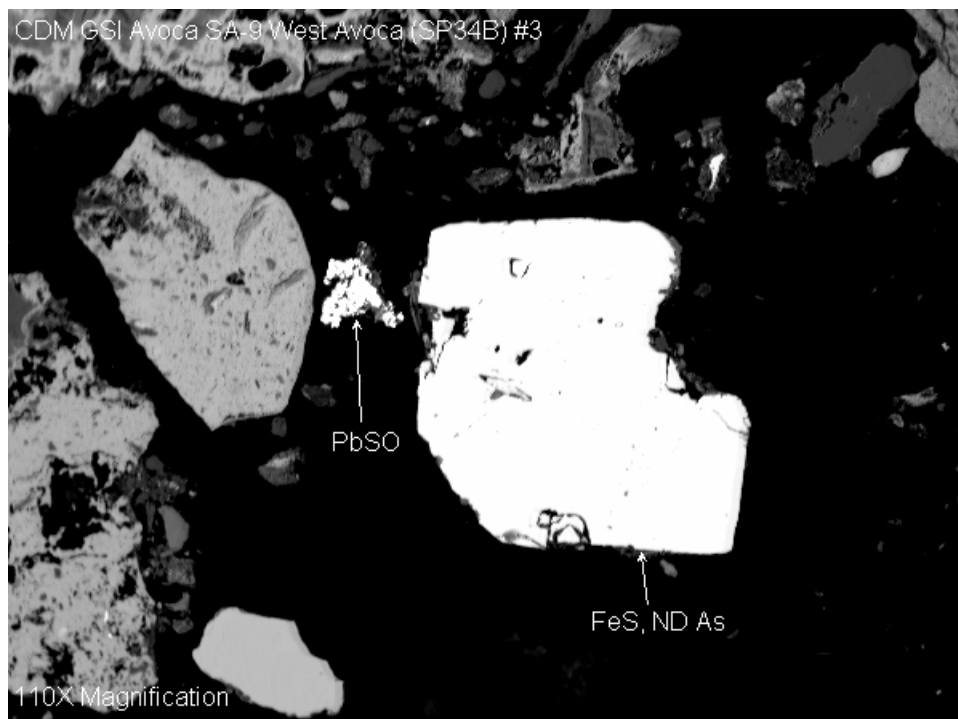
Photomicrograph 25 – Partially Oxidized Pyrite Adjacent to a Grain of Lead Sulfate.

Buried Spoils

The buried spoils are characterized by the following:

- Lead was present as sulfates (anglesite or partially oxidized galena), hydroxysulfates (3.5-13.1% Pb) and as aluminum-lead phosphates (12.2 – 25.3% Pb). Aluminum-lead sulfate-arsenate was also an important form of lead (21.3% Pb).

- Arsenic was present mostly within plumbojarosite (1.1-7.2%) and aluminum-lead sulfate-arsenate (5.9-13.0% As), but also within pyrite (ND-0.95%), lead-aluminum phosphate (0.9%), and Iron oxyhydroxide (0.5-0.9%). Primary arsenopyrite (FeAsS; 42.5-49.3% As) was found in one sample.

- Zinc and copper were present mainly as primary sulfides consistent with sphalerite and chalcopyrite, respectively. Within the Mount Platt samples, a copper sulfide mineral consistent with chalcocite (Cu_2S) or covellite (CuS) was also identified.

- Evidence of completely weathered sulfides, such as cubic-shaped voids in other minerals and iron oxyhydroxides with a relic sulfide crystal structure was present.

<u>Mount Platt – SP20 (BH-MP1 8) and (BH-MP2 16)</u>

The subsurface samples collected from Mount Platt contained minerals that were not found in the other subsurface samples, such as copper sulfide. In addition, the samples had abundant iron oxyhydroxides. Photomicrographs 26 and 27 show the abundance and character of the phase. In general, the iron oxyhydroxide occurs as either distinct grains or as a coating or cement associated with other grains. The material contained arsenic concentrations of about 0.5-0.9%, and in some cases relatively low levels of copper, on the order of 0.5%. However, copper was rarely detected within the material.

Iron-copper sulfide (consistent with chalcopyrite or bornite) was identified, as illustrated in Photomicrograph 28, but was not common.

Lead was present in high concentrations within lead-aluminum phosphate phases (12.2%-25.3%) and within iron-bearing aluminum lead arsenates (23.7%).

Although arsenic was present within the abundant iron oxyhydroxides within the sample, the majority of the arsenic mass was present as iron-bearing aluminum-lead arsenate (13.0% As).

Photomicrograph 26 – Arsenic-Bearing Iron Oxyhydroxide.

Photomicrograph 27 – Arsenic- and Copper-Bearing Iron Oxyhydroxide.

Photomicrograph 28 – Iron-Copper Sulfide mineral consistent with Chalcopyrite or Bornite.

Photomicrograph 29 – Copper sulfide mineral consistent with Covellite (CuS) or Chalcocite (Cu_2S).
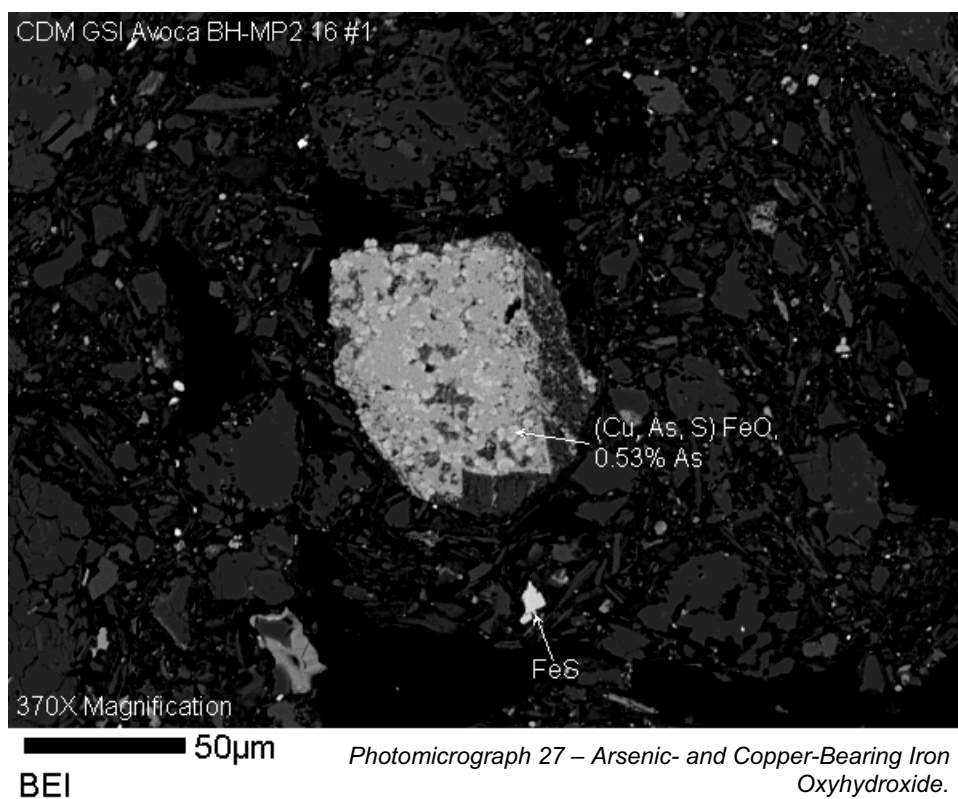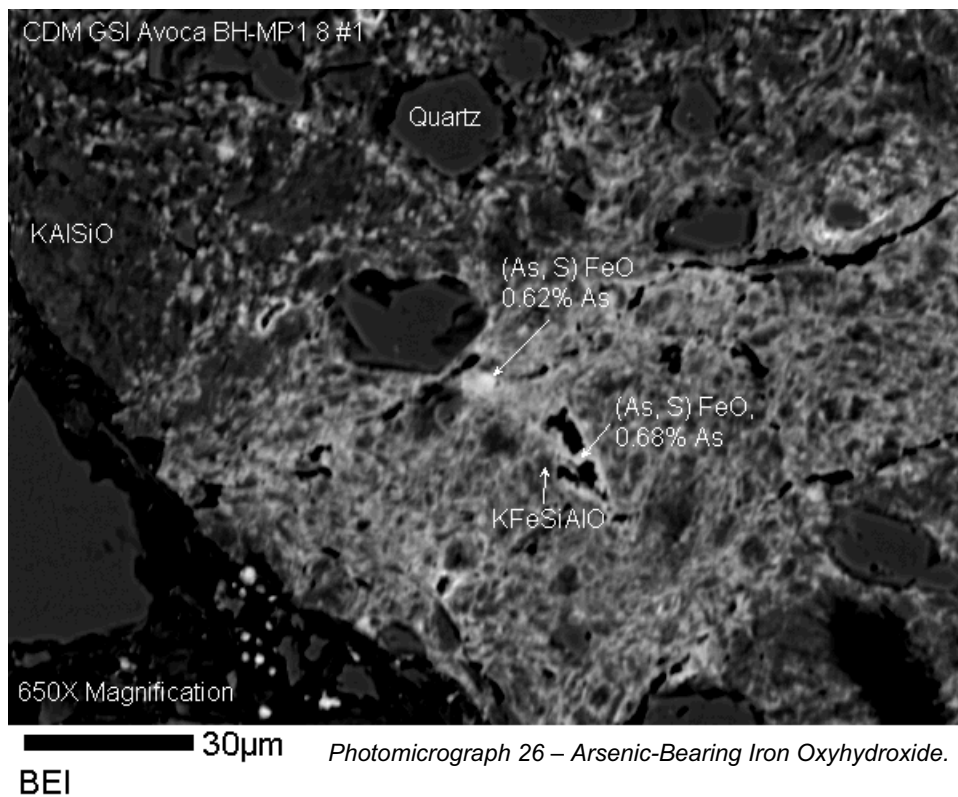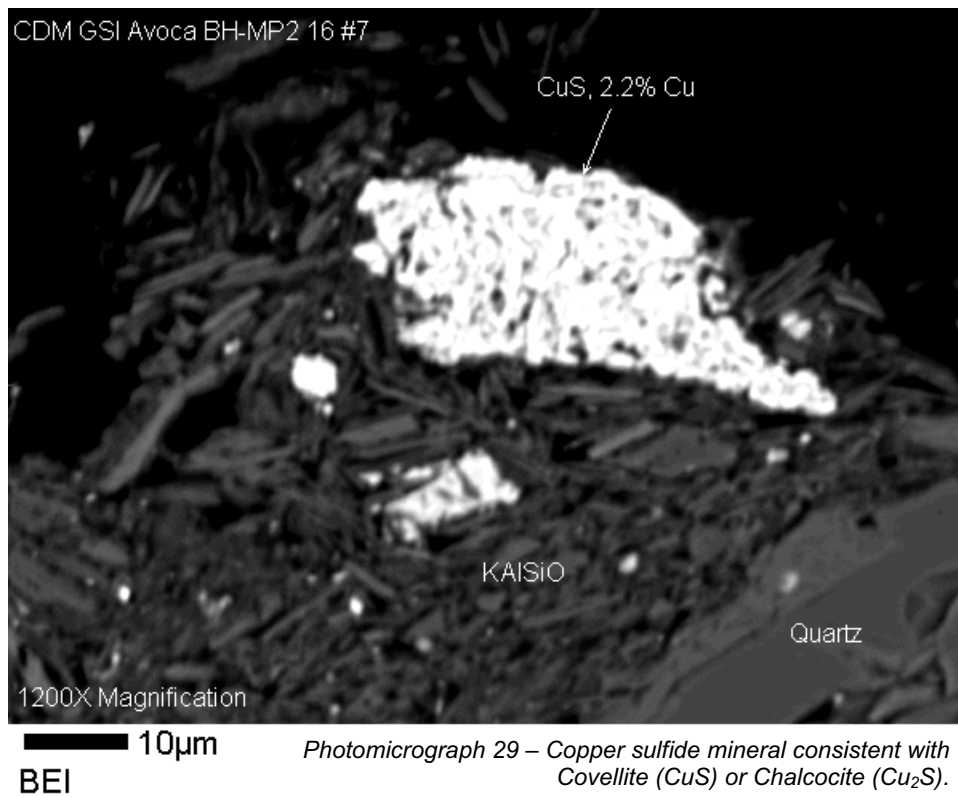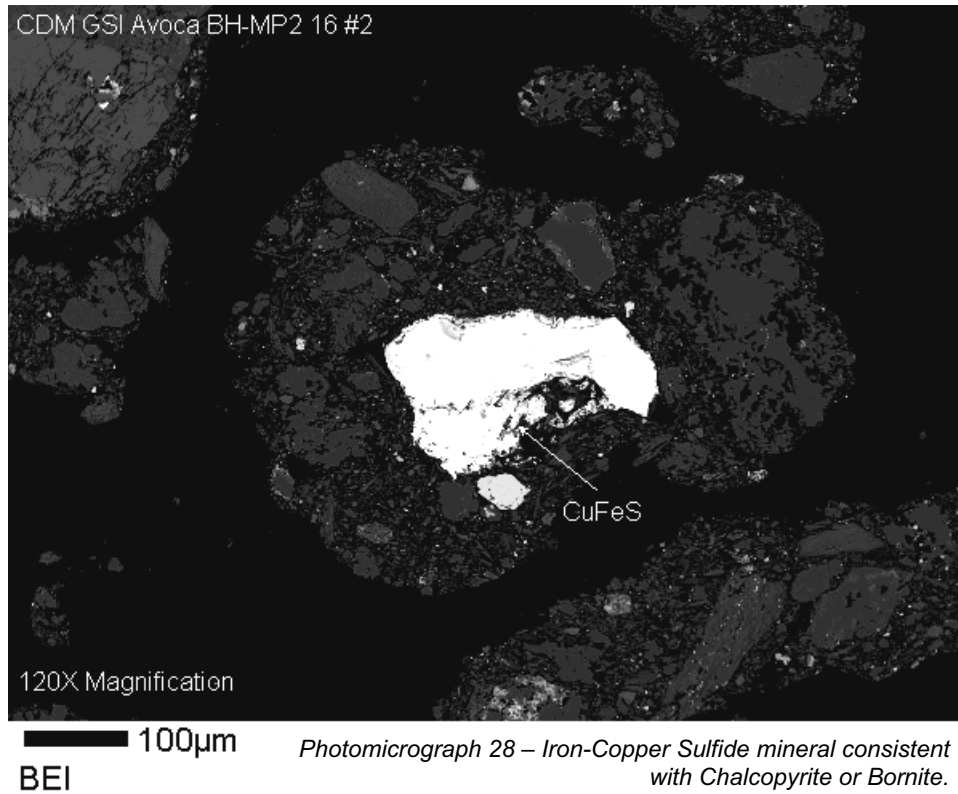
A copper sulfide mineral consistent with covellite (CuS) or chalcocite (Cu_2S) was also identified, but was rare (see Photomicrograph 29). The mineral was rather porous, which made it difficult to obtain an accurate copper analysis. In fact, the analysis performed on the WDS indicated a copper concentration of only 2.2%. However, the EDXRF spectra clearly showed that copper and sulfur were the only elements present (the WDS indicated that no oxygen or other light elements were present either). The low copper concentration obtained on the WDS analysis was likely due to the electron beam hitting a small epoxy-filled void in the mineral resulting in significant dilution of the copper analysis.
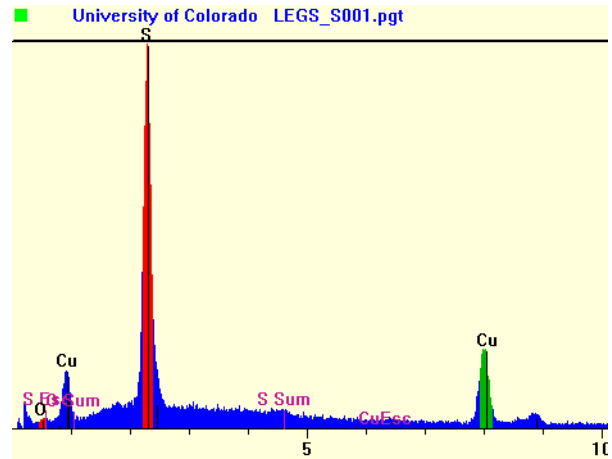
EDXRF Spectra of the Copper Sulfide Mineral Shown in Photomicrograph 29.

Connary – SP31 (TP-CO3 0.9-1.35) and (TP-CO4 0.3-0.4)

The subsurface samples from Connary were characterized by secondary phases. Primary sulfide minerals were not identified. The samples showed signs of having undergone extensive oxidation, as indicated by the presence of quartz with cubic-shaped voids where pyrite or galena likely weathered away. (photomicrograph 30). Photomicrograph 31 shows a grain of iron oxyhydroxide which exhibits the cubic crystal structure of pyrite. The grain was likely pyrite originally, but was later oxidized to iron oxyhydroxide. The center of the grain contains a large inclusion of potassium-aluminum silicate, which is consistent with potassium feldspar or sericite.

Lead and arsenic were present within plumbojarosite and lead-aluminum arsenate/sulfate (Photomicrograph 32). The later phase contained about 5.9% arsenic and 21.3% lead and may be considered a mixed jarosite and alunite ($KAl_3(SO_4)_2(OH)_6$) phase. Alunite is the aluminum analogue of jarosite and likely has the same substitutions of lead for potassium and arsenic for hydroxide and sulfate as does jarosite.

Another characteristic of the Connary samples was the abundance of a platy potassium-aluminum silicate mineral consistent with sericite (see Photomicrograph 32).
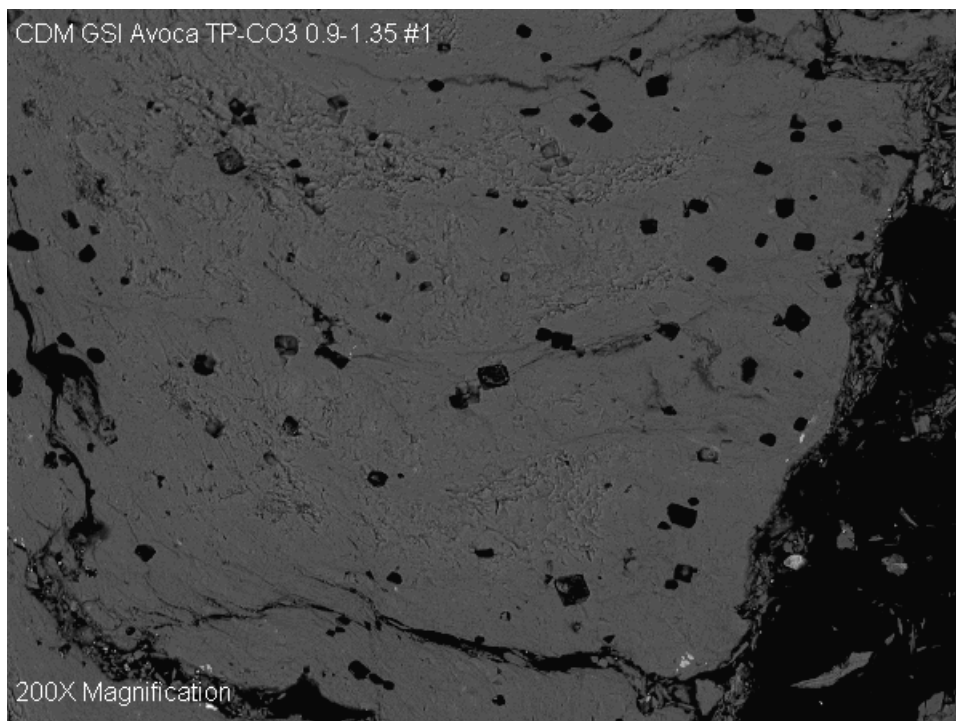
Photomicrograph 30 – Quartz Grain Showing Cubic-shaped Voids Where Sulfide Minerals weathered Out of the Grain.

Photomicrograph 31 – Iron Oxyhydroxide Grain Exhibiting the Relic Pyrite Crystal Structure from which it was Derived.

Photomicrograph 32 – Lead-Aluminum Arsenate/Sulfate in a Matrix of Jarosite and Sericite.
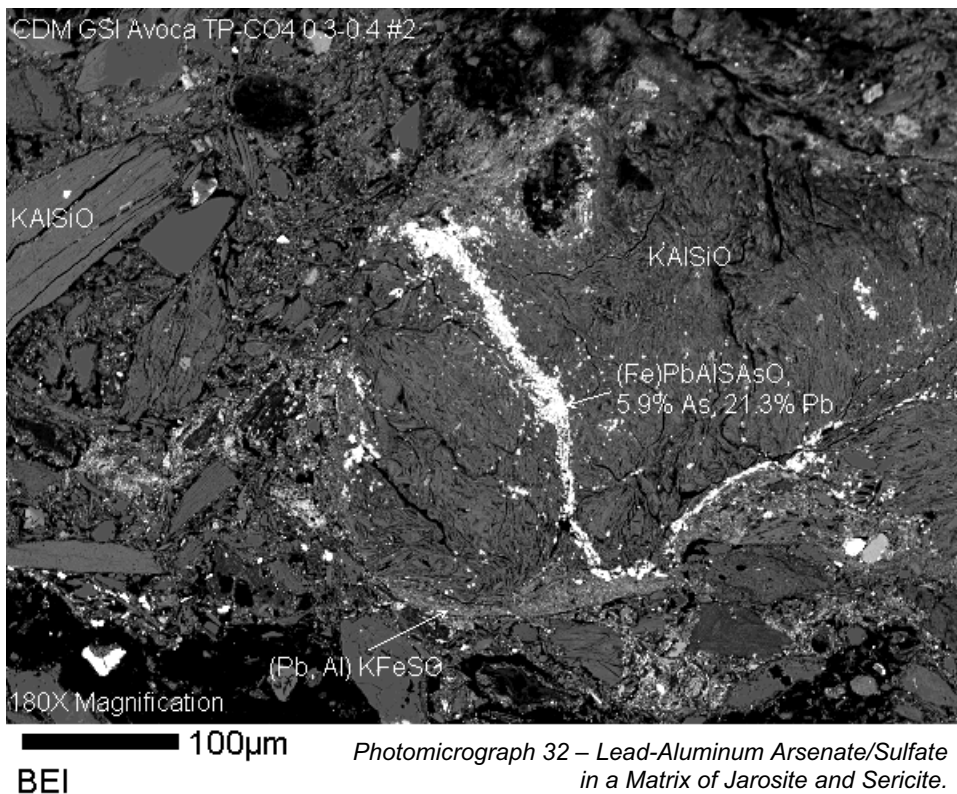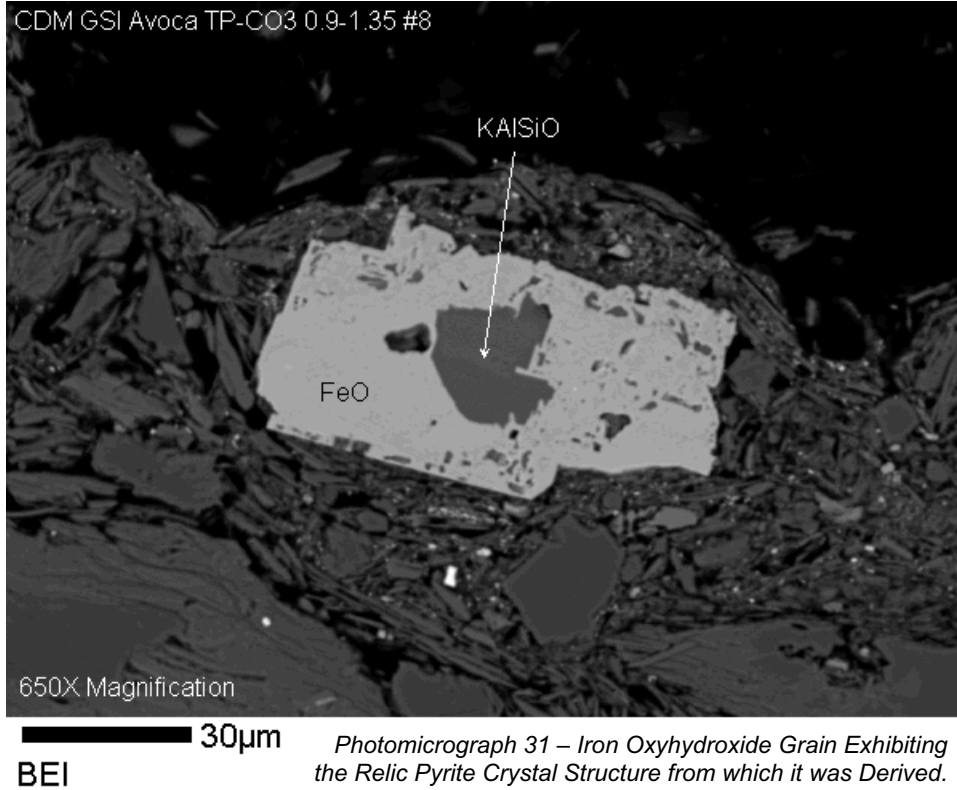
West Avoca – SP34 (BH-WA1 2.55)

The West Avoca subsurface sample was characterized by primary sulfides for arsenic, copper, and zinc and primary lead sulfate (consistent with anglesite) for lead. The arsenic was present within a mineral consistent with arsenopyrite (Photomicrograph 33), which has a composition between $FeAs_{0.9}S_{1.1}$ (42.5% As) and $FeAs_{1.1}S_{0.9}$ (49.3% As). Arsenic was not found within the pyrite in the sample, but this was likely due to the fact that not enough pyrite grains were analyzed to find a detection. Based on other samples, approximately 10% of the pyrite grains contain measurable arsenic.

Lead was found within a lead sulfate mineral consistent with anglesite (see Photomicrograph 34). The crystalline nature of the grains suggest that the mineral is primary and is not a secondary oxidation product of galena. Photomicrograph 34 shows a grain which is oriented to in such a way that it illustrates the hexagonal cross section of the mineral, which is consistent with anglesite. Oxidized or partially oxidized galena would likely either not exhibit a crystalline structure or would have the relic cubic structure of galena.

Other primary minerals included iron-zinc sulfide (consistent with sphalerite) and pyrite, as shoen in Photomicrographs 35 and 36, respectively.

Photomicrograph 33 – Iron-Arsenic Sulfide Mineral Consistent with Arsenopyrite.

CDM GSI Avoca BH-WA1 2.55 #20

PbSO

2,000X Magnification

10μm

BEI

Photomicrograph 34 – Lead Sulfate Mineral Consistent with Anglesite. Note the Hexagonal Cross Section.

CDM GSI Avoca BH-WA1 2.55 #5

ZnFeS

950X Magnification

20μm

BEI

Photomicrograph 35 – Iron-bearing Zinc Sulfide Mineral Consistent with Sphalerite.

BEI

Photomicrograph 36 – Cubic Pyrite Grain.

Summary

The forms of arsenic, lead, copper, and zinc appear to be determined by:

- The type of ore from which the mine waste was derived (i.e. supergene vs. sulfide zone and West Avoca vs. East Avoca)

- The type of mine waste (tailings vs. spoils)

- The depth of burial and age of the mine waste (surface sample vs. subsurface and relatively old spoils vs. newer spoils)

The buried supergene ore derived from the Cronebane Pit and now comprising Mount Platt contains a mixture of primary sulfide minerals and secondary phases. A copper sulfide mineral was found in one of the samples, which is consistent with the supergene copper minerals covellite (CuS), chalcocite (Cu_2S) or digenite (Cu_8S_9), all of which have been identified within the Cronebane Ore (Gallagher et al., 1997). The other distinctive feature of the Mount Platt samples was the relative abundance of iron oxyhydroxides. The overburden which was removed from the Cronebane area to access the ore consisted of significant gossan in the form of limonite ($FeOOH\ nH_2O$), goethite ($FeOOH$), and hematite (Fe_2O_3) (Gallagher et al., 1997). Plumbojarosite was also present and appears to be an important form of lead and arsenic. The presence of secondary plumbojarosite, even at a depth of 16 m (BH-MP2 16) suggests that the phase may have been formed within the oxidized portion of the ore body and represents part of the gossan cap overlying the ore.

In contrast, buried spoils derived from the sulfide zone (BH-WA1 2.55) contained metals and arsenic in the form of primary sulfides, including an iron-arsenic sulfide. According to Gallagher et al. (1997), arsenopyrite occurred throughout the Pond Lode, but was most abundant within the upper zones where concentrations reportedly reached 1%. Arsenopyrite was not found in any other sample, which is consistent with the rarity of the mineral in East Avoca. The buried spoils, while less oxidized than the surface spoils did contain evidence of oxidation, such as relic pyrite grains and cubic-shaped voids in quartz. However, within the surface spoils primary sulfides were rare, and when present were in the form of a remnant core within an otherwise oxidized grain. The samples from Connary showed less variation between the surface and subsurface samples, with secondary phases common in both types of sample. The reason for the lack of variation is probably due to the fact that the subsurface Connary samples were taken from test pits, which were relatively shallow (0.3-1.35 m) and the age of the Connary spoils which are much older than many of the other spoils. According to Gallagher et al. (1997), the Connary spoils are on the order of 100 years old. By contrast, many of the larger spoil piles on the site (i.e. West Avoca [SP34 and SP34B] and Mount Platt [SP20 and SP20A]) have only been around since the 1960s to 1980s period.

In general, the tailings were less oxidized than the spoils, exhibiting abundant sulfides with sharp grain edges. The surface tailings contained a mixture of secondary phases and rare primary sulfides while the buried tailings contained metals and arsenic almost

exclusively within primary sulfide minerals. There was no obvious difference between the buried Emergency Tailings and those from Shelton Abbey (no surface tailings were present in the Emergency Tailings area).

Another significant finding was that copper and zinc are abundant within the primary minerals (chalcopyrite and sphalerite) but much less abundant in the secondary oxyhydroxides and hydroxysulfates. On the other hand, lead and arsenic were present in high concentrations in both the primary minerals (arsenopyrite, pyrite, and anglesite) and in the secondary phases (plumbojarosite and phosphates). The implications of this finding will be discussed in the following section.

Discussion

The mineralogy found in the mine waste samples can be divided into two categories;

- Primary minerals

- Secondary minerals

The primary and secondary mineral forms of arsenic, lead, copper, and zinc are summarized in **Table A-3** below.

Table A-3 Summary of the Forms of Arsenic, Lead, Copper, and Zinc

Parameter	Primary Phase(s)	Secondary Phases
Arsenic	pyrite (arsenopyrite)[1]	plumbojarosite, schwertmannite, iron oxyhydroxide, (Al-phosphates)
Lead	anglesite[2] (galena)	plumbojarosite, Al-phosphates, (schwertmannite, iron oxyhydroxide)
Copper	chalcopyrite[2], (covellite, chalcocite, etc.)	(plumbojarosite, schwertmannite, iron oxyhydroxide)
Zinc	sphalerite[2]	(plumbojarosite, schwertmannite, iron oxyhydroxide)

1. Phases in parenthesis were a less important form of the element than the phases which are not in parenthesis.
2. Most likely phase present based on the mineralogy of the ore body

The conversion of the primary phases to secondary phases is due to oxidation, either within the ore body itself (such as for the Cronebane ore) or, more commonly, within the shallower more oxygenated zones on the mine waste. The oxidation of arsenic-bearing pyrite, sphalerite, and chalcopyrite, and the dissolution of anglesite results in pore water with high concentrations of arsenic, lead, zinc, copper and sulfate. Under the low pH conditions of the pore water, the mineral plumbojarosite is stable. However, based on the EMP results, lead and arsenic are incorporated into the phase to a much greater extent than copper and zinc. The result is that arsenic and lead are removed from the pore water, while copper and zinc stay in solution, where they are eventually transported to the Avoca River. The formation of arsenic-bearing plumbojarosite explains the low mobility and bioavailability of lead and arsenic within the mine wastes, despite the high concentrations within the waste materials themselves.

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The Department of Communications, Energy and Natural Resources

Feasibility Study for Management and Remediation of the Avoca Mining Site

**Phase 2
Human Health Risk Assessment**

October 2008

Report

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Section 1
Introduction

The Avoca River watershed above Arklow is situated in a rural, residential, agricultural, tourist, and, to a lesser extent, industrial area. Historic mining, milling, and smelting at the East Avoca and West Avoca sites, and tailings disposal at the Shelton Abbey site, have left contaminated materials (spoils) on the surface. In addition, mining, milling and smelting activities have resulted in historical and current releases of metals and/or other inorganic constituents to surface waters and waterways as a result of erosion of spoils and acid mine drainage. Finally, unsafe conditions exist as a result of abandoned shafts and adits, unstable ground, and potential subsidence. Potential health impacts related to existing spoils deposits and contamination in the Avoca River and other waterways. Unsafe conditions are addressed separately in the Avoca Mine Site Health and Safety Audit, April 2008.

Mining operations at Avoca in County Wicklow, Ireland have spanned over 200 years resulting in significant environmental degradation including widespread contamination of the mine site and surrounding land surface by spoil and serious pollution of the Avoca River by acid mine drainage.

A Preliminary Human Health Risk Assessment (Phase 1 HHRA) was conducted for the Avoca Mining Site (Site) in May 23, 2007. The Phase 1 HHRA accomplished the following objectives:

- Identified and described conditions based on the available data stemming from releases of mining-related contaminants that may result in adverse effects to people who live, work, or recreate in or near the study area currently or in the future

- Identified additional data needed to complete a final baseline HHRA for the Avoca Mining district

- Provided preliminary remediation goals to help address community concerns and to provide some initial human health risk assessment information to the preliminary assessment of remedial and management alternatives

This Phase 2 HHRA builds upon the Preliminary Phase 1 HHRA data, assumptions, and results primarily by incorporating additional abiotic media quality data into the analyses. These additional data, in the form of chemical data for surface water (rivers, tributaries, adits, springs, seeps), groundwater, sediment, soil (primarily soils from agricultural fields), and mine spoils (e.g., waste rock, tailings, etc.), supplement the more limited Phase 1 dataset.

The purpose of this Phase 2 HHRA is to quantify current or potential threats to people from mine-related environmental contaminants in the absence of any remediation, to help determine whether remedial efforts are needed, and, if so, to assist in developing appropriate cleanup objectives.

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In this report, initial evaluations of chemicals of potential concern (COPCs) and exposure pathways for people living, working, or recreating at and near the Site are re-evaluated to ensure consistency with the more complete site characterization recently completed. Exposure pathways are identified based on the sources and locations of contaminants on the Site, environmental fate of contaminants, and locations and activities of potentially exposed populations. Further, the HHRA describes exposure points and exposure point concentrations of COPCs and routes of exposure (ingestion, dermal contact, and inhalation) for each exposure pathway, as well as underlying assumptions regarding receptor characteristics and behavior (e.g., body weight, ingestion rate, exposure frequency). Finally, the HHRA assesses the toxicity of COPCs, and characterizes possible health hazards by combining estimates of exposure with chemical-specific toxicity criteria.

For this HHRA, the study area is defined as the Avoca River and valley from Meeting of the Waters downstream to Arklow Bay (Figure 1-1). The area under investigation includes much of the area identified by the Ireland Environmental Protection Agency (EPA) as Hydrometric Area (HA) 10, the Avoca – Vartry HA, which is in the Eastern River Basin District. This area identified by EPA as seriously polluted due to mining-related contamination.

1.1 Potential Risk Issues

This risk assessment addresses potential cancer risks and noncancer hazards associated with exposure to mine-related contaminants. Hazardous substances commonly associated with mining operations have been identified in soil, surface water, and sediment in the vicinity of and downstream of the mine site. Potential sources of this contamination are numerous, including extensive piles of spoil, tailings, waste rock piles, open pits, adits, and landfills.

The mine site is surrounded mainly by pasture, forest, and heathland. Several residences are, however, located on the margins of the Site. In addition, areas of the Site have been and are currently used for industrial purposes, for example automobile storage facilities are located at the Site of the former fertilizer plant. Near-site residents and onsite workers could be exposed to mine related contaminants in soil and/or mine wastes.

Grazing of farm animals takes place along the fringes of the mine site and even on some portions of the Site and these animals may take up mine-related constituents in soil and those accumulated in plants. Subsequent consumption of meat from these animals by people in the area is a possible risk issue.

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Connary

Mt. Platt

Tigroney Area

West Avoca

Shelton Abbey Tailings Facility

N

OSI Licence No - EN 0047 207

0   500   1,000   2,000   3,000
                                        Meters
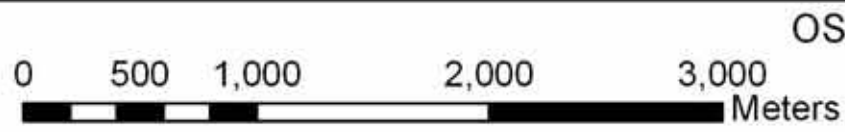
Fig 1-1 Study Area Map

People also visit areas near and on the Site for recreational purposes. Walking trails pass through mine areas and people are known to bicycle and ride quad bikes in the area. These visitors could be exposed to mine contaminants in soil and mine wastes or soil contaminants resuspended in air while engaged in recreation. Further, people recreating in the Avoca River might also be exposed to mine-related chemicals in surface water and sediment. Currently, uncontrolled acid mine drainage enters the river below Whitesbridge. Further, anglers may, in theory, be exposed to mine-related contamination through consumption of fish taken from the river. Some metals and metalloids observed in mine wastes can bioaccumulate in fish tissue. Although some areas of the river are considered biologically dead, recent electrofishing surveys carried out by the Fisheries Boards in the Avoca River catchment in 2002 indicate that salmon and trout stocks are present in the system and some fish (e.g., eel, lamprey, and minnow) are present in polluted stretches of the river.

Finally, groundwater may be affected by leaching of contaminants and could be used for drinking water. Groundwater is used as a source of drinking water in the region, suggesting at least some potential for exposure.

1.2 Approach and Report Organization

The overall approach for the HHRA follows guidance and recommendations provided in the Final Report of Expert group for Silvermines County Tipperary (EPA 2004) and in Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part A) (USEPA 1989), subsequent United States EPA (USEPA) supplemental risk assessment guidance documents and other guidance, literature, or site-specific information as appropriate. Where ever possible, Irish guidance and policy were used. Where such guidance was not available, the approach defaulted to standard USEPA methods. USEPA uses risk assessment as a tool to evaluate the likelihood and degree of chemical exposure and the possible adverse health effects associated with such exposure. USEPA guidance provides direction on all aspects of HHRA, including evaluating available data and identifying chemicals for quantitative analysis, developing exposure scenarios that depict expected exposure conditions, assessing toxicity of chemicals, combining this information to estimate potential carcinogenic and non-carcinogenic health risks, and addressing uncertainties in the analysis.

Using site-specific data as much as possible the HHRA:

- Identifies COPCs associated with historical releases at the Site (Section 2)

- Evaluates potential exposure pathways by which people may contact COPCs at the Site (Section 3)

- Summarizes the potential for each COPC to cause adverse effects in exposed individuals (Section 4)

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- Integrates the toxicity and exposure assessments into quantitative and qualitative expressions of risk and non-carcinogenic hazards (Section 5)

- Provides remediation goals (PRGs) to assist in the evaluation of remedial alternatives (Section 6)

- Describes the impact of uncertainties associated with the database, exposure assumptions, and toxicity assessment on the final step of the risk assessment, risk characterization (Section 7)

- Summarizes findings and provides risk management recommendations (Section 8)

- Provides references cited in the report (Section 9)

The following appendices are also included in this report.

- Appendix A   Bioaccessibility analyses for arsenic and lead
- Appendix B   Exposure point calculations, ProUCL statistical summaries
- Appendix C   Risk calculations
- Appendix D   Lead model results
- Appendix E   PRG Calculations

Section 2
Data Summary and Selection of Chemicals of Potential Concern

Assessment of human health risk and hazards relies in part on analytical data from samples collected at the Site. These data must be adequate to characterize contamination at the Site to support quantitative risk assessment. Data are ultimately used to estimate the amounts of contaminants that could be taken into the body orally, dermally, or through inhalation. The Phase 1 Preliminary Risk Assessment provided a preliminary screening of possible human health issues and identified data gaps. Major data gaps identified were the lack of sufficient data for soils, spoils, and sediment to adequately characterize exposures at the Site. Also no groundwater data for the area were available. Based on conclusions of the preliminary risk assessment, additional data were collected in order to characterize the Site and to support quantitative health risk assessment.

This section summarizes the available data and discusses the selection of COPCs.

2.1 Data Summary

Data collected during the Phase 2 Investigation are discussed in the following sections, followed by an evaluation of which mine constituents may pose a threat to human health.

2.1.1 Surface Soils/Spoils

During the Phase 2 investigation, solid surface samples from spoil areas were collected at seven areas including: Connary, Mount Platt/Cronebane, East Avoca/ Tigroney West, Ore Bins at Tigroney West, and West Avoca. Samples collected during the Phase 1 investigation are used for the Deep Adit Area and Shelton Abbey. Data associated with the Deep Adit location (EA-5) were collected by the GSI and used in this Phase 2 assessment to the extent possible. Samples were collected in known or suspected contaminant source areas and in areas where receptors could potentially be exposed to site-related contaminants; these areas were identified as preliminary exposure areas. Sample locations are shown in the Data Report on Figures 3-2a, b, c, d, and Figures 5-4 a, b, c. Additionally as part of the field investigation of spoil piles, subsurface materials were sampled from boreholes installed at Cronebane/Mt. Platt, East Avoca/Tigroney, West Avoca, and Shelton Abbey.

A statistical summary for analytical results for surface spoil samples is presented in Table 2-1. This table presents the range of measured concentrations for each element and the frequency of detection. Essential nutrients or electrolytes (e.g., Ca, Mg, P, Na, K) are not included on these tables.

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Table 2-1 Summary Statistics for Phase 2 Spoils Samples

EA	Statistic	Ag	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Th	Tl	Ti	U	V	Zn
1	Min	2.50	0.38	73.17	60.41	0.13	0.20	4.00	81.20	0.98	0.36	85.07	3.80	0.40	1,112	0.75	0.40	0.40	2.74	2.74	20.00	0.63	4.00	86.69
1	Mean	29.23	1.73	1,076	346	0.66	0.62	4.00	2,016	6.76	5.90	259	47.67	2.44	23,812	13.28	1.25	1.58	12.99	12.99	45.51	3.05	6.59	485
1	Max	82.56	4.21	3,509	1,384	1.57	1.37	4.00	7,078	11.15	16.68	861	108	5.47	78,441	39.42	2.79	6.07	29.48	29.48	73.11	4.88	14.28	1,313
1	#Samples/# Detects	18/18	18/18	18/18	18/18	18/18	13/18	0/18	18/18	18/18	18/18	18/18	18/18	16/18	18/18	18/18	11/18	8/18	18/18	18/18	13/18	18/18	7/18	18/18
1	FD	100%	100%	100%	100%	100%	72%	0%	100%	100%	100%	100%	100%	89%	100%	100%	61%	44%	100%	100%	72%	100%	39%	100%
2	Min	1.35	0.41	263	24.76	0.13	0.20	4.00	150	1.69	0.57	20.00	2.14	0.40	1,506	1.29	0.40	0.40	1.29	1.35	20.00	1.35	4.00	47.29
2	Mean	8.93	1.23	571	101	0.52	1.43	5.95	612	6.04	2.61	116	25.35	2.39	5,192	3.54	1.37	1.01	13.18	13.18	55.02	2.77	6.28	203
2	Max	19.05	2.46	1,046	343	1.21	3.68	37.58	1,337	14.56	17.48	417	53.82	11.52	24,266	7.45	3.94	5.25	26.24	26.24	209	12.82	15.54	376
2	#Samples/# Detects	24/24	24/24	24/24	24/24	24/24	24/24	2/24	24/24	24/24	24/24	24/24	24/24	20/24	24/24	24/24	18/24	5/24	24/24	24/24	15/24	24/24	7/24	24/24
2	FD	100%	100%	100%	100%	100%	92%	8%	100%	100%	100%	100%	100%	83%	100%	100%	75%	20%	100%	100%	63%	100%	29%	100%
3	Min	1	0.14	8	5	0	0.58	4.00	73.95	0.38	0.17	44.67	1.31	0.40	111.81	0.89	0.40	0.40	0.40	0.40	20.00	0.40	4.00	49.01
3	Mean	9.83	2.15	457	27.36	0.31	2.39	4.00	1,490	11.55	0.94	457	45.62	3.16	1,490	2.04	1.31	5.51	7.50	7.50	130	1.52	9.95	199
3	Max	31.38	3.46	942	93.23	0.53	5.92	13.33	2,912	16.97	3.76	1,043	88.34	8.16	21,753	4.62	3.06	24.59	9.46	9.46	259	2.36	22.96	415
3	#Samples/# Detects	10/10	10/10	10/10	10/10	10/10	10/10	3/10	10/10	10/10	10/10	10/10	10/10	9/10	10/10	10/10	3/10	9/10	10/10	10/10	9/10	10/10	4/10	10/10
3	FD	100%	100%	100%	100%	100%	100%	30%	100%	100%	100%	100%	100%	90%	100%	100%	70%	90%	100%	100%	90%	100%	40%	100%
4	Min	1.67	0.86	216	20.85	0.33	0.47	4.00	466	5.05	0.23	97.60	11.79	1.01	1,091	0.87	0.40	0.40	6.69	6.69	20.00	1.12	4.00	181
4	Mean	20.18	2.21	1,084	31.23	1.94	3.37	4.88	2,895	13.03	5.73	365	88.34	4.28	21,932	11.42	1.82	6.58	9.81	9.81	185.80	2.63	11.02	1,037
4	Max	44.62	3.59	2,893	70.97	6.30	8.54	11.03	11,116	20.12	20.87	471	186	11.44	74,877	44.01	6.17	13.75	14.14	14.14	849	4.80	26.28	2,628
4	#Samples/# Detects	10/10	10/10	10/10	10/10	10/10	10/10	1/10	10/10	10/10	10/10	10/10	10/10	9/10	10/10	10/10	7/10	9/10	10/10	10/10	9/10	10/10	7/10	10/10
4	FD	100%	100%	100%	100%	100%	100%	10%	100%	100%	100%	100%	100%	100%	100%	100%	70%	90%	100%	100%	90%	100%	70%	100%
5	Min	35.00	NA	371.91	10.00	50.00	30.00	75.00	410.12	NA	15.00	35.00	NA	25.00	1,128	20.00	20.00	30.00	NA	10.00	601	0.00	25.00	25.00
5	Mean	35.00	NA	982	421	50.00	411	75.00	1,210	NA	15.00	669	NA	25.00	7,846	79.72	20.00	30.00	NA	280	1,287	0.00	25.00	285
5	Max	35.00	NA	2,940	1,549	50.00	1,774	75.00	3,404	NA	15.00	957	NA	25.00	22,877	228.89	20.00	30.00	NA	949	2,299	0.00	25.00	796
5	#Samples/# Detects	0/16	NA	16/16	6/16	0/16	5/16	0/16	16/16	NA	0/16	15/16	NA	0/16	16/16	6/16	0/16	0/16	NA	13/16	16/16	0/16	0/16	12/16
5	FD	0%	NA	100%	38%	0%	31%	0%	100%	NA	0%	94%	NA	0%	100%	38%	0%	0%	NA	81%	100%	0%	0%	75%
6	Min	0.02	0.79	67.46	13.27	0.02	0.20	4.00	57.11	4.05	0.16	89.33	1.20	1.24	106.77	0.10	0.40	0.40	5.59	5.59	72.77	1.18	4.00	65.96
6	Mean	7.39	2.59	1,150	42.76	0.23	3.95	14.02	719	17.23	1.21	610	61.50	7.77	3,759	4.09	3.02	4.95	10.90	10.90	193	2.44	27.62	167
6	Max	55.35	5.51	3,903	92.40	1.32	17.64	90.21	2,822	30.80	8.20	1,777	188	31.33	28,363	19.93	9.76	26.67	16.55	16.55	779	5.32	180	733
6	#Samples/# Detects	25/26	26/26	26/26	26/26	22/26	25/26	8/26	26/26	26/26	26/26	26/26	26/26	26/26	26/26	25/26	23/26	22/26	26/26	26/26	26/26	26/26	23/26	26/26
6	FD	96%	100%	100%	100%	85%	96%	31%	100%	100%	100%	100%	100%	100%	100%	96%	88%	85%	100%	100%	100%	100%	88%	100%
7	Min	ND	NA	24.0	0.24	ND	59.7	35.2	31.1	NA	4.2	112	NA	24.3	29.4	ND	ND	ND	NA	NA	NA	NA	NA	4.9
7	Mean	ND	NA	62.3	1.2	ND	59.7	118	44.0	NA	4.4	297	NA	45.5	274	ND	ND	ND	NA	NA	NA	NA	NA	22.2
7	Max	ND	NA	184	2.2	ND	59.7	243	59.9	NA	4.6	791	NA	79.9	960	ND	ND	ND	NA	NA	NA	NA	NA	41.3
7	#Samples/# Detects	0/4	NA	4/4	4/4	0/4	4/4	4/4	4/4	NA	4/4	4/4	NA	4/4	4/4	0/4	0/4	0/4	NA	NA	NA	NA	NA	4/4
7	FD	ND	NA	100%	100%	ND	100%	100%	100%	NA	100%	100%	NA	100%	100%	ND	ND	ND	NA	NA	NA	NA	NA	100%
	Spoils MAX	82.56	5.51	3,903	1,384	6.30	59.74	243.27	11,116	30.80	20.87	1,777	188.31	79.87	78,441	44.01	9.76	26.67	29.48	949	849.29	12.82	179.87	2,628

units - mg/kg

EA = Exposure Area

FD - frequency of detection (%)

ND = constituent not detected above detection limit in any sample (FD=0)

NA = not analyzed for this constituent

Mean = arithmetic means include one half the detection limit for nondetect samples

Max = maximum detected concentration, overall maximums do not include EA maximums where constituent was not detected (i.e., where maximums are based only on half the detection limit)

N = number of samples

Note: Data for EA-5 are from GSI, and values associated with non-detect data (where FD=0) are invalid for comparison or risk estimation

Surface soil samples were collected from several fields and pastures in the vicinity of the Site. Some of these fields are downwind of spoil piles and may have been contaminated via windblown deposition. Seven surface soil samples were collected from Gerald Murphy's Field (GMF) south of Cronebane. North of Mount Platt/Cronebane surface soil samples were collected from two of Kavanagh's fields (KF1 and KF2) and Ivor Fitzpatrick's Field (IFF). Four surface soil samples were collected from Paddy Hogan's Field (PHF). Two of Tom Merrigan's fields (TMF1 and TMF2) located in West Avoca were also sampled. A statistical summary for analytical results for surface soil samples from fields/pastures is presented in Table 2-2.

2.1.2 Lead and Arsenic Speciation and Bioaccessability Study

Other data for soil/mine waste at the Avoca Mining Site collected for use in characterizing risks and setting remediation goals include (1) *in vitro* analysis of bioavailability of lead and arsenic in soils/mine waste, and (2) electron microprobe analysis of lead and arsenic speciation in soils/mine waste. These data allow arsenic and lead bioavailability for materials at the Site to be compared with those from previous bioavailability studies on mine wastes. An extremely good correlation has been found between results of animal studies of bioavailability and *in vitro* solubility in simulated stomach acid for lead, and a significant correlation for the same estimates for arsenic. Thus, *in vitro* assays and electron microprobe analyses can help establish a site-specific estimate of bioavailability for these two COPCs.

Bioavailability analyses for arsenic and lead were performed on 31 representative spoil samples. Bioavailability in this case is an estimate of the amount of lead or arsenic that might be absorbed from the GI tract after ingestion of soil. Relative bioavailability compares solubility of lead or arsenic in soil to a fully soluble form in simulated stomach. Relative bioavailability can then be converted to an estimate of the amount actually absorbed in the GI tract for use in risk analysis (absolute bioavailability).

Spoils at the Site were generated both during historical (1720-1888) and modern (1947-1982) periods. The methodology used in each period was very different resulting in differences in the physical and chemical properties of the spoils. For both metals, bioavailability varies dramatically depending on types of waste and soil geochemistry and is a key component in evaluating risks and hazards for these two contaminants.

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Table 2-2 Summary of Statistics for Phase 2 Surface Soil Samples

EA	Statistic	Ag	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Th	Ti	U	V	Zn
GMF	Min	1.02	53.8	23.7	0.35	1.30	9.52	192.2	0.09	185	5.05	3.19	346	0.41	0.40	1.43	4.12	100.6	1.56	15.7	89.5
GMF	Mean	2.75	84.0	35.5	0.49	2.04	13.07	283.0	0.22	295	6.32	4.77	568	0.64	0.46	1.76	5.40	134.8	1.81	22.2	134.7
GMF	Max	6.01	106.1	49.4	0.68	2.86	17.56	359.9	0.35	469	7.09	7.42	818	0.96	0.81	2.02	6.30	178.9	2.00	32.9	168.6
GMF	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
GMF	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.14	1	1	1	1	1	1
IFF	Min	0.16	15.7	12.1	0.15	0.20	4.00	26.7	0.01	23	1.04	0.40	39	0.10	0.40	0.40	2.62	20.0	0.81	4.00	17.3
IFF	Mean	0.26	22.8	15.1	0.25	0.62	5.13	42.8	0.03	88	2.52	1.36	62	0.16	0.40	0.47	3.94	54.8	1.12	9.65	33.6
IFF	Max	0.48	28.3	24.9	0.44	1.31	11.90	73.9	0.07	215	4.65	3.11	117	0.39	0.40	0.87	6.28	112.1	1.54	26.9	56.5
IFF	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
IFF	FD	1	1	1	1	0.86	0.14	1	0.71	1	1	0.71	1	0.29	0.00	0.14	1	0.86	1	0.43	1
KF1	Min	0.42	32.7	19.4	0.27	0.60	4.00	29.8	0.02	91	1.78	1.85	100	0.10	0.40	0.40	3.44	81.2	1.31	4.00	35.8
KF1	Mean	1.15	59.8	24.4	0.44	0.93	8.37	50.5	0.11	146	4.02	2.89	142	0.25	0.53	0.89	4.77	100.8	1.35	17.9	48.0
KF1	Max	2.43	144.4	28.8	0.72	1.39	12.06	83.9	0.18	187	7.16	3.50	219	0.45	1.06	1.27	5.97	143.0	1.38	24.8	68.6
KF1	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
KF1	FD	1	1	1	1	1	0.60	1	1	1	1	1	1	0.60	0.20	0.80	1	1	1	0.80	1
KF2	Min	0.38	40.6	36.5	0.22	1.41	10.68	81.0	0.11	180	3.21	3.37	143	0.10	0.40	0.40	4.12	78.1	1.73	19.6	59.5
KF2	Mean	0.48	47.3	73.9	0.33	2.67	18.25	110.7	0.13	289	4.22	6.84	195	0.16	0.51	0.40	5.19	114.8	1.87	26.8	78.5
KF2	Max	0.71	60.7	166.7	0.48	3.81	23.72	177.3	0.17	412	5.83	10.06	346	0.30	0.94	0.40	6.13	132.8	2.16	34.3	114.9
KF2	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
KF2	FD	1	1	1	1	1	1	1	1	1	1	1	1	0.40	0.20	0.00	1	1	1	1	1
PHF	Min	1.19	70.2	126.1	1.08	18.63	26.78	358.8	0.34	2,204	4.43	21.05	659	0.38	0.40	2.53	5.42	175.6	2.06	33.8	344.3
PHF	Mean	1.41	73.1	135.3	1.67	19.42	29.05	428.9	0.46	2,296	4.60	21.81	728	0.47	0.40	2.90	5.90	196.0	2.29	35.9	541.6
PHF	Max	1.57	74.7	147.2	2.11	20.67	31.20	515.6	0.56	2,345	4.76	22.25	766	0.54	0.40	3.52	6.52	215.1	2.57	38.0	647.2
PHF	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
PHF	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	1.00	1	1	1	1	1	1
TMF1	Min	0.72	114.8	44.4	0.15	4.00	12.64	158.5	0.13	405	5.65	5.17	227	0.43	0.40	1.15	5.50	69.6	2.05	19.6	118.7
TMF1	Mean	1.83	184.3	65.6	0.34	5.84	16.43	313.0	0.25	565	8.18	9.40	379	0.85	0.78	1.69	6.57	97.8	2.62	26.9	162.0
TMF1	Max	2.63	275.5	89.2	0.48	9.80	29.78	574.7	0.65	861	12.39	13.11	643	1.87	1.30	2.69	7.83	137.4	3.76	57.2	227.4
TMF1	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
TMF1	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.57	1	1	1	1	1	1
TMF2	Min	0.30	47.6	43.6	0.13	2.62	9.48	94.0	0.09	271	2.33	3.42	145	0.21	0.40	0.40	4.13	54.2	1.77	19.9	69.7
TMF2	Mean	1.30	106.1	77.4	0.35	8.98	27.10	124.4	0.17	715	7.66	11.34	190	0.40	0.80	1.04	5.40	132.6	2.25	49.0	146.4
TMF2	Max	4.12	227.9	111.7	0.58	31.95	73.94	163.8	0.33	1,381	18.56	41.11	225	0.75	1.43	2.67	8.97	387.3	2.77	128.3	335.7
TMF2	N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
TMF2	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.43	0.71	1	1	1	1	1
	SS MAX	6.01	275.5	166.7	2.11	32.0	73.9	574.7	0.65	2,345	18.56	41.11	818	1.87	1.43	3.52	8.97	387.3	3.76	128.3	647.2

units - mg/kg

EA = Exposure Area

Mean = arithmetic means include one half the detection limit for nondetect samples

Max = maximum detected concentration

N = number of samples

FD - frequency of detection (fraction)

Bioavailability of arsenic and lead at the Site is relatively low and is not directly related to the soil concentration (i.e., a higher soil concentration does not equate with a higher bioavailability). Qualitatively, these results indicate relatively low potential exposure to lead and arsenic. Bioavailability of lead as assessed in the *in vitro* assays for the Site show relatively low bioavailability, significantly below the IEUBK default (30 percent). Relative bioavailability estimates range from 0.15 to 28 percent and average about 6 percent. Since fully soluble lead is only about 50 to 60 percent absorbed, and since absolute bioavailability is used in lead models, relative bioavailability is corrected to absolute. When relative bioavailability values are adjusted to absolute values, bioavailability estimates for lead range from 0.07 to 13 percent and average about 3 percent. Arsenic bioavailability for mine wastes at the Site appear to be significantly less than the USEPA default value of 80 percent. *In vitro* results for arsenic range from 0.001 to 8 percent. These estimates are consistent with microprobe analyses that indicated that the most arsenic is present in relatively insoluble forms in association with arsenic bearing plumbojarosite. These data form a reasonable basis for estimating site-specific arsenic bioavailability. For this assessment, it is assumed that relative and absolute bioavailabilities of arsenic are about the same because soluble arsenic is essentially completely absorbed from the gut. Thus unmodified estimates are used.

Relative bioavailability estimates are summarized in Table 2-3. Results of the bioaccessability study and calculations are provided in Appendix A.

Table 2-3 Bioavailability Results for Arsenic and Lead in Spoils

Exposure Area	Sample ID	Arsenic		Lead	
		Soil Concentration[1] (mg/kg)	Relative Bioavailability (%)	Soil Concentration[1] (mg/kg)	Relative Bioavailability (%)
EA-1	SP25 (0,0)	1,189	0.05	28,755	2.22
	SP25 (0,1)	625	0.60	7,896	9.48
	SP25 (0,-1)	1,038	0.43	55,523	21.99
	SP25 (0,-2)	2,525	0.15	56,022	10.59
	SP25 (1,0)	1,452	0.13	35,527	12.02
	SP25 (-1,0)	975	-0.02	29,193	3.03
	SP31 (0,1)	2,170	0.16	41,435	12.10
	SP31 (0,2)	2,560	0.12	37,514	1.98
	SP31 (1,1)	2,008	0.12	35,591	10.59
EA-2	SP20 (0,0)	539	0.15	3,302	1.26
	SP20 (0,-1)	488	-0.18	3,151	0.57
	SP20 (0,2)	654	0.03	5,524	2.03
	SP20 (0,-2)	677	-0.01	4,774	2.57
	SP20 (0.5, 2)	801	0.10	8,061	2.20
	SP20 (1,0.5)	582	0.06	2,877	0.82
	SP20 (-1,-2)	462	0.30	5,397	0.45
	SP20A (-3,1)	407	0.13	3,405	1.19
EA-3	SP10 (0,2)	130	0.29	549	12.75
	SP4 (0,0)	427	0.27	2,657	4.45
	SP5 (0,0)	1,035	0.18	9,816	1.85
	SP5 (0,1)	789	0.001	9,323	3.53
	SP5 (0,-1)	336	0.27	2,649	4.63
	SP5 (-1,0)	706	0.06	7,331	3.73
EA-4	SP2 (0,0)	1,053	1.67	17,170	2.60
	SP2 (1,1)	1,122	0.004	49,541	1.28

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Table 2-3 Bioavailability Results for Arsenic and Lead in Spoils

Exposure Area	Sample ID	Arsenic		Lead	
		Soil Concentration[1] (mg/kg)	Relative Bioavailability (%)	Soil Concentration[1] (mg/kg)	Relative Bioavailability (%)
EA-6	SP34 (0,0)	1,424	0.01	1,251	2.88
	SP34 (1,0)	160	0.28	289	1.45
	SP34 (1,-4)	1,611	0.18	1,764	7.18
	SP37 (0,3)	15	7.58	59	27.89
	SP37 (-1,1)	418	0.86	2,452	1.78
	SP37A (0,0)	346	0.03	2,204	0.15

[1] Concentration in < 250 micron sized particles

2.1.3 Groundwater

The lack of groundwater data for the preliminary Phase 1 HHRA was identified as a critical data gap. Groundwater samples were collected from a variety of well types in the vicinity of the Site in order to characterize potential risks associated with domestic use of groundwater. Six homeowner "wells" in the vicinity of the Site were sampled. Generally homeowners in the vicinity of the Site do not use their groundwater wells as drinking water sources. Homeowner "wells" sampled include: Heffernan, Meehan, Richard, Kerin, Cosgrove, and the Holy Well. The Cosgrove "well" is spring fed. The Holy Well water is flowing from a pipe installed into the hillside. One homeowner, Kerin, uses their groundwater well as a drinking water source. Another homeowner, Cosgrove, uses their well to water livestock. Other types of wells sampled include monitoring wells installed by County Wicklow, and six recently installed monitoring wells. These wells, installed during the Phase 2 investigation, were completed in shallow alluvium near the Avoca River to better understand the impact of diffuse flow on the Avoca River.

Water from springs in the area was also sampled. The Radio Tower Spring is considered a water source beneficial for health. People visit the spring and fill up containers with water to take home. This water is also piped to two homes in the area. Paddy's Spring is not used for drinking water.

A statistical summary for analytical results for groundwater samples is presented in Table 2-4.

Table 2-4 Summary of Phase 2 Groundwater Data Collected in 2007

Chemical	Maximum Total Concentration in Homeowner Wells (1)	Maximum Total Concentration in Monitoring Wells (2)	Maximum Dissolved Concentration in Monitoring Wells (3)
Aluminium	1,186	62,440	1,300,000
Antimony	1	ND (<1)	ND (<1)
Arsenic	ND (<1)	ND (<1)	27
Barium	46	47	41
Cadmium	ND (<1)	30	294
Chromium	4	4	370
Cobalt	ND (<1)	116	1,087
Copper	81	8,028	85,460
Iron	502	1,058	136,000
Lead	3	10	231

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Table 2-4 Summary of Phase 2 Groundwater Data Collected in 2007

Chemical	Maximum Total Concentration in Homeowner Wells (1)	Maximum Total Concentration in Monitoring Wells (2)	Maximum Dissolved Concentration in Monitoring Wells (3)
Manganese	25	5,537	51,310
Mercury	0.0014	NA	NA
Nickel	8	58	575
Selenium	ND (<1)	ND (<1)	3
Silver	ND (<2)	ND (<2)	ND (<2)
Thallium	ND (<1)	ND (<1)	ND (<1)
Tin	2	4	ND (<1)
Titanium	5	21	9
Uranium	4	7	93
Vanadium	2	4	2
Zinc	234	9,855	137,700

Units are in micrograms per liter (µg/L)
(1) Maximum reported total concentration for all residential wells sampled (µg/L), (six wells)
(2) Maximum reported total concentration (µg/L) for shallow monitoring wells sampled, 3 wells
(3) Maximum reported dissolved concentration (µg/L) for shallow monitoring wells sampled, 12 wells

2.1.4 Surface Water Data

The Preliminary Phase 1 HHRA used available water quality survey data for the Avoca River collected in 2002 and 2003 (Toner et al. 2003). These data indicated that the Avoca River is seriously polluted with copper, zinc, and to a lesser extent, lead. The Preliminary Phase 1 HHRA identified the limited surface water data set as a data gap; in order to support risk assessment, many additional samples were collected from surface water features in the areas potentially impacted by mine site contamination as part of the Phase 2 investigation.

Samples were collected during the Phase 2 investigation from two categories of surface water: 1) rivers and tributaries, and 2) adits, springs, and miscellaneous surface waters. Data for the Avoca River and major tributaries are grouped together. The second category includes a large number and variety of smaller or more isolated water bodies, including mine adits, springs, small ponds, very small tributaries, or other waters that flow only intermittently (e.g., stormwater flows). Surface water samples were collected from the following adits, seeps, and lakes: Ballygahan Adit, Cronebane Intermediate Adit, Cronebane Pit Lake, Cronebane Seeps, Cronebane Shallow Adit, Deep Adit, Deep Adit Confluence, Deep Adit Runoff, Drews Discharge, East Avoca Pit Lake, Killmacoo, Mt. Platt Seep East, Mt. Platt Seep West, Mulcahy Ditch, Red Road, Road Adit, Road Adit Confluence, Shelton Abbey Base Pond, Spa Adit, and Valve Box Seep. Table 2-5 presents a summary of analytical data based on the Phase 2 investigation surface water sampling and analyses for Rivers and Tributaries. A statistical summary for other types of surface water is presented in Table 2-6. Summaries report minimum, mean, and maximum concentrations, by location, for potentially hazardous chemicals in rivers and tributaries. Total concentrations are presented; however, for some samples only dissolved concentrations are available and for these locations dissolved concentrations are presented.

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Table 2-5 Summary Statistics for Phase 2 Surface Water (River and Tributaries)

Surface Water	Number of Samples	Number of Detects	Frequency of Detects (percentage)	Minimum Concentration	Mean Concentration	Maximum Concentration
COPC						
Aluminum	21	21	100%	89	656.0	3,717
Antimony	21	1	5%	1	1.0	2
Arsenic	21	8	38%	1	1.4	6
Barium	21	21	100%	29	35.8	42
Cadmium	21	1	5%	1	1.0	2
Chromium	21	21	100%	2	4.2	6
Cobalt	21	7	33%	1	1.1	2
Copper	21	21	100%	31	45.2	63
Iron	21	21	100%	330	650.5	1,073
Lead	21	21	100%	2	8.1	17
Manganese	21	21	100%	10	67.9	317
Mercury	21	0	0%	ND	ND	ND
Nickel	21	21	100%	5	6.4	8
Selenium	21	5	24%	1	2.1	15
Silver	21	0	0%	ND	ND	ND
Thallium	21	0	0%	ND	ND	ND
Tin	21	21	100%	1	1.9	3
Titanium	21	21	100%	3	4.1	6
Uranium	21	21	100%	3	3.8	5
Vanadium	21	8	38%	1	1.3	3
Zinc	21	21	100%	73	230.0	741

ND = Not Detected
Concentrations in µg/L

Table 2-6 Summary Statistics for Phase 2 (Adits, Springs, Miscellaneous Surface Water)

Surface Water	Number of Samples (total)	Number of Detects (total)	Frequency of Detects (percentage)	Minimum Total Concentration	Mean Total Concentration	Maximum Total Concentration	Maximum Dissolved Concentration
COPC							
Aluminum	11	11	100%	107	61,989.1	271,000	1,032,000
Antimony	11	1	9%	1	1.0	1.0	2.0
Arsenic	11	6	55%	1	1.5	6.0	154
Barium	11	11	100%	23	35.8	60.0	113
Cadmium	11	11	100%	1	59.7	248.0	519
Chromium	11	11	100%	2	5.2	14.0	102
Cobalt	11	11	100%	1	99.7	257.0	495
Copper	11	11	100%	52	3,113.2	8,809	88,760
Iron	11	11	100%	323	38,330.4	130,600	722,600
Lead	11	11	100%	2	722.4	1,944	98
Manganese	11	11	100%	309	4,761.0	13,670	14,860
Mercury	11	0	0%	ND	ND	ND	ND
Nickel	11	11	100%	6	54.9	129.0	329
Selenium	11	5	45%	1	1.5	3.0	3
Silver	11	0	0%	ND	ND	ND	ND
Thallium	11	7	64%	1	2.0	4.0	1
Tin	11	7	64%	1	1.2	2.0	1.0
Titanium	11	11	100%	5	6.0	8.0	11
Uranium	11	11	100%	3	10.7	31.0	61
Vanadium	11	5	45%	1	1.1	2.0	2
Zinc	11	11	100%	2339	21,117.7	76,380	132,900

ND = Not Detected
Concentrations in µg/L

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2.1.5 Sediment Data

A limited dataset for aquatic sediments was available for the preliminary Phase 1 HHRA and this relative lack of data was identified as a data gap. Sediments are defined as the finer grained solid media underlying surface water at the time of sampling. Sediments that have been deposited along stream banks that are currently not covered by water are considered riparian soils and not sediments. Sediments were collected from the following areas during the Phase 2 Investigation:

- Transects 1, 2, 3, and 4 in the Avoca River
- Deep Adit Confluence
- Road Adit Confluence
- Aughrim River at Golf Course
- Across from Shelton Abbey Tailings Impoundment

Sediment Sample locations are shown in the Data Report on Figures 3-1a, b, and 3-2 a, b. A statistical summary for site-wide sediment is presented in Table 2-7.

Table 2-7 Summary Statistics For Site-wide Phase 2 Sediment Samples Avoca Mine Site (1)

Compound	Number of Detects	Number of Samples	Frequency of Detection	Minimum Concentration (mg/kg)	Arithmetic Mean (mg/kg)	Maximum Concentration (mg/kg)	Location of Maximum Concentration
Aluminum	10	10	100%	0.49	2.2	2.8	SA/T1-2
Antimony	2	10	20%	1.1	1.4	1.7	Road Adit
Arsenic	10	10	100%	21.6	82	481	Road Adit
Barium	10	10	100%	4.6	46.6	70.1	Aughrim at Golf Course
Bismuth	9	10	90%	0.29	0.8	1.8	Deep Adit
Cadmium	10	10	100%	0.17	0.47	0.98	Transect 2
Chromium	9	10	90%	9.7	27.6	33.9	Transect 3
Cobalt	10	10	100%	1.77	14.5	18.7	SA/T1-2
Copper	10	10	100%	21.8	142.2	503.5	Road Adit
Iron	10	10	100%	3.7 %	10.3 %	42.1 %	Road Adit
Lead	10	10	100%	21.4	184	704	Deep Adit
Manganese	10	10	100%	77.5	2,311	8,069	Transect 2
Mercury	2	10	20%	0.12	0.1	0.16	Deep Adit
Molybdenum	10	10	100%	0.57	1.09	2	Deep Adit
Nickel	10	10	100%	3.6	20.3	25.8	SA/T2-1
Selenium	0	10	0%	ND	ND	ND	Not Detected
Silver	8	10	80%	0.04	0.14	0.35	Deep Adit
Thorium	10	10	100%	2.0	5.8	7.4	SA/T1-2
Tin	2	10	20%	1.5	1.5	1.5	Road Adit
Titanium	10	10	100%	45.1	207.2	291.5	Aughrim at Golf Course
Uranium	10	10	100%	0.49	1.6	3.8	Transect 2
Vanadium	9	10	90%	13.5	26	30.2	SA/T2-1
Zinc	10	10	100%	102.9	178	244	Transect 4

(1) Does not include Transect 1 upstream of site
ND= Not Detected

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2.1.6 Ecological Data

The Phase 2 Investigation included several studies for ecological assessment. Some of these studies, particularly plant bioaccumulation, may be useful in the qualitative evaluation of future potential human health risks. The primary goal of the plant bioaccumulation study was to identify potential impacts to livestock in areas with exposure to elevated levels of metals. One of the main areas of concern was the agricultural area near Connary, where sheep graze in fields located near or on spoils piles. Results of the bioaccumulation study are discussed in the BERA in Section 9.4.4.

2.2 Selection of Chemicals of Potential Concern

COPCs are mine-related constituents that could pose a threat to people that use the Site. These constituents are selected in a conservative fashion—that is, the selection process is biased toward including constituents that pose little or no threat as COPCs, rather than miss ones that could pose a threat. Thus, COPCs identified for evaluation in the risk assessment include those chemicals that may imply significant risk and hazard to human receptors. The list may also include some constituents that are ultimately shown not to be important for assessing human health risk.

Site-related COPCs are selected through a screening process where measured COPC concentrations are compared to available conservative screening levels. The COPC screening process uses data collected in the Phase 2 investigation described in the previous sections to select COPCs. Identification of COPCs is based on direct comparison of measured concentrations of all constituents in various Site media to conservative EPA or USEPA risk-based screening levels and/or commonly accepted benchmarks approved by EPA for screening purposes. COPCs are retained for further risk evaluation when measured maximum concentrations exceed their respective screening levels. Screening levels are conservative risk-based or other estimated concentrations that, if not exceeded, would be protective for human receptors under all possible chronic exposure conditions. Screening levels are generally based on potential cancer and non-cancer effects to humans. Screening levels are constituent-specific and media-specific. Sources of screening levels used in the HHRA for one or more media (e.g., sediment, surface soil, surface water, etc.) include the following, in order of priority:

- Ireland EPA Expert Group (EPA 2004) guidelines for metals in soil and sediment from Final Report of Expert Group for Silvermines County Tipperary, Lead and Other Relevant Metals. ISBN 1-84095-129-1. Issued February 2004.

- Ireland EPA, Expert Group (EPA 2008) Drinking Water Regulations (Drinking Water Regulations Guidance Booklet No. 2 Issued 8th January 2008. Office of Environmental Enforcement, Ireland EPA)

- Ireland EPA, regulatory limits for Dangerous Substances in Surface Water [Water Quality (Dangerous Substances) Regulations, S.I. No. 12 of 2001, Minister of State at the Department of the Environment and Local Government, Ireland]

■ USEPA Region 3 risk based concentrations (RBCs) for residential and commercial/ industrial exposures (USEPA 2007)

2.2.1 Surface Soil/Spoils COPCs

Maximum concentrations reported in surface spoil samples were compared to EPA Ireland recommended screening levels where available or USEPA screening levels. COPCs were selected on a site-wide basis for soils/spoils. The Expert Group (EPA 2004) has recommended guidelines for lead and other relevant metals in soil and sediment in order to minimize risk of exposure to children, adults, animals, crops, and the wider environment. Screening guidelines are available for lead and cadmium. Based on these guidelines lead is selected as COPCs for soil/spoils. The Expert Group considered that specific soil guidelines for arsenic, zinc, copper, or mercury were unnecessary. Instead, the Expert Group considered that remedial actions triggered by guidelines specified for lead and cadmium would be sufficient to ensure that human health is protected in relation to arsenic, zinc, copper, and mercury.

However, for completeness, maximum concentrations reported in surface soil/spoils samples for chemicals other than cadmium and lead were compared to USEPA RBCs for residential soil; based on this comparison antimony, arsenic, cobalt, copper, iron, manganese, thallium, and vanadium were also selected as COPCs. Soil COPCs are summarized on Table 2-8. For some areas of the site, only XRF data are available; results from these data tend to be higher and less confidence is attributed to this data set. COPCs selected based only on XRF results include antimony, cobalt, and thallium. Note that, as is common practice, nontoxic and essential elements such as calcium and magnesium were not selected. Note also that this analysis does not take into account the potential for some mine-related constituents to bioaccumulate. This issue is separately addressed below in Section 2.2.5.

Table 2-8 Screening of Surface Spoil/Soil COPCs Avoca Mining Area

Chemical	Maximum Site Wide Concentration (mg/kg)	ESL EPA Ireland[1] (mg/kg)	USEPA Region 3 RBCs for Soil[2] (mg/kg) Residential	Commercial /Industrial	COPC
Aluminum	5.5		78,214	1,022,000	No
Antimony	229		31	409	**Yes**
Arsenic	3,903		0.43	1.91	**Yes**
Barium	1,549		15,643	204,400	No
Bismuth	2,238		NA	NA	No
Calcium	0.8		NA	NA	No
Cadmium	6.3	pH /land use dependent	39	511	**Yes**
Cobalt [4]	1,774		902.89	1921.35	**Yes**
Chromium[5]					
Chromium III	90		117,321	1,533,000	No
Chromium VI	90		235	3,066	No
Copper	11,116		3,129	40,880	**Yes**
Iron	363,041		54,750	715,400	**Yes**
Lead	78,441	1000			**Yes**
Mercury[3]	21		23	307	No
Magnesium	4.6		NA	NA	No

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Table 2-8 Screening of Surface Spoil/Soil COPCs Avoca Mining Area

Chemical	Maximum Site Wide Concentration (mg/kg)	ESL EPA Ireland[1] (mg/kg)	USEPA Region 3 RBCs for Soil[2] (mg/kg)		COPC
			Residential	**Commercial /Industrial**	
Manganese	1,777		1,564	20,440	**Yes**
Molybdenum	188.3		391	5,110	No
Nickel	31.3		1,564	20,440	No
Phosphorus	0.5		NA	NA	No
Selenium	9.8		391	5,110	No
Silver	82.6		391	5,110	No
Sodium	0.1		NA	NA	No
Sulfur	12,951		NA	NA	No
Tin	26.7		46,929	613,200	No
Thallium	949		5.48	71.54	**Yes**
Thorium	29.5		NA	NA	No
Titanium [4]	2,299		1.0E+05	1.0E+05	No
Uranium	12.8		16	204	No
Vanadium	180		78	1,022	**Yes**
Zinc	2,628		23,464	306,600	No
Cadmium Soil Guidelines[1]			**Soil Guideline Value (mgCd/kgDWSoil)**		
Scenario			pH 6	pH 7	pH 8
Residential with homegrown vegetables			1	2	8
Allotments			1	2	8
Residential without homegrown vegetables			30	30	30
Commercial/Industrial			1400	1400	1400

ESL = Environmental Screening Level
RBC = Risk Based Concentration
PRG = Preliminary Remediation Goal
COPC = Chemical of Potential Concern
mg/kg = milligrams per kilogram
mgCd/kgDWSoil = milligrams cadmium per kilogram dry weight soil
[1] EPA Ireland, Final Report of Expert group for Silvermines County Tipperary, Lead and Other Relevant Metals (2004)
[2] USEPA Region 3 RBCs and PRGs
[3] RBC/PRG for Mercuric Chloride
[4] USEPA Region 9 PRG
[5] Using total Cr concentration and assuming 1:7 ratio of Cr III to Cr VI

2.2.2 Groundwater COPCs

Groundwater samples were collected from private homeowner wells and monitoring wells. Screening of COPCs for groundwater is based on comparing maximum concentrations measured in homeowner wells and monitoring wells separately to EPA regulatory limits for drinking water (EPA 2008) and USEPA Region 3 PRGs for tap water. COPCs based on results from homeowner wells for groundwater are aluminum and iron. COPCs selected based on monitoring wells results are aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc (Table 2-9). Results from homeowner wells generally indicate good water quality. Results from monitoring wells indicate poor water quality exists in the shallow alluvium near the Avoca River. Groundwater from this aquifer is not currently used as a drinking water source and is unlikely to be used as such in the future.

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Table 2-9 Screening of Groundwater COPCs Avoca Mining Area

Chemical (1)	Maximum Total Concentration in Homeowner Wells (2)	Maximum Total Concentration in Monitoring Well (3)	Maximum Dissolved Concentration in Monitoring Well (4)	EPA Drinking Water Standard	USEPA Region 3 Residential PRG for Tap Water	COPC (5)	COPC (6)
Aluminium	1,186	62,440	1,300,000	200	36,500	**Yes**	**Yes**
Antimony	1	ND (<1)	ND (<1)		15	No	No
Arsenic	ND (<1)	ND (<1)	27	10	0	No	**Yes**
Barium	46	47	41		7,300	No	No
Cadmium	ND (<1)	30	294	5	18	No	**Yes**
Chromium	4	4	370	50		No	**Yes**
Chromium III	4	4	370		54,750	No	**Yes**
Chromium IV	4	4	370		110	No	**Yes**
Cobalt	ND (<1)	116	1,087		730	No	**Yes**
Copper	81	8,028	85,460	2,000	1,460	No	**Yes**
Iron	502	1,058	136,000	200	25,550	**Yes**	**Yes**
Lead	3	10	231		15	No	**Yes**
Manganese	25	5,537	51,310	50	730	No	**Yes**
Mercury	0.0014	NA	NA	1		No	NA
Nickel	8	58	575	20	730	No	**Yes**
Selenium	ND (<1)	ND (<1)	3		183	No	No
Silver	ND (<2)	ND (<2)	ND (<2)		183	No	No
Thallium	ND (<1)	ND (<1)	ND (<1)		3	No	No
Tin	2	4	ND (<1)		21,900	No	No
Titanium	5	21	9		145,979	No	No
Uranium	4	7	93		110	No	No
Vanadium	2	4	2		37	No	No
Zinc	234	9,855	137,700	5,000	10,950	No	**Yes**

(1) Units are in micrograms per liter (μg/L)
(2) Maximum reported total concentration for all residential wells sampled (μg/L)
(3) Maximum reported total concentration (μg/L) for shallow monitoring wells sampled, 3 wells
(4) Maximum reported dissolved concentration (μg/L) for shallow monitoring wells sampled, 12 wells
(5) Chemical COPC Based on Homeowner Wells.
(6) Chemical COPC Based on Monitoring Wells.

2.2.3 Surface Water COPCs

Surface water COPCs are selected for two major categories: 1) rivers and tributaries and 2) adits, springs, and miscellaneous surface waters. The first category includes the Avoca River and major tributaries; the second category includes a large number and variety of smaller or more isolated water bodies, including mine adits, springs, seeps, small ponds, very small tributaries, or other waters that flow only intermittently (e.g., stormwater flows).

Screening of surface water COPCs is based on comparing maximum total concentrations measured in surface water to EPA regulatory limits for Dangerous Substances in surface water. Water quality standards for lead and other heavy metals are more stringent under the Water Quality (Dangerous Substances) Regulation (EPA 2001) than under the Drinking Water Abstraction Regulations (EPA 2008). This

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reflects the sensitivity of certain aquatic species to lead, copper, and zinc in the environment. EPA regulatory limits for surface water are unavailable for all metals detected in Phase 2 surface water samples. Zinc is the only COPC for rivers and tributaries selected based on EPA regulatory limits for Dangerous Substances in surface water. Since total concentration data are not available for all surface water bodies included in the second category, maximum dissolved concentrations are used to select COPCs for this group. COPCs selected for adits are arsenic, copper, lead, nickel, and zinc (Table 2-10). All chemicals selected as COPCs based on the limited Phase 1 data set were also selected as COPCs using the more extensive Phase 2 data set.

Generally exposures to contaminants in surface water by people recreating in the area are expected to be minimal. In order to further evaluate potential human health risks drinking water standards (EPA 2008) and USEPA Region 3 PRGs for tap water are also presented. As a conservative measure maximum concentrations of metals in surface water are compared to EPA drinking water standards and USEPA PRGs for tap water. Maximum concentrations of aluminum, iron, lead, and manganese in surface water from rivers and tributaries exceed EPA drinking water standards. In the second category of surface water (i.e., adits, etc.) maximum concentrations of aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc exceed EPA drinking water standards. Arsenic is the only additional compound that would be included as a COPC if USEPA Region 3 PRGs were used as surface water screening criteria.

Table 2-10 Screening of Surface Water COPCs Avoca Mining Area

Surface Water	Maximum Concentration (µg/L)		Screening Level (µg/L)		
Element	Rivers (1)	Adits (2)	ESL (3)	EPA Drinking Water Standard (4)	Residential PRG USEPA Region 3, Tap Water
Aluminum	3,717	1,032,000		200	36,500
Antimony	2	2.0			15
Arsenic	6	154	25	10	0.04
Barium	42	134			7,300
Cadmium	2	519		5	18
Chromium (5)	6	102		50	110
Cobalt (6)	2	495			730
Copper	63	88,760	5	2,000	1,460
Iron	1,073	722,600		200	25,550
Lead (7)	17	2,176	5	10	15
Manganese	317	17,050		50	730
Mercury (8)	0.05	0.05		1	11
Nickel	8	329	8	20	730
Selenium	15	5.0			183
Silver	2	2.0			183
Thallium	1	5.0			3
Tin	3	1.0			21,900
Titanium (9)	6	11			145,979
Uranium	5	61			110
Vanadium	3	3.0			37
Zinc	741	132,900	8	5,000	10,950

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Table 2-10 Screening of Surface Water COPCs Avoca Mining Area

Surface Water	Maximum Concentration (µg/L)		Screening Level (µg/L)		
Element	Rivers (1)	Adits (2)	ESL (3)	EPA Drinking Water Standard (4)	Residential PRG USEPA Region 3, Tap Water

ESL = Environmental Screening Level
PRG = Preliminary Remediation Goal
(1) Maximum total concentration in µg/L
(2) Maximum dissolved concentration in µg/L
(3) Ireland EPA Dangerous Substances Regulations Limit for Surface Water 2001
(4) Ireland EPA Drinking Water Regulations Guidance Booklet No. 2 January 2008
(5) USEPA Region 3 PRG for Chromium VI
(6) USEPA Region 3 PRG for this metal is unavailable, PRG is from USEPA Region 9
(7) Lead Drinking Water Standard of 10 µg/L to be met by 25 December 2013, current standard is 25 µg/L
(8) USEPA Region 3 PRG for mercuric chloride

2.2.4 Sediment COPCs

Screening values for sediments are not generally available for people in direct contact with sediments. As a conservative measure, screening criteria based on potential exposure to contaminants in soils were used for COPC selection.

Maximum concentrations reported in sediment samples were compared to EPA recommended screening levels where available or USEPA screening levels. The Expert Group (EPA 2004) considered that the risks to children or adults from *in situ* or recently dredged sediments are very low because direct contact with these sediments is unlikely. The Expert Group (EPA 2004) recommends a similar guideline value for lead in sediment as in soils; i.e., 1,000 mg/kg. Based on USEPA screening values for residential soil, arsenic, iron, lead, and manganese would be selected as COPCs for sediment using all sediment data available. The COPC screening process for sediment is summarized on Table 2-11.

Table 2-11 Screening of Sediment COPCs Avoca Mining Area

Chemical	Maximum Site Wide Concentration (mg/kg)	ESL EPA Ireland[1] (mg/kg)	USEPA Region 3 PRGs for Soil[2] (mg/kg)		COPC
			Residential	Commercial /Industrial	
Aluminum	2.81		78,214	1,022,000	No
Antimony	1.68		31	409	No
Arsenic	481.25		0.43	1.91	**Yes**
Barium	70.55		15,643	204,400	No
Bismuth	1.84		NA	NA	No
Calcium	0.21		NA	NA	No
Cadmium	1.84		39	511	No
Cobalt [4]	20.20		902.89	1921.35	No
Chromium[5]					
Chromium III	33.87		117,321	1,533,000	No
Chromium VI	33.87		235	3,066	No
Copper	503.46		3,129	40,880	No
Iron	297,720		54,750	715,400	**Yes**
Lead	704.21	1000	400	1000	**Yes**
Mercury[3]	0.16		23	307	No

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Table 2-11 Screening of Sediment COPCs Avoca Mining Area

Chemical	Maximum Site Wide Concentration (mg/kg)	ESL EPA Ireland[1] (mg/kg)	USEPA Region 3 PRGs for Soil[2] (mg/kg)		COPC
			Residential	**Commercial /Industrial**	
Magnesium	0.78		NA	NA	No
Manganese	8,069		1,564	20,440	**Yes**
Molybdenum	2.0		391	5,110	No
Nickel	25.83		1,564	20,440	No
Phosphorus	0.05		NA	NA	No
Selenium	1.28		391	5,110	No
Silver	1.05		391	5,110	No
Sodium	0.07		NA	NA	No
Sulfur	2.81		NA	NA	No
Tin	1.49		46,929	613,200	No
Thallium	NA		5.48	71.54	No
Thorium	8.02		NA	NA	No
Titanium [4]	291.46		1.0E+05	1.0E+05	No
Uranium	3.84		16	204	No
Vanadium	30.21		78	1,022	No
Zinc	267.95		23,464	306,600	No
Cadmium Soil Guidelines[1]			**Soil Guideline Value (mgCd/kgDWSoil)**		
Scenario			pH 6	pH 7	pH 8
Residential with homegrown vegetables			1	2	8
Allotments			1	2	8
Residential without homegrown vegetables			30	30	30
Commercial/Industrial			1400	1400	1400

ESL = Environmental Screening Level
PRG = Preliminary Remediation Goal
COPC = Chemical of Potential Concern
mg/kg = milligrams per kilogram
mgCd/kgDWSoil = milligrams cadmium per kilogram dry weight soil
[1] EPA Ireland, Final Report of Expert group for Silvermines County Tipperary, Lead and Other Relevant Metals (2004)
[2] USEPA Region 3 PRGs for soil, sediment PRGs are unavailable
[3] USEPA Region 3 RBC/PRG for Mercuric Chloride
[4] USEPA Region 9 PRG
[5] Using total Cr concentration and assuming 1:7 ratio of Cr III to Cr VI

2.2.5 Chemicals that Bioaccumulate/Bioconcentrate in Fish

Bioconcentration is the process whereby chemicals are taken up from water and retained in tissues. When all potential exposure pathways (in addition to water uptake) are considered, the process is referred to as bioaccumulation (USGS 2006). Typically bioconcentration factors (BCFs) greater than 1,000 indicate that a chemical has a high potential for bioconcentration; BCFs between 1,000 and 250 result in moderate potential; and BCFs less than 250 result in low potential. Due to a limited number of studies, BCFs are not available for all chemicals. For the preliminary Phase 1 HHRA, a chemical was selected as a COPC on the basis of bioaccumulation potential if its maximum detected concentration exceeded the fish BCF of 250, if the chemical was a human carcinogen, or if the chemical was listed as an Important Bioaccumulative Compound by EPA (USEPA 2000). Chemicals detected in surface water that are potential COPCs due to bioconcentration potential in fish include cadmium, copper, lead, manganese, nickel, and zinc. Note that copper, manganese,

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nickel, and zinc have low toxicity following oral exposure in humans. At this time, data are insufficient to quantitatively evaluate potential human exposures to contaminants which may bioaccumulate in fish. This potential exposure pathway is discussed in Section 5.3.5.

Section 3
Exposure Assessment

Populations that may be exposed to chemicals at a site and pathways by which these populations may come into contact with site chemicals are identified in the exposure assessment. In identifying potential pathways of exposure, both current and possible future land use of the Site and surrounding area are considered. Exposure assessment defines, in qualitative or quantitative fashion, the ways that people living, working, or recreating in the study area might be exposed to contaminants released as a result of historic mining operations.

3.1 Exposure Assessment Process

Exposure is defined as human contact with a chemical or physical agent (USEPA 1989). Exposure assessment is the estimation of magnitude, frequency, duration, and pathway(s) of exposure to a chemical. Assessment of exposure consists of three steps:

- Characterization of Exposure Setting
- Identification of Exposure Pathways
- Quantification of Exposure

The first step involves identifying the environmental setting of a site (e.g., climate, land use, topography) and the current and potential future human populations on and near the Site. Human populations are described with regard to characteristics that could affect exposure to site-related chemicals, including location relative to the Site, activities, and the presence of sensitive subgroups (e.g., children).

Step two of the exposure assessment identifies pathways by which human populations might be exposed to site-related chemicals. Chemical sources, release and transport mechanisms, and inter-media transfer are evaluated. Exposure pathways are identified based on the location and activities of potentially exposed populations and on the types of potentially contaminated media. Included in this step is identification of exposure parameters, such as contact rates, body weight, and exposure frequency, that can be used to estimate magnitude of possible exposure.

The final step, exposure quantification, has two components: estimation of exposure point concentrations and calculation of chemical intake. Exposure point concentrations are chemical concentrations at the point of human contact. Site-specific chemical data from previous investigations for media of concern are used to estimate exposure point concentrations. Calculation of chemical intake uses exposure point concentrations and exposure parameters to estimate intake.

3.2 Site Description

The Avoca mining area is located in the eastern foothills of the Wicklow Mountains approximately 55 kilometers (km) south of Dublin. The Avoca Mines are located within the Avoca River Catchment which includes an area of 650 km². The East and

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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 a further 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.

Many areas of the Site have been highly disturbed by past mining activities and include open pits, waste/spoil piles, highly eroded surface areas, covered and uncovered tailings, and roads. Beyond the highly disturbed areas are mostly agricultural areas subject to small scale farming and grazing as well as residential properties with grass, planted shrubs, and trees. In some cases, agricultural land uses extend into the riparian corridor of the Avoca River, and in fact grazing or farming up to the river edge is observed in a few locations.

3.3 Land Use

Land uses in the Avoca River valley adjacent to the river are diverse, and include historic mining areas where mine wastes and/or mine tailings have been deposited, agricultural uses, isolated and small clusters of residences and small communities such as Avoca Village, past industrial uses such as the former fertilizer plant, current light industrial uses such as the new automobile storage facilities at the site of the former Fertilizer Plant, institutional use (e.g., the prison at the former Shelton Abbey), landfills or capped waste areas with known and unknown types of contaminants (e.g., on the property of the former fertilizer plant), and recreational areas (e.g., golf course at Woodenbridge and public riparian walking trails along the south bank of the river northwest of Arklow). A number of designated walks the 'Red Walk,' the 'White Walk,' and the walk to the Mottee Stone bring visitors through the Avoca mine areas.

Several unmanaged fisheries along the Avoca catchment attract anglers. Three trout production farms are located on its tributaries. The catchment is predominantly upland. The upper reaches of the catchment consist of the Wicklow Mountains to the east, north, and northwest. Forestry, agriculture, tourism, industry, horticulture, and aquaculture are the main land uses in the catchment. Now inactive, mining was an important economic factor in the catchment for 230 years. Currently almost 11.5 km of river has been seriously polluted principally by drainage from the old Avoca copper mines. The average volume of acid mine drainage discharging from the two major adits (Deep and Road) is 35 liters per second (l/s), depending on weather conditions (University of Newcastle 2006).

The Vale of Avoca Development Association (VADA) was formed to plan for the future development and prosperity of the area through an area action plan. Future proposed uses of the Site include preservation of mining heritage through a miners' park and preservation of historic buildings. Nature and sculpture parks are also proposed. Most stakeholders agree that future uses of the Site and any measures

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towards remediation must be planned and delivered with full sensitivity to the Site, its cultural heritage, economical, geological, wildlife, and flora resources. Future plans are to promote tourist access to the county for angling, walking/hiking, equestrian, golf, and other activities.

3.4 Hydrogeology

County Wicklow has relatively poor groundwater resources, with no regionally important (i.e., major) aquifers. However, a significant number of small to medium sized public water supply sources depend on groundwater (providing about 15 percent of the county's public water supply), as do thousands of residents in rural areas who have their own private water wells (Woods 2003). Despite the generally high to extreme vulnerability of the groundwater resources in Wicklow, the quality of the groundwater is generally good. The mean rainfall in the area is approximately 1,200 millimeters (mm) per year.

Virtually all of the shallow groundwater in the area of the mine site can be assumed to ultimately discharge into the Avoca River. A network of shafts, tunnels, and adits discharge into the Avoca River via the Deep Adit (East Avoca Mines) and the Ballymurtagh (Road) Adit (West Avoca Mines). Small amounts of water also discharge to the river as diffuse flow and as minor adit discharges (Flynn 1994).

During a GSI study conducted in 1995, groundwater levels in the vicinity of the mine were found to be generally between 5 and 15 meters (m) below ground level and did not tend to fluctuate greatly. However, a significant head difference existed between the bedrock and the enclosed mine voids, with water levels outside the mined features being substantially higher (Flynn 1994). This head difference causes groundwater to flow into the mined zone, confirmed by the occurrence of seepage faces flowing into the open pits and underground workings from adjacent areas. This is consistent with the concept of mine voids acting as "master drains" for this area.

3.5 Overview of Exposure Assessment

An exposure pathway (the sequence of events leading to contact with a chemical) generally consists of the following elements:

■ A chemical source and mechanism of release to the environment

■ An environmental transport medium for the released chemical to locations where human contact is possible

■ A point of potential human exposure with the contaminated medium (i.e., the exposure point)

■ A route of exposure (e.g., ingestion, dermal absorption, inhalation) into the receptor

An exposure pathway is considered complete only if all of these elements are present. Exposure pathways are evaluated for both current and potential future land uses

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(residential, occupational, and recreational). Some pathways, though not currently complete, can be assumed to be complete in the future. Such pathways are evaluated as potential future sources of exposure.

In addition to completeness, exposure pathways are evaluated for potential to contribute significantly to overall exposures. Some complete pathways may contribute so little to total exposure that quantitative assessment is unnecessary. Such pathways are addressed on a screening level or qualitative basis in the HHRA.

Complete exposure pathways that may contribute significantly to exposure are quantitatively evaluated by calculating chronic daily intakes for COPCs. Chronic daily intakes are based on exposure point concentrations and assumptions for intake rates, exposure frequencies, exposure durations, etc.

3.6 Overview of the Site Conceptual Exposure Model

The site conceptual exposure model (SCEM) is a schematic representation of components of important exposure pathways for people using the mine areas, including:

- Sources of contamination

- Contaminated and potentially contaminated media

- Chemical release mechanisms and mechanisms of contaminant transfer between media

- Potential receptors

- Potential exposure pathways

The SCEM is developed as a "roadmap" to the exposure assessment (Figure 3-1). It shows, at a glance, the important issues to be addressed to quantify human exposure. The SCEM is not complete without a narrative description of components of the model, which is provided in the sections below.
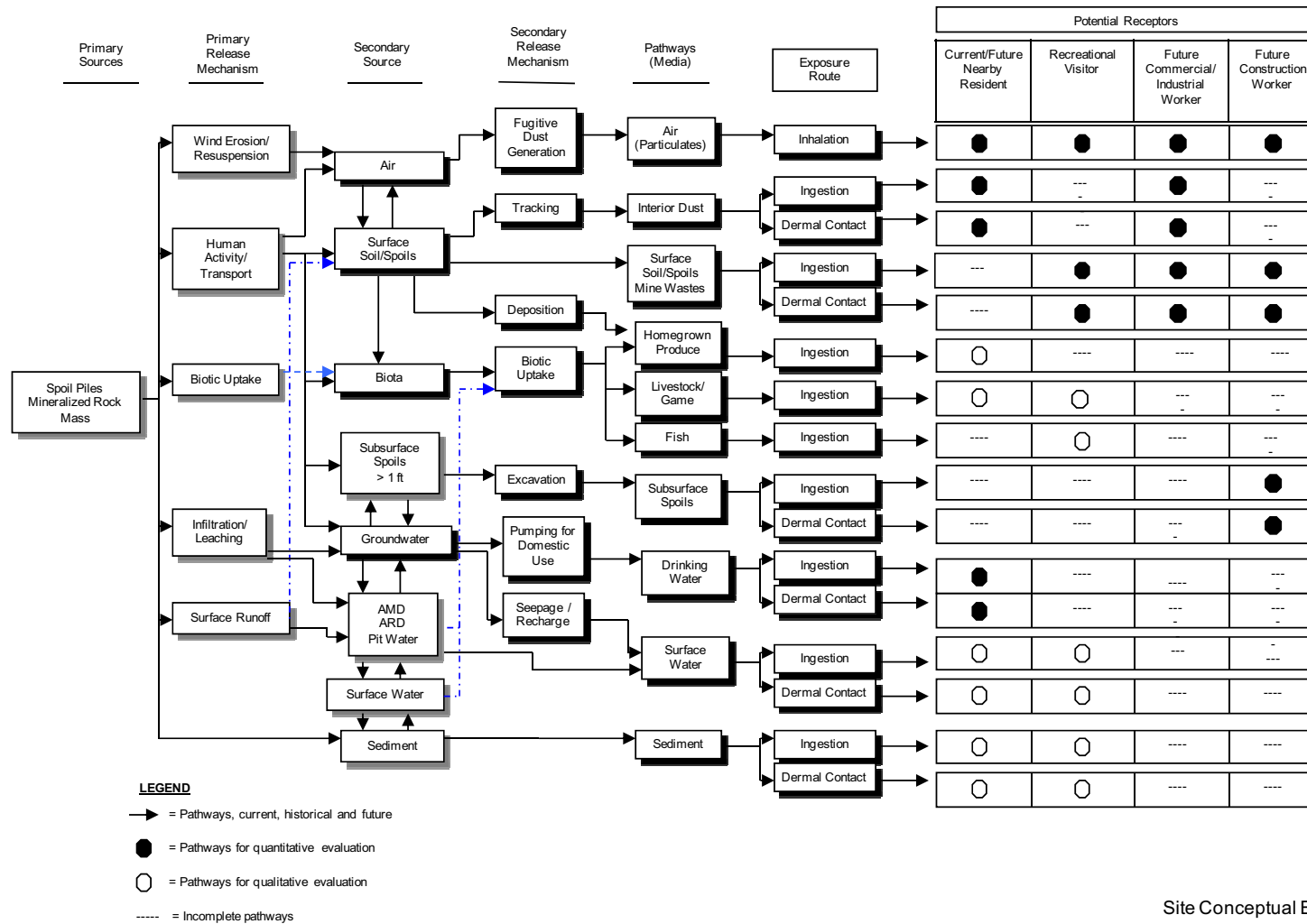
Figure 3-1
Site Conceptual Exposure Model
Human Health
Avoca Mine Site

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3.6.1 Potential Sources of Chemical Releases

Hazardous substances commonly associated with mining operations have been identified in soil/spoils, surface water, and sediment in the vicinity of and downstream of the mine site. Potential sources of this contamination are numerous, including mine rock piles located throughout the mine site, spoil piles, open pits, tailing deposits, shafts, and adits. Contamination of the Site unrelated to mining activities may have occurred resulting from the use of open pits as landfills. Mining operations have left large open scars in open pits areas, and large piles of wastes in others. Erosion, runoff, and seepage from surrounding mine rock piles and tailing deposits have released hazardous substances to Avoca River sediment and riparian areas. Impacts to the river system from these releases may extend from the mines to Arklow. Contaminants may also have been released to groundwater beneath and adjacent to the mine site. Contaminated groundwater may release contaminants to surface waters where shallow groundwater discharges to the river. As previously discussed, two major and several smaller adits discharge acid mine waters to the Avoca River.

3.6.2 Release Mechanisms and Fate and Transport

Many potential sources could release inorganic chemicals to the environment. The ultimate fate of COPCs in the environment depends on chemical-specific characteristics, such as solubility, persistence, potential for bioaccumulation, and chemical and biological transformation, and on a variety of environmental conditions such as wind speed and direction, slope steepness and stability, river gradient and flow, soil porosity, rainfall, depth to groundwater and runoff, and soil and sediment grain sizes.

Metals present in soil/spoils may be adsorbed to soil particles or may become incorporated into mineral forms in soil. Metals may also migrate through spoils depending on solubility and other soil/spoils characteristics, or they may be entrained into the air with fugitive dust. The fate of metals in soil/spoils is dependent upon such factors as soil/spoil mineralogy, pH, particle size, amount of metal present, organic matter content of the soil, presence of inorganic colloids and iron oxides, and cation exchange capacity. For example, adsorption of arsenic to clays, organic matter, and iron oxides generally decreases its mobility. Also, the solubility of the compound may be decreased as metals such as arsenic become encased in precipitates or incorporated into mineral matrices.

Transport of metals in water also depends on chemical form, oxidation state, and interactions with other substrates present. The amount of metals that remain in solution depends on the pH of the water, total and dissolved organic content, and on dissolved salt content. In most surface waters, the concentration of many metals in solution tends to be low because metals often form precipitates with anions such as hydroxides, carbonates, sulfates, and phosphates.

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Metals present in spoils may be entrained into air through wind erosion or mechanical disturbances of the spoils. Typically, only small particles are light enough to be carried up in the air column and transported significant distances. Metals in air can be a source of exposure, and may impact distant soils due to particulate re-deposition. Particles can also deposit into surface waters and onto biota.

As shown in the human health SCEM (Figure 3-1), COPCs may be released from source areas through direct release, wind erosion, surface water runoff, seasonal flooding, and infiltration/leaching to groundwater. Spills are less likely now that mining activity has ceased, but they are still possible during investigation, remediation, and possibly redevelopment of the Site. These releases may result in degraded quality of primary environmental media: air, surface and subsurface soil, surface water, and groundwater.

COPCs released to primary media may be subsequently transported to and among primary and other media. Chemical constituents in surface water may be released to sediment (through deposition and sorption), biota (through uptake), and groundwater (through infiltration). Chemicals in soil may be released to biota (through uptake or inhalation), groundwater (through infiltration), surface water (through runoff), air (through erosion), and interior house dust (through human activities). Chemicals in air may be released to soil and surface water through wet or dry deposition. Chemicals in groundwater may discharge to surface water, and chemicals in sediment may be released to surface water (through desorption/ sorption) and biota (through uptake). Cycling of COPCs among Site media will also occur, for example, metals may partition between surface water and sediment and migrate between surface water and groundwater in gaining and losing river reaches.

Pathways for transport of hazardous substances and other contaminants from sources to groundwater may include: leaching from tailing deposits, underground workings, waste piles, surface deposits, and affected spoils via precipitation infiltration, and runoff. Open pits collect precipitation and storm water runoff and directs it to groundwater.

Pathways for transport of hazardous substances to surface water may include: leaching and runoff from sources described above to surface water, seepage or recharge of surface water from affected groundwater, direct discharge from underground mine workings via adits, and exposure of surface water to affected stream sediment.

Biota may take up COPCs associated with the mine site. Exposure pathways to aquatic biota may involve exposure to affected surface water and sediment. Aquatic biota may also be exposed to hazardous chemicals by ingestion of affected food. Pathways to terrestrial biota (game animals/livestock) may include direct contact with hazardous constituents in soil, groundwater or sediment, inhalation of dusts, and consumption of affected food and water. Riparian plants may take up

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contaminants in soil and water. Homegrown produce may take up contaminants from soil or irrigation water.

Various release and transport mechanisms are identified in the SCEM to show potential movement of COPCs from sources to human receptors. These mechanisms are not quantitatively evaluated due to lack of data to support the complexity of models that would be required. Instead, this HHRA depends on recently measured concentrations of COPCs in various media and at various times and locations. Fate and transport of contaminants among different environmental media are, however, important for understanding of uncertainties in the evaluation of human health threats, and for evaluating remedial alternatives.

3.6.3 Contaminated Media

COPCs found at the Site are consistent with the mining operations that have taken place for over 200 years. Mine rock piles, spoil piles, contaminated soil and sediment, and tailing deposits are continuing sources of COPCs to surface water and sediment, and possibly groundwater, air, and biota. As depicted in the SCEM, release and transport of contaminants from waste sources might affect the following media:

- Soil
- Surface water
- Sediment
- Groundwater
- Air
- Interior dust
- Plants/homegrown produce
- Livestock
- Fish

The SCEM for human health (Figures 3-1) illustrates potential pathways for exposure associated with these media for people living, working, and recreating in the area. Complete and significant exposure pathways are further discussed in the following sections along with identification of potential human receptors.

3.6.4 Potential Receptor Populations and Exposure Pathways at or Near the Avoca Mining Site

Potential receptor populations at or near the mine site and potential exposure pathways for these populations are selected for quantitative evaluation in this section. Combinations of exposure pathways for an individual receptor group (e.g., near-site residents) make up exposure scenarios. Three general exposure scenarios are considered in this risk assessment; these scenarios are shown in schematic form in the SCEM for the Site (Figure 3-1). The first scenario is residential. This scenario addresses potential exposure for nearby residents who might be exposed to COPCs released from the mine site. The second scenario is occupational. This scenario addresses potential exposures to people who regularly work near the mine site currently, or

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who may work on the mine site in the future if parts of the Site are redeveloped for non-mining purposes. A closely related scenario is for workers involved in construction activities at the Site. Many of the pathways of exposure for residents also apply to workers. The final scenario is recreational. This scenario addresses potential exposure to people who recreate near or on the mine site on a frequent basis. Potential pathways of exposure for people recreating near or on the mine site are somewhat different than those for either residents or workers.

Currently, residences are located adjacent to the mine site. People living in these locations could be exposed to mine related contamination if significant amounts of dust from mine wastes deposited into their yards or if contaminants were carried into yards by runoff. Complaints of blowing dust and stormwater erosion have apparently not been common near the mines, suggesting that these transport pathways are minor. Soil data collected from fields and pastures downwind of the site appear to confirm that this assumption is correct. Potential future residential use of the Site itself seems very unlikely, given site conditions (steep walled pits, unstable slopes, acid mine drainage and acid rock drainage). Thus, a future onsite resident is not included for quantitative evaluation in the SCEM.

Areas adjacent to the mine site are used for agricultural purposes, mainly for pastures for sheep and/or cattle. Animals could ingest contaminants in soil or contaminants taken up by plants in some areas where migration in dust or stormwater transported mine waste to pasture lands. As noted above, these transport pathways do not appear to be significant. Unauthorized grazing of sheep on areas of the Site has been observed, however. People who use these animals for meat could be exposed to mine-related COPCs. Residents could also be exposed to contaminants in groundwater if private wells are installed in the vicinity of the Site.

Future proposed uses of the Site would include onsite workers, for example caretakers of museums or parks. These workers then could be potentially exposed to Site-related contaminants. Any redevelopment of the area could also expose construction workers to site related contamination.

Current uses of the Site are mainly recreational and the primary receptors for the mine site are recreational visitors. This land use is the most likely for future use of the Site as well. Many areas of the Site are currently fenced; however, there are gaps and holes in the fence that allow easy access and several of these areas, especially the Mount Platt and the Tigroney West areas, are popular with children and others for bicycling and quad bike riding. Also, walking trails allow recreational visitors access to some areas of the Site. Future uses of the Site are most likely to include recreational uses such as walking and biking trails, an outdoor mining heritage museum, fishing access, and parklands.

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As shown in the Site SCEM, Figure 3-1, populations that could theoretically be exposed to contaminants from the mine site may include:

- Current and future recreational visitors (these receptors could also be residents and/or workers)
- Nearby residents (current and in the future)
- Onsite commercial/industrial workers (future)
- Future construction workers

Potential exposure pathways for these populations may include one to several of the following:

- Incidental ingestion of and dermal contact with soil and spoils material
- Inhalation of particulates in ambient air
- Incidental ingestion of surface water and sediment
- Dermal contact with surface water and sediment
- Ingestion of groundwater (incidental and/or voluntary [domestic groundwater use])
- Dermal contact with groundwater (showering/bathing)
- Ingestion of animal products from animals fed affected feed, or watered with affected surface water or groundwater
- Ingestion of produce from gardens with affected soil and/or watered with affected surface water or groundwater
- Ingestion of contaminated fish

3.6.5 Summary of Exposure Pathways

The following exposure pathways were considered to be complete and will be evaluated as part of the assessment of exposure to contaminants at the site.

Current/Future Land-Use Scenario

- Site Visitors (Adults and Adolescents, ages 12 to 18 years)

    Soil – Incidental ingestion
    – Dermal contact
    – Inhalation of fugitive dust

- Nearby Residents (Adults and Children, ages 0 to 6 years)

    Soil – Incidental ingestion
    – Dermal contact
    – Inhalation of fugitive dust

    Groundwater – Ingestion
    – Dermal contact during showering and bathing

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Future Land-Use Scenario

■ Onsite Commercial/Industrial Workers *(Adults)*

   Soil   –   Incidental ingestion
          –   Dermal contact
          –   Inhalation of fugitive dust

■ Onsite Construction Workers

   Soil   –   Incidental ingestion
          –   Dermal contact
          –   Inhalation of fugitive dust

3.7 Potential Hazards

The community has expressed concern about potential risk to children currently recreating on the mine site. Children are identified as a sensitive subpopulation due to their potential for greater sensitivity and/or exposure to heavy metals. Early development, even prenatal development, has been shown to be affected by contamination of heavy metals, especially lead. Children with increased levels of lead in the blood may have damage to the brain, anemia, muscle weakness, stomach ache, and other health effects. Lead can also pass from a mother to the fetus and may lead to premature birth, decrease birth weight, and learning deficiencies. Besides greater sensitivity to certain chemicals, children may have a greater exposure than adults. Behaviors that may increase exposure in children include biking on mine wastes, digging and playing in soil, and frequent hand-to-mouth contact. Thus, development of PRGs based on childhood exposure is likely to be protective for all age groups.

An exception is arsenic. Arsenic is a known human carcinogen and cancer risks are currently assessed to be proportional to total lifetime dose. Thus, long-term exposure from childhood to adulthood provides the most conservative estimates of possible cancer risks. PRGs for arsenic are assessed assuming long-term exposure.

Children and others may be exposed via several pathways including incidental ingestion, dermal contact, and inhalation of particulates. Incidental ingestion of soils may occur via hand to mouth activities. This pathway may be significant, especially for younger children who tend to ingest larger quantities of soil during play. Dermal exposure pathways are not expected to contribute significantly to overall exposure because most metals are inefficiently absorbed through the skin. However, some measurements exist for absorption of arsenic in soil through the skin and these data can be used to estimate dermal exposure to this COPC. Thus, dermal absorption is quantitatively estimated for this COPC in soils. For other soil COPCs no dermal absorption estimates are made. The Integrated Exposure Biokinetic Uptake Model (IEUBK) (USEPA 2001) recognizes the insignificance of the dermal pathway by not including dermal absorption as a route of exposure for lead. In similar fashion, significant absorption of copper, iron, manganese, thallium, and vanadium from soil/spoils or sediment seems highly unlikely and also is not quantified. Inhalation of

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contaminants in spoils may occur during recreational activities especially those that generate dust such as riding quad bikes over spoil piles.

3.8 Exposure Areas

Exposure areas are identified for the HHRA to estimate potential risks to receptors within specific areas based on concentrations of COPCs in media of concern. The primary criteria for designation of specific exposure areas (EAs) are the magnitude and distribution of COPCs, known or suspected contaminant source areas, as well as receptor behavior. Exposure areas for each media of concern are discussed in the following sections.

3.8.1 Soil and Spoils Exposure Areas

Exposure areas for surface soil and spoils are identified based on potential receptor behavior and on known or suspected contaminant source areas. Surface soil samples were collected from several fields and pastures in the vicinity of the site. Some of these fields are downwind of spoil piles. These EAs are used to evaluate potential exposure by nearby residents to mine-related contaminants in soil. The following areas are identified as surface soil EAs; each is a unique sampling area identified by the owner of the fields from which the samples were collected.

- Gerald Murphy's Field (GMF)
- Ivor Fitzpatrick's Field (IFF)
- Kavanagh's Field #1 (KF1)
- Kavanagh's Field #2 (KF2)
- Paddy Hogan's Field (PHF)
- Tom Merrigan's Field #1 (TMF1)
- Tom Merrigan's Field #2 (TMF2)

The following seven EAs are identified as spoils EAs. Spoils samples for all spoil EAs except EA-5 were collected in 2007 as part of the Phase 2 Investigation. Data associated with the Deep Adit location (EA-5) were collected by the GSI and used in this Phase 2 assessment to the extent possible. Data from spoil EAs are used to evaluate potential exposure to contaminants in soil for recreational visitors.

- EA-1 – Connary
- EA-2 - Mount Platt
- EA-3 - East Avoca/Tigroney West
- EA-4 – Ore Bins areas at Tigroney West
- EA-5 – Deep Adit Area
- EA-6 – West Avoca
- EA-7 – Shelton Abbey

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3.8.2 Surface Water Exposure Areas

Exposure to contaminants in surface water is evaluated qualitatively via a recreational scenario. Surface water is grouped into two major categories: 1) Rivers and Tributaries and 2) Adits, Springs, and Miscellaneous Surface Waters. The latter includes a large number and variety of smaller or more isolated water bodies, including mine adits, springs, small ponds, very small tributaries, or other waters that flow only intermittently (e.g., stormwater flows).

River and Tributaries
For the HHRA, the Avoca River and its tributaries are considered as one exposure unit from above Whitesbridge to Arklow. The reference area for the Avoca River includes from above Meeting of the Waters (Ballinacleish Bridge and Lions Bridge) downstream to above Whitesbridge. This includes stations at Ballinacleish Bridge, Lions Bridge, and Transect 1. Vale View stream also enters in this reach.

Adit, Spring, and Miscellaneous Surface Water Exposure Areas
Most surface water bodies in this category are not used for recreational or drinking water purposes. People have not been observed playing in adit or pit lake waters. Some adits are buried and contribute surface water flow via seeps and some flow only seasonally. Characteristics of these surface water bodies suggest that they would not be attractive as recreational areas; therefore, any potential exposure is expected to be infrequent and of short duration. A few are springs that represent groundwater discharging to the surface. Radio Tower Spring is used as drinking water and is evaluated as a groundwater drinking source. Other springs and seeps are ephemeral or are not used by people.

3.8.3 Sediment Exposure Areas

Exposure to contaminants in sediment is evaluated qualitatively via a recreational scenario. Sediment exposure areas are assigned to the same EA designations as used for surface water exposure areas. Sediment from the Avoca River and its tributaries are considered as one exposure unit from above Whitesbridge to Arklow. The reference area for the Avoca River includes from above Meeting of the Waters (Ballinacleish Bridge and Lions Bridge) downstream to above Whitesbridge. Sediments collected from the Road Adit Confluence and the Deep Adit Confluence are considered as separate exposure areas.

3.8.4 Groundwater Exposure Areas

Exposure to contaminants in groundwater is evaluated quantitatively for residents. Groundwater is grouped by use and aquifer into two groups: private residential wells (typically bedrock wells) and shallow monitoring wells. As previously discussed most homeowners do not use private wells as a drinking water source. Groundwater that surfaces as surface water in springs (i.e., Radio Tower Spring) and is subsequently used as drinking water is evaluated via the domestic use of groundwater scenario for residents.

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3.9 Exposure Point Concentrations

One of the necessary components of a quantitative exposure assessment is an exposure point concentration (EPC). This concentration is one representative of concentrations of chemical at points of potential human contact with the environmental media of interest. EPCs may be estimated by (1) using analytical results alone, or (2) using a combination of analytical results and environmental fate and transport models. In this assessment, ingestion, dermal contact, and inhalation exposures are estimated using soil and groundwater analytical data. EPCs for air are estimated from COPC concentrations in soil.

EPCs can be used, along with appropriate exposure assumptions, to reflect a range of potential exposures (average, reasonable upper range, worst case). Most often, and where data quantity allow, single EPCs are used to represent possible arithmetic average exposure concentrations. This average is often estimated using the 95% upper confidence limit (95% UCL) of the mean. Use of the 95% UCL helps ensure that the actual average concentration is not underestimated. The choice of the arithmetic mean as an appropriate statistic for characterizing exposure at an exposure point is based on the assumption of random exposure within the exposure area. Calculation of an acceptable 95% UCL requires data representative of COPC concentrations within an exposure area and a sufficient number of individual measurements to support statistical calculations.

3.9.1 Calculation of Exposure Point Concentrations

This section briefly describes the methodology employed to calculate EPCs for the COPCs for each medium. For each data set (representing a single chemical in each medium) with 10 or more samples, a 95% UCL on the arithmetic mean concentration was calculated and compared to the maximum detected concentration for that chemical. A 95% UCL was also calculated for site-specific bioavailability estimates for lead and arsenic. The lower value of the UCL and the maximum detected value is the EPC, as recommended by EPA (USEPA 1992).

Several different statistical methods can be used to estimate the 95% UCL of a data set, depending upon the data distribution. Therefore, two key steps are required to estimate the 95% UCL of a data set:

■ Determine the distribution of the data (i.e., normal, lognormal, gamma, or neither), and

■ Compute the 95% UCL using the appropriate procedure for the data distribution

In this assessment, both steps were performed with the ProUCL (Version 4.0) statistical software developed for USEPA (2007a). The ProUCL program tests the normal, lognormal, gamma, and non-parametric distributions of each data set and 95% UCLs are calculated with statistical procedures recommended by USEPA, based on the findings of Singh, Singh, and Engelhardt (1997, 1999) (EPA 2007a). ProUCL

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computes the 95%UCL using 5 parametric and 10 non-parametric methods, depending on the distribution.

- For normal distributions, the Student's t-statistic is used to calculate the UCL.

- For lognormal distributions, one of four different computation methods is used to calculate the UCL depending on the skewness of the data (as indicated by the standard deviation of the log-transformed data) and the sample size.

- For gamma distributions, one of two computation methods is used to calculate the UCL based on a k value, the shape parameter of a gamma distribution.

- For values of $k \geq 0.1$, the exposure point concentration term is computed using an adjusted gamma UCL of the mean (when $0.1 \leq k \leq 0.5$) or an approximate gamma UCL of the mean (when $k > 0.5$).

- For values of $k < 0.1$, a 95% UCL may be obtained using either the bootstrap-t method or Hall's bootstrap method when the sample size is small (less than 15), or the approximate gamma for larger data sets.

- For data sets that do not fit a normal, a lognormal, or gamma distribution, the ProUCL program calculates and recommends a 95% UCL from 1 of the 10 non-parametric methods (USEPA 2007a).

Tables 1 through 3 in Appendix B present the EPC for each COPC in each medium and for bioavailability estimates. As noted previously, the EPC is the lower value of the UCL and the maximum detected value. ProUCL output for COPCs is also included in Appendix B.

3.10 Exposure Assumptions

This section presents assumptions that are used to quantify potential exposures in the HHRA. Exposure parameters are presented for recreational visitors, nearby residents, future onsite commercial/industrial workers, and future onsite construction workers. Exposure assumptions for current receptors also apply to future receptors under the same exposure scenario. Exposure assumptions were identified based on characteristics of specific receptor groups reasonably assumed to be affected by mine wastes. Exposure assumptions are presented for estimates of reasonable maximum exposure (RME). RME is designed to represent high-end exposure, well above the average, but still within the possible range of exposures. RME may fall within the 90th to 99.9th percentile of possible exposures (USEPA 1993), and is generally considered to be the highest exposure that is reasonably expected to occur at a site. Estimates for RME usually form the basis for remedial decisions at a site. Chemical intake estimates for RME use upper range values for some, but not all, exposure assumptions so that their combination results in a reasonable upper range estimate of exposure for that pathway. USEPA guidance for recreational and construction scenarios is scarce, and evaluation of this scenario usually relies heavily on professional judgment and site

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observations. Thus, confidence in exposure estimates for these scenarios are low relative to residential and commercial/industrial worker exposure estimates.

3.10.1 Exposure Assumptions for the Recreational Scenario

People who may visit the Site are primarily exposed to soil contaminants via incidental ingestion and inhalation of fugitive dust although dermal exposures may also occur. To evaluate possible exposures to metals in soil/spoils, assumptions are made about the quantity of contaminant ingested, inhaled, or absorbed through the skin, how often such exposure will occur, etc. Exposure parameters chosen are intended to be conservative (protective) so as to not underestimate potential risks and hazards. Exposure parameters used in this assessment are summarized in Table 3-1 and discussed below.

Table 3-1 Exposure Assumptions for Recreational Visitors

Exposure Parameter	Recreational Visitor Adult	Recreational Visitor Teenager
Body Weight (kg)	70 [a]	55 [c,e]
Averaging Time - Carcinogenic (days)	25,550 [a]	25,550 [a]
Averaging Time – Non-carcinogenic (days)	10,950 [a]	2,920 [c]
Exposure Frequency (days/yr)	104 [c]	104 [c]
Exposure Duration (years)	30 [c]	8 [c]
Ingestion Rate (mg/day)	100 [c]	100 [c]
Skin Surface Area Available for Contact (cm^2/event)	3,300 [c,f]	4,570 [c,f]
Contact Rate (adherence factor) (mg/cm^2)	0.1 [f]	0.1 [f]
Inhalation rate (m^3/day)	20 [e]	15.2 [c,e]

[a] USEPA, 1989a. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual, Part A. EPA/540/1-89/002. Office of Emergency and Remedial Response. Washington D.C.
[b] USEPA, 1989b. Exposure Factors Handbook. EPA/600/8-89/043.
[c] Site-specific. Professional judgment. See text.
[d] USEPA 2001. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Peer Draft Review. March.
[e] USEPA, 1997. Exposure Factors Handbook. EPA/600/P-95/002Fa
[f] USEPA, 2004b. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual, Part E. EPA/540/R/99/005. Office of Emergency and Remedial Response. Washington D.C. OWSER Directive. July.

Note that actual recreation activities are very difficult to predict, especially for future conditions. This assessment for possible recreational exposures is based on the concept of screening. In a screening evaluation, exposure parameters are chosen to assure that exposure estimates are at or above any exposures that are likely to actually occur. Risks and hazards for recreational visitors can be assumed to be ceiling values that will overestimate threats to human health. Where such estimates are below levels of concern, no action is necessary to protect visitors to the Site.

Exposure pathways potentially complete for recreational visitors that are evaluated qualitatively include: incidental ingestion of and dermal contact with surface water and sediment, ingestion of fish, and ingestion of game.

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The recreational scenario assumes that the individual lives nearby and visits the Site frequently. The scenario assumes that adults and teenagers would visit the Site two days a week (104 days/year) for about 2 hours per visit. All visits are assumed to occur in only contaminated areas of the Site. Actually, recreational visitors are likely to access non-contaminated areas also, given the size of the Site. Thus, this assumption for frequency of site visits should represent the high end of possible recreational activity.

The adult is assumed to weigh 70 kg and to have an exposure duration of 30 years. Thirty years is an upper range estimate of time at one residence and suggests that recreational visitors would continuously use the Site for nearly half of their lifetime. This assumption is consistent with a screening assessment, and is likely to overestimate exposure potential. Incidental soil ingestion rate is estimated to be 100 mg/kg per day. For dermal contact with soil, the adult recreational visitor is assumed to wear a short-sleeved shirt, long pants, and shoes; therefore, the exposed skin surface is limited to the head, hands, and forearms. This exposed skin surface area for adults is 3,300 cm^2, the average of the 50th percentile for males and females greater than 18 years of age (EPA 2004c). The default inhalation rate of 20 m^3/day (0.83 m^3/hr) was assumed for the adult. Both of these estimates are taken from standard USEPA guidance and both are upper range estimates that tend to over rather than under estimate risks and hazards.

The teenager is assumed to range in age from 10 to 18 years, and to have an average weight of 55 kg. Average weight is typically used for exposure calculations by USEPA and can be expected to represent a high average weight for 10 to 18 year old males (USEPA 1997). Exposure duration is 8 years, the total time spent as a "teenager" in this scenario. Incidental soil ingestion rate is estimated to be 100 mg/kg. It is assumed that 25 percent of the teen's total body surface area (4,570 cm^2) is exposed, which is roughly equivalent to hands, head, forearms, and lower legs, or more practically a person wearing short sleeves, shorts, and shoes (USEPA 2004c). The dermal adherence factor or contact rate for recreational visitors is assumed to be 0.1 mg/cm^2. This rate is an estimate of soil adherence to skin and varies based on moisture content, part of the body, and type of activity. It was assumed that recreational visitors would conduct moderate outdoor activity (similar to a soccer player) that would result in soil adhering to hands, arms, legs, and the face (USEPA 1997). A high-end estimate for inhalation rate for the teen was assumed to be of 15.2 m^3/day (0.63 m^3/hr). Values for soil ingestion and inhalation are high-end estimates taken from USEPA guidance (USEPA 1997). They are consistent with the concept of a screening assessment.

A dust loading factor is necessary to estimate a chemical concentration in air from that in soil. A dust loading factor of 1.316×10^9 m^3/kg is used. This value is taken from USEPA (2004a). This generic factor is thought to be appropriate for fairly dusty environments and could substantially overestimate dust loading in Ireland where moist conditions will predominate. On the other hand, this factor may underestimate dust generation during bicycle and Quad Bike riding, particularly when the ground

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surface is dry. Additional modeling of dust generation was not performed for this risk assessment, and dust generation remains an important uncertainty.

Finally, adjustments for bioavailability of arsenic and lead in mine waste are made in the estimation of risk. Often, bioavailability of such COPCs is limited in mine wastes because these constituents are either encased in or part of insoluble soil matrices (e.g., sulfide minerals). Reduced bioavailability implies that reduced potential human health threat. Site-specific bioavailability studies have been conducted for all spoil exposure areas except EA-5; spoils in this area are similar to EA-4; therefore, bioavailability estimates for EA-4 are used for EA-5. Relative bioavailability estimates of lead range from less than 0.1 to 28 percent and absolute bioavailability of lead ranges from 1 to 13 percent. Relative bioavailability estimates for arsenic range from 1 to 8 percent.

3.10.2 Exposure Assumptions for Nearby Residents

Residents living near the Avoca Mine Site may come in contact with mine–related contamination and are quantitatively evaluated for incidental ingestion of and dermal contact with soil, ingestion and dermal contact with interior dust, inhalation of interior dust, inhalation of particulates in outdoor air, and ingestion of and dermal contact with groundwater. Assumptions used to evaluate these pathways are discussed below.

Residents are assumed to be adults and young children. The HHRA evaluates exposure to carcinogens and non-carcinogens. Rather than evaluating both types of exposures for adults and children, children are evaluated for non-carcinogenic exposures and a combination of child and adult exposures is evaluated for carcinogens. This approach substantially reduces the amount of data to be presented in the HHRA, focuses the HHRA on the most important issues, and still provides protective risk estimates for both carcinogens and non-carcinogens.

This approach is possible because young children generally have high relative intake rates (food, water, incidentally ingested soil, etc.) and lower body weights compared to older children and adults, and therefore tend to have higher chemical exposures per kilogram (kg) of body weight. Non-carcinogens are assessed by calculating an average daily dose normalized to body weight. Evaluating young children yields the highest estimates for average daily dose and, therefore, is protective for all other age groups.

For exposure to carcinogens, exposure duration is also an important factor. Since exposure duration is longer for adults than for children, adults are included in the assessment of carcinogenic exposures. Carcinogenic risks during the first 30 years of life are estimated using age-adjusted factors. These factors approximate the integrated exposure from birth until age 30 by combining contact rates, body weights, and exposure durations for two age groups small children and adults. Since cancer risks are proportional to cumulative lifetime dose, an age-adjusted estimate of cumulative exposure provides the highest estimates and therefore is protective for all age groups.

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Calculation of age-adjusted factors is demonstrated by the example below.

For soil ingestion:

$$IFS_{adj} = \frac{IR\text{-}S_c \times ED_c}{BW_c} + \frac{IR\text{-}S_a \times (ED_{tot} - ED_c)}{BW_a}$$

where:

IFS_{adj}	=	Age-adjusted soil ingestion factor (mg-yr/kg-day)
$IR\text{-}S_c$	=	Soil ingestion rate (child) (mg/day)
ED_c	=	Exposure duration (child) (yr)
BW_c	=	Body weight (child) (kg)
$IR\text{-}S_a$	=	Soil ingestion rate (adult) (mg/day)
ED_{tot}	=	Total exposure duration (yr)
BW_a	=	Body weight (adult) (kg)

Exposure parameters for residents are summarized in Table 3-2 and discussed below.

Table 3-2 Exposure Assumptions For Nearby Residents

Exposure Parameter	Resident Adult	Resident Child
Body Weight (kg)	70 [a]	15 [c,e]
Averaging Time - Carcinogenic (days)	25,550 [a]	NA [a]
Averaging Time - Noncarcinogenic (days)	NA [a]	2,190 [c]
Exposure Frequency (days/yr)	350 [c]	350 [c]
Exposure Duration (years)	30 [c]	6 [c]
Exposure Parameters Specific to Soil		
Ingestion Rate (mg/day)	100 [c]	200 [c]
Skin Surface Area Available for Contact (cm^2/event)	5,700 [c,f]	2,800 [c,f]
Soil Contact Rate (adherence factor) (mg/cm^2)	0.07 [e]	0.2 [e]
Inhalation rate (m^3/day)	20 [e]	15.2 [c,e]
Exposure Parameters for Specific to Groundwater		
Ingestion Rate (L/day)	2 [c]	1 [c]
Skin Surface Area Available for Contact (cm^2/event)	18,000 [c,f]	6,600 [c,f]
Exposure Time (hr/day)	0.58	1

NA = Not applicable

[a] USEPA, 1989a. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual, Part A. EPA/540/1-89/002. Office of Emergency and Remedial Response. Washington D.C.

[b] USEPA, 1989b. Exposure Factors Handbook. EPA/600/8-89/043.

[c] Site-specific. Professional judgment. See text.

[d] USEPA 2001. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Peer Draft Review. March.

[e] USEPA, 1997. Exposure Factors Handbook. EPA/600/P-95/002Fa

[f] USEPA, 2004c. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual, Part E. EPA/540/R/99/005. Office of Emergency and Remedial Response. Washington D.C. OWSER Directive. July.

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3.10.2.1 Exposure Assumptions Common to Residential Exposure Pathways

The following section describes exposure assumptions common to residential exposure pathways. These parameters include exposure duration, averaging time, and body weight. The assumed values for these parameters remain constant for all residential exposure pathways.

Exposure Duration. Total exposure durations for evaluation of carcinogenic exposures combine exposure durations for two age groups – young children and adults. These values are used to calculate age-adjusted factors as discussed above. Exposure durations used to evaluate non-carcinogenic exposures are based on single values – exposure durations for young children.

Exposure duration for evaluation of carcinogens is 30 years, which is an upper range estimate (approximately 95th percentile) for residency at one address (USEPA 1991a, 2002). High-end exposure durations for adults and children are 24 years and 6 years, respectively (USEPA 1997). These values are used to calculate age-adjusted contact rates for evaluation of carcinogens.

Exposure durations for evaluation of non-carcinogens are the exposure durations for children. For young children the recommended value used is 6 years (USEPA 1993b).

Body Weight. Using a population average is recommended for the body weight parameter. USEPA (1991a, 2002) recommends an average body weight of 70 kg for adults. More recent USEPA guidance (1997) recommends an average body weight of 71.8 kg for adults. Both average body weights are based on both men and women. The more recent value is only marginally higher than the previous recommendation. A value of 70 kg is adopted for this assessment to be consistent with toxicity criteria. Use of the slightly larger value would require adjustment of cancer slope factors, because these criteria are calculated using an adult body weight of 70 kg. Using the lower body weight is more conservative.

The average body weight for male and female children up to 6 years of age is 15 kg. This value is the overall average for different age groups within the 0- to 6-year age range. Body weight data for these age groups are taken from USEPA (2002).

Averaging Time. Averaging time is the period in days over which intake is averaged. Averaging times differ for carcinogens and noncarcinogens because the effects of carcinogenic chemicals are assumed to have no threshold. Therefore, any exposure to a carcinogen carries a finite risk of cancer during the individual's lifetime. Within reason, this means that a single large exposure to a carcinogen is expected to carry the same risk as the same dose divided into many small exposures. Therefore, carcinogen intakes are expressed in terms of lifetime exposures, regardless of the actual exposure duration (USEPA 1989). Carcinogenic exposures are averaged over a lifetime. Consistent with typical EPA practice, a lifespan of 70 years is used in this HHRA (USEPA 1989); multiplying 70 years by 365 days/year results in an averaging time of 25,550 days.

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For non-carcinogenic chemicals, hazards are anticipated to be proportional to average daily exposure, and intakes are, therefore, averaged over the exposure duration multiplied by 365 days (USEPA 1989). Averaging time for non-carcinogenic exposures is calculated by multiplying exposure duration by 365 days/year (USEPA 1989). Young children are evaluated for non-carcinogenic exposures. Exposure duration for children is assumed to be 6 years. Averaging time for non-carcinogenic exposures is, therefore, 2,190 days.

Exposure Frequency. Exposure frequency is the number of days per year that an individual participates in a particular activity. For the residential scenario, an exposure frequency of 350 days per year is used as the number of days a person spends all or part of their time at home (USEPA 2002).

3.10.2.2 Assumptions for Soil Exposure Pathways

This section discusses exposure parameters specific to incidental ingestion and dermal contact with soil and dust and inhalation of particulates. Exposure assumptions for these pathways for residents are summarized in Table 3-2.

Soil Ingestion Rate. The ingestion rate for soil and dust is presented as the rate for soil ingestion alone. USEPA (1997) does not recommend an upper range soil ingestion rate for adults; however, USEPA (2002) had previously recommended a soil ingestion rate of 100 mg/day for evaluation of RME in adults. This value is used to evaluate incidental ingestion of soil by adult residents under the RME scenario. Soil ingestion rates for the child resident are assumed to be 200 mg/day for the RME scenario (USEPA 2002). The age-adjusted soil ingestion rate factor for RME, based on 6 years of exposure during childhood and 24 years as an adult, is 114 mg-yr/kg-day (USEPA 2002). Age-adjusted factors are used to evaluate RME for exposure to carcinogens.

Fraction Ingested from Contaminated Source. Children and adults are assumed to incidentally ingest soil when playing or working in their yards. No other source is assumed. Fraction ingested from the contaminated source is, therefore, equal to one.

Bioavailability Factor for COPCs in Soil or Dust. Site-specific bioavailability studies have been conducted for the Site. Estimates of the 95%UCL for absolute bioavailability for lead were calculated for spoil samples; values ranged from approximately less than 1 percent to 13 percent. Relative bioavailability estimates for arsenic range from less than 1 percent to 8 percent.

Skin Surface Area Available for Contact with Soil. Residents may contact contaminated soil dermally in their yards or fields. Dermal contact is also possible to some extent with household dust that originated from contaminated soil. A relatively large exposed skin surface area is, therefore, assumed. For the dermal pathway, skin surface areas were selected for body parts that could come into contact with surface soil during outdoor activities such as gardening, yard work, or play, using statistical distributions of surface area provided in the Risk Assessment Guidance for Superfund

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Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment (USEPA 2004c)).

The adult resident is assumed to wear a short-sleeved shirt, shorts, and shoes. A body surface area of 5,700 square centimeters (cm^2) was used for adult residents (50th percentile, USEPA 2004c). This surface area assumes exposure to the face, forearms, hands, and lower legs.

The child resident (<1 to <6 years old) is assumed to wear a short-sleeved shirt and shorts (no shoes); therefore, the exposed skin is limited to the head, hands, forearms, lower legs, and feet. The recommended surface area for the child resident is 2,800 cm^2 and is the average of the 50th percentile for males and females (<1 to <6 years old) (USEPA 2004c).

Age-adjusted skin area factors are 361 cm^2-yr/kg, for evaluation of RME. Age-adjusted skin area factors include soil to skin adherence factors, which are discussed in the following paragraph.

Adherence Factor. The adherence factor describes the amount of soil that adheres to the skin per unit of surface area. Soil adherence factors for different body parts and activities have been summarized by USEPA (2004c). Adherence factors are used to calculate the age-adjusted skin surface factors presented above.

A soil-to-skin adherence factor of 0.07 mg/cm^2-event was used for the adult resident RME scenario. This value is the 50th percentile weighted adherence factor for gardeners, the activity selected to represent a reasonable high-end activity for the adult (USEPA 2004c).

A soil-to-skin adherence factor of 0.2 mg/cm^2-event was used for the child resident RME scenario (USEPA 2004c). This value is the 50th percentile for children playing in wet soil (USEPA 2004c).

Dermal Absorption Factors. Dermal absorption factors are chemical-specific and relatively few data exist regarding chemical-specific dermal absorption from soil. USEPA (2004c) discusses existing data for a limited number of chemicals and presents possible ranges for dermal absorption based on these data. The recommended dermal absorption factor from soil for arsenic is 0.03. This value is used in the HHRA. For COPCs without USEPA (2004c) recommended dermal absorption factors, dermal absorption from soil is not estimated.

Event Frequency. The dermal contact event frequency is assumed to be one event per day for each day on which exposure occurs (USEPA 2004c) for both adult and child residents. Thus, dermal contact even frequency is the same as exposure frequency, 350 days per year.

Inhalation of fugitive dusts generated by wind erosion may occur; however, this pathway is not expected to contribute significantly to Site-related risks since moist

soils are predominating in the area. Exposure assumptions for inhalation of dust by residents are discussed below and are summarized in Table 3-2. A calculated particulate emission factor is applied to convert soil concentrations to estimated dust concentrations.

Inhalation Rate. The RME inhalation rate used for adult residents is 20 cubic meters (m^3) per day (USEPA 2002). The child inhalation rate under the RME scenario was assumed to be 10 m^3/day based on the average inhalation rates of males and females from 6 to 8 years in age (USEPA 1997). The age-adjusted inhalation factor for evaluation of carcinogenic exposures is 11 m^3-yr/kg-day for RME. These values assume an exposure duration of 24 hours/day. The values are, therefore, conservative and account for potential exposures to dust indoors and outdoors.

Particulate Emission Factor. Inhalation of chemicals absorbed to respirable particles is assessed using the USEPA Region 9 default particulate emission factor (PEF) equal to 1.316 x 10^9 m^3/kg. The PEF relates the contaminant concentration in soil with the concentration of respirable particles in air due to fugitive dust emissions from contaminated soils (USEPA 2004d). This value assumes a vegetative cover of 50 percent and a mean annual windspeed of 4.69 miles per second (m/s).

3.10.2.3 Groundwater Exposure Assumptions

Exposure assumptions for ingestion of and dermal contact with groundwater by current and future nearby residents are discussed below. Assumptions for this pathway are summarized in Table 3-2. Exposure assumptions for exposure duration, body weight, and averaging times were presented in Section 3.10.1.1 and are not repeated in this section. Exposures associated with groundwater are based on maximum COPC concentrations observed in residential wells. For comparison purposes exposure estimates were also calculated using maximum COPC from shallow alluvial monitoring wells.

Groundwater Ingestion Rate. The recommended 90th percentile drinking water ingestion rate for adults is 2.3 liters (L) per day (USEPA 1997). A reasonable maximum (95th percentile) drinking water ingestion rate for young children is 1.5 L/day (USEPA 1997). As discussed above, carcinogenic risks are estimated using age-adjusted factors, which integrate exposure from birth until age 30 by combining exposure assumptions for young children and adults. Age-adjusted factors for tap water intake are 1.39 L-yr/kg-day.

Exposure Frequency. Residents are assumed to consume contaminated groundwater daily with the exception of a single, 2-week vacation. Exposure frequency for groundwater ingestion is, therefore, 350-days per year. This assumption is considered representative of RME by USEPA (1991a).

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Skin Surface Area Available for Contact. Residents are assumed to use contaminated groundwater for purposes such as hand washing, dish washing, irrigating, and showering. Dermal exposure would likely be longest and the greatest amount of skin would be exposed during bathing and showering. Showering and bathing are thus evaluated in the risk assessment. Using conservative assumptions for showering and bathing time is expected to compensate for additional exposures that may occur during hand washing and similar activities.

USEPA (1989) recommends using average values for skin surface areas. For contact with water, a 50th percentile total body surface area of 18,000 cm²/day is recommended for adults (USEPA 2004c). The term is represented as per day because the quantity of surface area is expected to be exposed each day of exposure. USEPA also represents total skin surface areas for boys and girls. The skin surface areas for boys are used here, because they are more conservative. Males tend to be larger and have more skin surface area than females of the same age group. The average total skin surface area for 5- to 6-year-old boys is 6,600 cm²/day (USEPA 2004c).

The adult is most highly exposed individual and is evaluated for carcinogenic exposures associated with dermal exposure to groundwater.

Dermal Permeability Constant. Chemical-specific dermal permeability coefficients for dermal contact with water are presented in USEPA (2004c). Arsenic is the only groundwater COPC for which dermal exposure is estimated; the permeability coefficient for arsenic is 0.001 cm/hr. Arsenic was not detected above 1 µg/L in homeowner wells but was detected above the EPA Drinking Water Standard (10 µg/L) in monitoring wells.

Event Duration. USEPA (2004c) presents durations for showering/bathing. For the RME scenario, shower duration for adults is assumed to be 15 minutes, with an additional 20 minutes for drying off, brushing teeth, combing hair, etc., for a total of 0.58 hour (EPA 2004c). For the RME scenario, children (0 to 6 years) are assumed to spend 27 minutes in the bath, with an additional 33 minutes spent in the bathroom afterwards, for a total of 1 hour (USEPA 2004c).

Event Frequency. The dermal contact event frequency is assumed to be one event per day for each day on which exposure occurs for both adult and child residents. Thus, dermal contact event frequency is the same as exposure frequency (see below).

Exposure Frequency. For the residential scenario, an exposure frequency of 350 days per year is used, as the number of days per year a person spends all or part of their time at home (USEPA 1991a).

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3.10.3 Exposure Assumptions for Commercial/Industrial Workers

A wide range of potential exposure levels (as determined by the range of potential Site activities) characterizes both the commercial and industrial categories. To be protective of workers under the commercial/industrial worker category the HHRA evaluates a worker that is a full-time employee who spends most of the workday outdoors. Since several different types of outdoor worker scenarios are possible depending on future uses of the Site, the HHRA bases the future worker scenario on the generic commercial/industrial outdoor worker as defined in USEPA's soil screening guidance (USEPA 2001). This worker may be, for example, a park caretaker who conducts maintenance activities outdoors that may involve moderate digging or landscaping and typically involves onsite exposures to surface and shallow subsurface soils. The outdoor worker is expected to be the most highly exposed receptor in the outdoor environment under commercial/industrial conditions and is expected to have a higher soil ingestion rate than indoor workers. Potentially complete exposure pathways for future commercial/industrial workers consist of incidental ingestion of surface soil following contact and subsequent hand-to-mouth activities, ingestion of dust tracked from surface soil into offices, and inhalation of COPCs released from soil into air through wind or dust-generating activities (e.g., use of vehicles, drilling, and digging). Workers could also be exposed through dermal contact with soil and interior dust.

Groundwater is not expected to be used as a future drinking water source for workers and is not evaluated for this receptor group.

Future commercial/industrial workers are unlikely to have significant exposure to surface water and sediment during routine activities; recreational visitors are expected to be the most important receptors for evaluating potential exposures to these media. Additionally workers are also less likely to ingest produce, fish, and/or livestock from the Site; these exposure pathways are, therefore, considered incomplete or insignificant and are not further evaluated. These pathways are more reasonably addressed within the residential and recreational exposure pathways.

Exposure assumptions for future onsite commercial/industrial workers are discussed below and summarized on Table 3-3.

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Table 3-3 Exposure Parameters For Workers

Exposure Parameter	Commercial/Industrial Worker	Construction Worker
Body Weight (kg)	70 [a]	70 [c,e]
Averaging Time - Carcinogenic (days)	25,550 [a]	25,550 [a]
Averaging Time - Noncarcinogenic (days)	9,125 [a]	365 [c]
Exposure Frequency (days/yr)	250 [c]	132 [c]
Exposure Duration (years)	25 [c]	1 [c]
Exposure Parameters Specific to Soil Ingestion Rate (mg/day)	50 [c]	330 [c]
Skin Surface Area Available for Contact (cm^2/event)	3,300 [c,f]	3,300 [c,f]
Soil Contact Rate (adherence factor) (mg/cm^2)	0.2 [f]	0.37 [f]
Inhalation rate (m^3/hour)	2.5 [e]	2.5 [c,e]
Exposure Time (hours/day)	8	8

[a] USEPA, 1989a. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual, Part A. EPA/540/1-89/002. Office of Emergency and Remedial Response. Washington D.C.

[b] USEPA, 1989b. Exposure Factors Handbook. EPA/600/8-89/043.

[c] Site-specific. Professional judgment. See text.

[d] USEPA 2001. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Peer Draft Review. March.

[e] USEPA, 1997. Exposure Factors Handbook. EPA/600/P-95/002Fa

[f] USEPA, 2004c. Risk Assessment Guidance for Superfund. Volume I - Human Health Evaluation Manual, Part E. EPA/540/R/99/005. Office of Emergency and Remedial Response. Washington D.C. OWSER Directive. July.

3.10.3.1 Assumptions for Soil Exposure Pathways

Exposure Duration. USEPA (1991a, 2002) recommends using an exposure duration of 25 years for evaluation of upper-range exposure at the workplace. This value is used here to evaluate RME.

Exposure Frequency. Workers are likely to spend 250 days per year at their place of employment (USEPA 2002). This value is based on a 5-day work week and 10 vacation days per year; this value is used for RME.

Body Weight. USEPA (1991a, 2002) recommends a body weight of 70 kg for adults. This value is used to evaluate onsite workers. This average weight is based on both males and females and for RME.

Averaging Time. Carcinogenic exposures are averaged over 70 years (USEPA 1991a, 2002). Averaging time is expressed in units of days. Seventy years multiplied by 365 days per year is equal to 25,550 days.

Averaging times for non-carcinogens are calculated by multiplying the exposure duration by 365 days/year (USEPA 1989). The averaging time for exposure to non-carcinogens is 9,125 for RME.

Soil Ingestion Rate. Future onsite commercial/industrial workers may incidentally ingest small quantities of soil when working or taking breaks outside. Incidental ingestion may occur through hand-to-mouth activities such as smoking, eating, etc.,

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when these activities are done with dirty hands. The soil incidental ingestion rate of Site workers is assumed to be 100 mg/day (USEPA 2002) for the RME.

Fraction Ingested from Contaminated Source. The fraction of soil ingested from the contaminated source is assumed to be one. For days that they are evaluated for incidental ingestion of soil at the Site, future onsite commercial/industrial workers are assumed not to incidentally ingest soil anywhere else.

Dermal Skin Surface Area. To evaluate RME it is assumed that future onsite commercial/industrial workers could contact contaminated soil with their heads, hands, and forearms. The worker is assumed to wear a short-sleeved shirt, long pants, and shoes. The 50th percentile surface area for these body parts in adult males and females is 3,300 cm²/day (USEPA 2004c).

Adherence Factor. USEPA (2004c) presents soil adherence factors for different types of workers. Recommended adherence factors are considered representative of activities (e.g., groundskeepers, landscapers, equipment operators, construction workers, and utility workers) that may be conducted by commercial/industrial workers onsite. RME for soil adherence are based on the 95th percentile weighted adherence factors, is 0.2.

Dermal Absorption Factor. There are relatively few data regarding chemical-specific dermal absorption from soil. USEPA (2004c) discusses existing data for a limited number of chemicals and presents possible ranges for dermal absorption based on these data. The USEPA recommended dermal absorption factor from soil for arsenic is 0.03. For COPCs without USEPA recommended dermal absorption factors dermal exposure is assessed.

Event Frequency. The dermal contact event frequency is assumed to be one event per day for each day on which exposure occurs (USEPA 2004c) for workers. Thus, dermal contact event frequency is the same as exposure frequency (see below).

Inhalation of fugitive dusts generated by wind erosion may occur; however, this pathway is not expected to contribute significantly to site-related risks. A calculated particulate emission factor is applied to convert soil concentrations to estimated dust concentrations.

Inhalation Rate. An inhalation rate of 2.50 m³ per hour for an 8-hour day was assumed for workers under RME (USEPA 2002).

Particulate Emission Factor. Inhalation of chemicals absorbed to respirable particles is assessed using the EPA Region 9 default PEF equal to 1.316×10^9 m³/kg. The PEF relates the contaminant concentration in soil with the concentration of respirable particles in air due to fugitive dust emissions from contaminated soils (USEPA 2004d). This value assumes a vegetative cover of 50 percent and a mean annual windspeed of 4.69 miles per second (m/s).

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3.10.4 Exposure Assumptions for the Construction Worker Scenario

Construction scenarios are difficult to assess since construction activities can range from only a few days to many months of exposure and little guidance is available for this scenario. In the future use scenario, construction workers are assumed to be exposed to Site soil during the duration of a single construction project (typically a year or less). If multiple non-concurrent construction projects are anticipated, it is assumed that different workers will be employed for each project. The activities for this receptor typically involve substantial exposures to surface and subsurface soils via incidental ingestion, dermal contact, and inhalation of fugitive dust. Screening guidance errs on the upper end of this range because it only seeks an initial screen for possible human health impacts. Exposure assumptions for future onsite construction workers are considered representative of RME; since, there is little published guidance on how to evaluate a construction worker scenario in general, and no guidance that could be used to distinguish between RME and average exposure. Exposure assumptions for potential exposure pathways for the construction worker are discussed below and are summarized in Table 3-3.

If construction takes place onsite in the future, construction workers could be exposed to contaminants in both surface and subsurface soil via incidental ingestion, dermal contact, and inhalation of fugitive dust. For soil ingestion exposure parameters, future construction workers are assumed to ingest 330 mg of soil per day (USEPA 2002). This value is based on the 95th percentile value for adult soil intake rates (USEPA 2002). Workers are assumed to incidentally ingest soil during construction activities at the Site. No other source is assumed. Fraction ingested from the contaminated source is, therefore, equal to one. For dermal contact with soil, the adult construction worker was assumed to wear a short-sleeved shirt, long pants, and shoes; therefore, the exposed skin surface is limited to the head, hands, and forearms. The exposed skin surface area for workers is 3,300 cm^2, the average of the 50th percentile for males and females greater than 18 years of age (USEPA 2004). An adherence factor for an activity associated with relatively intensive soil contact is selected from the scenarios presented in USEPA (2004), since intensive contact with soil is likely for construction workers. Adherence factors based on utility workers are use. The 95th percentile adherence factor of 0.3 mg/cm^2 for utility workers is used to evaluate the RME scenario.

Inhalation of fugitive dusts generated by wind erosion may occur. Inhalation of carcinogenic and noncarcinogenic volatile chemical particle from surface soil may also occur. An inhalation rate of 20 m^3/day was assumed for workers (USEPA 2002) or 2.5 m^3/hour for 8 hours per day. Inhalation of chemicals absorbed to respirable particles is assessed using the EPA Region 9 default particulate emission factor (PEF) equal to 1.316×10^9 m^3/kg. The PEF relates the contaminant concentration in soil with the concentration of respirable particles in air due to fugitive dust emissions from contaminated soils (USEPA 2004d). This value assumes a vegetative cover of 50 percent and a mean annual windspeed of 4.69 m/s.

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Construction workers are assumed to be exposed for 132 days per year. This site-specific estimate corresponds to 22 days per month (5 days per week) for a 6 month period. This value is based on professional judgment and is conservative since significant exposure would only occur during excavation. The exposure duration for construction workers is 1 year. A life expectancy of 70 years (USEPA 1989) was used for all receptor groups as the averaging time for exposure to carcinogenic contaminants. The averaging time for non-carcinogenic effects is equal to the exposure duration, or 365 days for construction workers. A body weight of 70 kg was used for site workers (USEPA 2002).

In some areas of the Site (e.g., riparian areas, drainage areas), shallow alluvial groundwater could be contacted during excavation. However, incidental exposure to groundwater would most likely be infrequent and would not contribute significantly to total exposure and is therefore not quantified. The residential scenario is used to evaluate potential exposures to mine-related contamination in groundwater.

3.11 Calculation of Chronic Daily Intakes

This section describes methods that are used to calculate chronic daily intakes (CDIs) for exposure pathways that have been selected for quantitative evaluation. The calculations use exposure parameters presented in the previous sections along with exposure point concentrations developed using methods discussed in Section 3.9 Calculations for CDIs are presented in Appendix C. Exposures are quantified using standard exposure equations presented in USEPA (1989). These equations take the general form:

$$\text{CDI} = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

where: CDI   =   Chronic daily intake (mg/kg/day)
     C   =   Concentration of chemical at point of exposure (e.g., mg/kg of chemical in soil)
     IR   =   Intake rate (e.g., mg soil ingested/day)
     EF   =   Exposure frequency (days/yr)
     ED   =   Exposure duration (years)
     BW   =   Body weight (kg)
     AT   =   Averaging time (years × 365)

Conversion factors are employed where appropriate to ensure that units are kept constant. General equations used to calculate CDIs for each exposure pathway are shown below.

Ingestion of Soils, Interior Dust, and Mine Waste
To determine CDIs associated with incidental ingestion of chemicals in solid media (e.g., surface soils, interior dust, and mine waste), the following equation is used (USEPA 1989).

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$$CDI = \frac{CS \times CF1 \times IR\text{-}S \times FI \times EF \times ED}{BW \times AT}$$

where:
	CDI	=	Chronic daily intake (mg/kg/day)
	CS	=	Chemical concentration in soil or dust (mg/kg)
	CF1	=	Conversion factor (10-6 kg/mg)
	IR-S	=	Ingestion rate of soil (mg/day)
	FI	=	Fraction ingested from contaminated source (unitless)
	EF	=	Exposure frequency (days/yr)
	ED	=	Exposure duration (years)
	BW	=	Body weight (kg)
	AT	=	Averaging time (days)

For residential receptor, the following equation is used:

$$CDI = \frac{CS \times CF1 \times IR\text{-}S \times FI \times EF \times ED \times [(FS \times BAF_{soil}) + (C \times FD \times BAF_{dust})]}{BW \times AT}$$

where:
	BAF	=	Bioavailability factor for COPC in soil or dust (unitless), chemical specific
	FS	=	Fraction attributed to soil (unitless)
	FD	=	Fraction attributed to dust (unitless)
	C	=	Soil-to-dust transfer coefficient (unitless)

Ingestion of Sediments

To determine CDIs associated with incidental ingestion of chemicals in sediments during recreational activities, the following equation is used (USEPA 1989). Note that exposure to contaminants in sediment is evaluated qualitatively is used to address uncertainties associated with this pathway.

$$CDI = \frac{CSed \times CF1 \times IR\text{-}Sed \times FI \times EF \times ED}{BW \times AT}$$

where:
	CDI	=	Chronic daily intake (mg/kg/day)
	CSed	=	Chemical concentration in sediment (mg/kg)
	IR-Sed	=	Ingestion rate (mg/day)
	CF1	=	Conversion factor (10^{-6} kg/mg)
	FI	=	Fraction ingested from contaminated source (unitless)
	EF	=	Exposure frequency (days/year)
	ED	=	Exposure duration (years)
	BW	=	Body weight (kg)
	AT	=	Averaging time (days)

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Ingestion of Groundwater

To determine CDIs for ingestion of COPCs in contaminated groundwater, the following equation is used (USEPA 1989).

$$CDI = \frac{CW \times CF1 \times IR\text{-}W \times FI \times EF \times ED}{BW \times AT}$$

where: CDI   =   Chronic daily intake (mg/kg/day)
CW   =   Chemical concentration in water (μg/L)
IR-W   =   Groundwater ingestion rate (L/day)
CF1   =   Conversion factor (10^{-3} mg/μg)
EF   =   Exposure frequency (days/year)
ED   =   Exposure duration (years)
BW   =   Body weight (kg)
AT   =   Averaging time (days)

Ingestion of Surface Water

To determine CDIs for ingestion of COPCs in contaminated surface water during recreational activities, the following equation is used (USEPA 1989). Note that exposure to contaminants in surface water is evaluated qualitatively is used to address uncertainties associated with this pathway.

$$CDI = \frac{CSW \times CF1 \times IR\text{-}SW \times FI \times ET \times EF \times ED}{BW \times AT}$$

where: CDI   =   Chronic daily intake (mg/kg/day)
CSW   =   Chemical concentration in surface water (μg/L)
IR-SW   =   Surface water ingestion rate (L/hour)
CF1   =   Conversion factor (10^{-3} mg/μg)
ET   =   Exposure time (hours/day)
EF   =   Exposure frequency (days/year)
ED   =   Exposure duration (years)
BW   =   Body weight (kg)
AT   =   Averaging time (days)

Dermal Contact with Contaminated Soil and Sediment

To determine CDI for dermal contact with soil and sediment or dermally absorbed dose (DAD), the following equation is used (USEPA 2004c).

$$DAD = \frac{DA_{event} \times SA \times EV \times EF \times ED}{BW \times AT}$$

where: DAD   =   Dermally absorbed dose (mg/kg-day)
DA_{event} =   CS x CF1 x AF x ABS_d

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DA_{event} = Absorbed dose per event (mg/cm²-event)
CS = Chemical concentration in soil or sediment (mg/kg)
CF1 = Conversion factor (10^{-6} kg/mg)
AF = Adherence factor (mg/cm²-event)
ABS_d = Dermal absorption fraction (unitless)
SA = Skin surface area available for contact (cm²)
EV = Event frequency (events/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

Dermal Contact with Contaminated Groundwater and Surface Water

To determine CDI or DAD for dermal contact with groundwater and surface water, the following equation is used (USEPA 2004c).

$$DAD = \frac{DA_{event} \times SA \times EV \times EF \times ED}{BW \times AT}$$

where: DAD = Dermally absorbed dose (mg/kg-day)
DA_{event} = K_p x CW x CF1 x CF2 x t_{event} (mg/cm²-event)
DA_{event} = Absorbed dose per event (mg/cm²-event)
K_p = Dermal permeability coefficient (cm/hr)
CW = Chemical concentration in water (µg/L)
CF1 = Conversion factor 1 (10^{-3} mg/µg)
CF2 = Conversion factor 2 (10^{-3} L/cm³)
t_{event} = Event duration (hr/event)
SA = Skin surface area available for contact (cm²)
EV = Event frequency (events/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

Inhalation of Fugitive Dust

To determine CDIs associated with inhalation of COPCs in fugitive dust, the following equation is used (USEPA 1989).

$$CDI = \frac{CA \times IR\text{-}A \times ET \times EF \times ED}{BW \times AT}$$

where: CDI = Chronic daily intake ((mg/kg)/day)
CA = CS/PEF
CA = Chemical concentration in air (mg/m³)
CS = Chemical concentration in soil (mg/kg)

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PEF = Particulate emission factor (m^3/kg)
ET = Exposure time (hours/day)
IR-A = Inhalation rate (m^3/hour)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

3.12 Methods for Evaluating Exposure to Lead

Exposures to lead are not evaluated using the same methods as those described above for other site-related COPCs. USEPA has not published conventional quantitative toxicity criteria for lead because available data suggest a very low or possibly no threshold for adverse effects, even at exposure levels that might be considered background. In lieu of evaluating risk using typical intake calculations and toxicity criteria USEPA developed models specifically to evaluate lead exposures. The IEUBK model (USEPA 2001) is used to evaluate exposures to lead for young children in a residential situation. Methods are not readily available to assess possible lead exposures for a recreational scenario involving 10 to 18 year olds; the best available method is the USEPA adult lead model. The adult lead model is used is evaluate exposure for older children and adults.

3.12.1 IEUBK Model for Young Children

Blood lead level calculations for young children used *Windows* Version 1.0, Build 261 of the IEUBK model. The IEUBK model is a software package that allows the user to estimate, for a hypothetical child or population of children, a plausible distribution of blood lead concentrations centered on the geometric mean blood lead concentration predicted by the model from available information about children's exposure to lead. The model uses standard age-weighted exposure parameters for the consumption of food, drinking water, soil, dust, and inhalation of air, matched with site-specific concentrations of lead in these media, to estimate exposure for a child. The model simulates lead uptake, distribution within the body, and elimination of lead from the body. Except as described below, default parameters in this model were used in the analysis.

Site-specific estimates of bioavailability of lead in soil and dust were incorporated into model runs for each EA, based on results of *in vitro* tests (Section 2.1.2). Bioavailability of lead from the GI tract was assumed vary from 1 to 13 percent, significantly less than the default of 30 percent. All other parameters in the IEUBK model were left at their default values. Input parameters and output from the calculations are provided in Appendix D.

Site-specific measurements of lead in groundwater from residential drinking wells suggest concentrations of 3 µg/L or lower, which is not notably different from the default value of 4 µg/L; thus, the default value for this parameter was retained.

All other input parameters to the IEUBK model were retained as model defaults. These parameters include geometric standard deviation (GSD), 1.6; maternal blood lead concentration, 2.5 microgram per deciliter (μg/dL); concentration of lead in air, 0.1 micrograms per cubic meter (μg/m^3); and other sources of lead exposure, 0 μg/d. A complete list of input parameters for the IEUBK model runs is provided along with the output from these runs in Appendix D.

3.12.2 Adult Lead Model

USEPA's adult lead model (ALM) (USEPA 1996) was used to assess intermittent or variable exposures to lead at the Site by recreational users (older children) and workers. This model actually predicts lead exposure to the fetus of a pregnant women and is therefore not directly applicable to the older child (ages 10 to 18 years) that is evaluated for intermittent lead exposure. Lead toxicity may occur after only a few months exposure *in utero*; however, the fetus of young women at the upper end of the teenage age range could conceivably be appropriately addressed in the model. Still, the model should be highly conservative for essentially all of the age group; this issue is further discussed in later sections.

The model recommended by USEPA (1996) for use in evaluating lead exposures does not include inputs for either dermal or inhalation exposure to lead in soil. Implicitly, EPA has determined that these exposure routes are insignificant compared to incidental soil ingestion. This conclusion is consistent with the IEUBK model for evaluating lead exposure in young children (USEPA 2002). This model does not consider dermal exposure to lead, and demonstrates that even inhalation exposure represents only a small fraction of total lead exposure in residential situations. Neither dermal nor inhalation exposure are considered in the quantitative estimates of possible impacts of lead exposure on blood lead levels.

For evaluation of adult exposures, the methodology consists of algorithms that concentrate on estimated fetal blood lead concentrations in pregnant women exposed to lead-contaminated soils. The adult lead model can also be applied to recreational and adolescent receptors, provided that the appropriate model conditions are met. Empirical data on biokinetic slope factors appear to be similar for young children and adults; however, there is uncertainty in applying a similar estimate for adolescents. Reported low baseline blood concentrations for children between the ages of 12 and 18 years of age (Brody et al. 1994) may be due to a growth spurt in which there is a shift of lead from blood to bone.

Exposure assumptions used in the ALM are discussed below and are summarized in Table 3-4.

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Table 3-4 Exposure Parameters Used in the Adult Lead Model

Exposure Parameter	Definition	Parameter Value	Reason for Variable Selection	Reference
PbB - Fetal	Target fetal blood lead – no more than 5% should exceed	10 µg/dL	Recommended by EPA	USEPA 1996
IR	Soil ingestion rate			
	Recreational User, Adolescent	100 mg/day	Professional judgment	
	Construction Worker	330 mg/day	Professional judgment	
	Commercial/industrial Worker	100 mg/day	Recommended by EPA	USEPA 2002
R fetal/maternal	Ratio of fetal to maternal blood lead	0.9	Recommended by EPA	USEPA 1996
PbB - adult	Background adult blood lead concentration			
	Adult Receptors	1.7 –2.2 µg/dL	EPA Range	USEPA 1996
	Recreational User, Adolescent	1.5 µg/dL	Default value for Homogenous populations	USEPA 1996
	Adult (Workers)	1.5 µg/dL	NHANES III Survey data	USEPA 2002
BKSF	Biokinetic slope factor	0.4 µg/dL/µg/day	Recommended by USEPA	USEPA 1996
GSD	Geometric standard deviation	1.8-2.1	USEPA recommended range	USEPA 1996
	GSD Used in Assessment	2.18	NHANES III Survey data	USEPA 2002
EF	Exposure Frequency			
	Recreational User	104 days/year	Site-specific	Professional Judgment
	Construction Worker	132 days/year	Site-specific	Professional Judgment
	Commercial/Industrial Worker	250 days/year	Recommended by USEPA	USEPA 1996
AT	Averaging time			
	Recreational User	365 days/year	Recommended by USEPA	USEPA 1996
	Construction Worker	365 days/year	Recommended by USEPA	USEPA 1996
	Commercial/Industrial Worker	250	Recommended by USEPA	USEPA 2002
AF	Absorption Fraction	0.12	Recommended by USEPA	USEPA 1996

µg/dL = micrograms per deciliter
mg/day = milligrams per day
µg/day = micrograms per day

Target Risks – Fetal Blood Lead Level
Target risks for lead are based on fetal blood lead level. The lead PRGs presented in the HHRA are protective of the fetus based on exposure of a pregnant female. A fetal blood lead level of 10 µg/dL is the goal for the 95th percentile blood lead concentration among fetuses born to women having exposures to the lead in soil. This means the likelihood of fetus blood lead concentration greater than 10 µg/dL would be 5 percent or less.

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Background Blood Lead Concentration

The background adult blood lead concentration (PbB) is the typical blood lead concentration in women of child bearing age in the absence of exposures to the Site that is being assessed. Baseline blood lead concentrations (PbB) seem to vary by age, socioeconomic status, and race/ethnicity. Lower PbB are often found among non-Hispanic white women, and higher levels among non-Hispanic black women. USEPA (2002) provides a range of values for each of these parameters, and some guidance for choosing values appropriate for a given site. Since site-specific data are unavailable, the default value of 1.5 for homogenous populations is used for all receptors.

Biokinetic Slope Factor

The biokinetic slope factor relates the increase in adult blood lead concentration to average daily lead uptake (µg/dL blood lead increase per µg/day lead uptake). The default value of 0.4 µg/dL per µg/day provided by USEPA (1996) is based on steady-state conditions. This value is used for all receptors.

Geometric Standard Deviation

In USEPA adult lead methodology, the geometric standard deviation (GSD) is the estimated value of GSD among women of child-bearing age that have exposures to similar onsite lead concentrations but that have non-uniform response to site lead and non-uniform offsite lead exposures. GSD estimates seem most sensitive to how heterogeneous the population that may use the site is compared to the general population. USEPA provides default for GSD for four census regions and race/ethnicity (USEPA 2002). The model default of 2.18 for homogenous populations was used for all receptors. i

Averaging Time

An averaging time (AT) of 365 days is used to calculate PbB and Risk Based Remediation Goals (RBRGs) for both construction workers and recreational users, respectively.

Absorption Fraction

This parameter is the absolute gastrointestinal absorption fraction (AFs) for ingested lead in soil and lead dust derived from soil. The default value used in the ALM recommended by the Technical Workgroup (TRW)(USEPA 1996) is 0.12 (unitless). The default value is based on the assumption that the absorption factor for soluble lead is 0.2 ($AF_{soluble}$) and that the relative bioavailability of lead in soil compared to soluble lead ($RBF_{soil/soluble}$) is 0.6:

$$AF_s = AF_{soluble} (0.2) * RBF_{soil/soluble} (0.6) = 0.12$$

This value is adjusted based on site-specific bioavailability estimates. Calculation of absorption factors are presented in Appendix D.

Soil Ingestion Rate

USEPA (2002) recommends a default value of 330 mg/day for construction workers engaged in short-term activities that may involve intimate contact with soils (e.g.,

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excavation). USEPA does not recommend RME values for soil ingestion rates in children older than 6 years. The soil ingestion rate of 100 mg/day is used for the recreational user and commercial/industrial worker.

Exposure Frequency

Exposure frequency (EF) is the number of days per year that an individual may be exposed to site-related contaminants. Construction workers generally participate in only part of the construction or remedial activities, so that a few weeks of exposure are probably all that a single individual might be exposed for example, during excavation of a building foundation. Exposures for construction workers are generally short-term and the kinetics of lead exposure require several months before a new equilibrium of blood lead concentration is reached. For this analysis, an EF of 132 days/year is used for construction workers. This site-specific estimate corresponds to 22 days per month (5 days per week) for a 6 month period. Commercial/industrial workers are assumed to be exposed fro 250 days per year (USEPA 2002).

There is significant uncertainty regarding the number of days a recreational receptor may visit the Site. For this analysis a site-specific value of 104 days (professional judgment) per year is used for the recreational user. This assumes the recreational child visits the Site two times per week throughout the year.

3.13 Summary of Exposure Assessment

Populations that may be exposed to chemicals at the Site and pathways by which these populations may come into contact with mine-related chemicals were identified in the exposure assessment. In identifying potential pathways of exposure, both current and possible future land use of the Site and surrounding area are considered. Exposure assessment defines, in qualitative or quantitative fashion, the ways that people living, working or recreating in the study area might be exposed to contaminants released as a result of historic mining operations.

Populations that could theoretically be exposed to contaminants from the mine site may include:

- Current and future recreational visitors (these receptors could also be residents and/or workers)
- Nearby residents (current and in the future)
- Onsite commercial/industrial workers (future)
- Future construction workers

Potential exposure pathways for these populations may include one to several of the following:

- Incidental ingestion of and dermal contact with soil and spoils material

- Inhalation of particulates in ambient air

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- Incidental ingestion of surface water and sediment

- Dermal contact with surface water and sediment

- Ingestion of groundwater (incidental and/or voluntary [domestic groundwater use])

- Dermal contact with groundwater (shower/bathing)

- Ingestion of animal products from animals fed affected feed, or watered with affected surface water or groundwater

- Ingestion of produce from gardens with affected soil and/or watered with affected surface water or groundwater

- Ingestion of contaminated fish

Exposure point concentrations along with exposure assumptions are used to quantify risks and health hazards for complete exposure pathways.

Section 4
Toxicity Assessment

The toxicity assessment provides qualitative and quantitative descriptions of potential health impacts of COPCs. The toxicity assessment provides chemical-specific information that can be used along with estimates of exposure to estimate possible cancer risks and non-cancer health hazards.

Quantitative expressions of toxicity are particularly important to the risk assessment. Toxicity values are used to evaluate the potential for each COPC to cause adverse effects in exposed individuals. Adverse effects include both carcinogenic and noncarcinogenic health effects in humans. Toxicity values are numerical expressions of the relationship between dose (exposure) and response (adverse health effects). Separate toxicity values are developed for carcinogenic and non-carcinogenic (i.e., systemic) health effects. Toxicity values for carcinogens are provided as cancer slope factors (CSF) in units of risk per milligram of chemical per kilogram of body weight per day. A CSF is developed based on the assumption that no threshold for carcinogenic effects exists, and that any exposure is associated with some finite risk of cancer. Toxicity values for non-carcinogen or for significant systemic effects caused by carcinogens are provided as reference doses (RfD) in units of mg/kg-day. RfDs are interpreted as thresholds below which adverse health effects are not expected to occur, even in the most sensitive individuals in a population. CSFs and RfDs are used in conjunction with estimates of exposure to quantify risks and health hazards to exposed individuals.

Health criteria used in this risk assessment were obtained from a variety of toxicological sources according to a hierarchy established in OSWER directive 9285.7-53 (USEPA 2003). EPA relies on a variety of toxicological sources including USEPA sources. The toxicity value hierarchy is as follows:

- Tier 1— USEPA's Integrated Risk Information System (IRIS)

- Tier 2—USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs): The Office of Research and Development/ National Center for Environmental Assessment (NCEA)/Superfund Health Risk Technical Support Center (STSC) develops PPRTVs on a chemical specific basis when requested by EPA's Superfund program.

- Tier 3—Other Toxicity Values: Tier 3 includes additional USEPA and non-USEPA sources of toxicity information. Priority is given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer-reviewed.

The latter two bullets comprise data sources used for toxicity information in the USEPA Region 3 PRG tables. Values presented on USEPA Region 3, or Region 9 PRG tables were used if not available from IRIS.

The following sections briefly describe how toxicity criteria for carcinogens and noncarcinogens are developed and expressed, and summarize toxicity values for COPCs. The general basis for the development of toxicity values for carcinogens and noncarcinogens is presented in Sections 4.1 and 4.2, respectively. Tables 4-1 through 4-4 present toxicity values for chemicals selected as COPCs.

4.1 Health Effects Criteria for Potential Carcinogens

For chemicals that exhibit carcinogenic effects, EPA as well as other scientific authorities recognizes that one or more molecular events can evoke changes in a single cell or a small number of cells that can lead to malignancy. This non-threshold theory of carcinogenesis purports that any level of exposure to a carcinogen can result in some finite possibility of causing cancer. Generally, regulatory agencies assume the non-threshold hypothesis for carcinogens in the absence of information concerning the mechanisms of carcinogenic action for the chemical.

The CSF (in units of [(mg/kg body weight-day)$^{-1}$] is a number which, when multiplied by the lifetime average daily dose of a potential carcinogen (in mg/kg body weight-day), yields the upper-bound lifetime excess cancer risk associated with exposure at that dose. CSFs are developed for a specific route of exposure, either oral or inhalation. Upper-bound is a term used by USEPA to reflect the conservative nature of the CSFs: risks estimated using CSFs are considered unlikely to underestimate actual risks and may overestimate risks for a given exposure. Excess lifetime cancer risks are generally expressed in scientific notation and represent incremental probabilities that an individual will develop cancer as a result of exposure to a carcinogenic chemical over a 70-year lifetime under specified exposure conditions. When the upper-range CSF is multiplied by the lifetime average daily dose of a potential carcinogen, the product is an estimate of the upper-range lifetime individual cancer risk associated with exposure at that dose. The calculated risk is an estimate of the increased likelihood of cancer resulting from exposure to a chemical. For example, if the product of the CSF and the average daily dose is 1×10^{-6}, the predicted upper-range cancer risk for the exposed population is one in one million, or 0.0001 percent. This risk is in addition to any "background" risk of cancer not related to the chemical exposure.

In practice, CSF estimates are derived from the results of human epidemiology studies or chronic animal bioassays. The animal studies are conducted for a range of doses, including a high dose, in order to detect possible adverse effects. Since humans are expected to be exposed at lower doses than those used in animal studies, the data are adjusted via mathematical models. The data from animal studies are typically fitted to the linearized multistage model to obtain a dose-response curve. EPA evaluates a range of possible models based on the available data before conducting

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the extrapolation. The most appropriate model to reflect the data is selected based on an analysis of the data set.

The 95% UCL slope of the dose-response curve, subject to various adjustments and an inter-species scaling factor, is applied to derive the health protective CSF estimate for humans. Dose-response data from human epidemiological studies are fitted to dose-time-response curves. These models provide rough, but reasonable, estimates of the upper limits on lifetime risk. CSF estimates based on human epidemiological data are also derived using health protective assumptions and, as such, they too are considered unlikely to underestimate risks. Therefore, while the actual risks associated with exposures to potential carcinogens are unlikely to be higher than the risks calculated using a CSF estimate, they could be considerably lower. In addition, there are varying degrees of confidence in the weight of evidence for carcinogenicity of a given chemical. USEPA (1989) has proposed a system for characterizing the overall weight of evidence based on the availability of animal, human, and other supportive data. The weight-of-evidence classification is an attempt to determine the likelihood that an agent is a human carcinogen and thus qualitatively affects the estimation of potential health risks.

Three major factors are considered in characterizing the overall weight-of-evidence for human carcinogenicity: (1) the availability and quality of evidence from human studies, (2) the availability and quality of evidence from animal studies, and (3) other supportive information which is assessed to determine whether the overall weight-of-evidence should be modified. Under USEPA's 1986 risk assessment guidelines (USEPA 1986), classification of the overall weight-of-evidence has the following five categories:

- **Group A — Human Carcinogen:** There is at least sufficient evidence from human epidemiological studies to support a causal association between an agent and cancer.

- **Group B — Probable Human Carcinogen:** There is at least limited evidence from epidemiological studies of carcinogenicity in humans (Group B1) or that, in the absence of adequate data in humans, there is sufficient evidence of carcinogenicity in animals (Group B2).

- **Group C — Possible Human Carcinogen:** There is inadequate evidence of carcinogenicity in humans.

- **Group D — Not Classified:** There is inadequate data or no existing data for the chemical.

- **Group E — No Evidence of Carcinogenicity in Humans:** There is no evidence for carcinogenicity in at least two adequate animal tests in different species or in both epidemiological and animal studies.

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According to USEPA's newest guidelines for carcinogen risk assessment (USEPA 2005b), USEPA is changing the classification of carcinogens from the letter categories listed above to narrative descriptions of the available scientific information. The following are the five recommended standard hazard descriptors:

- Carcinogenic to humans
- Likely to be carcinogenic to humans
- Suggestive evidence of carcinogenic potential
- Inadequate information to assess carcinogenic potential
- Not likely to be carcinogenic to humans

The weight-of-evidence classification is based on evaluation of the data and in context of weight-of-evidence narratives, no one-to-one correspondence between the former groupings for carcinogens exists. For example, a B2 classification may change to "there is suggestive evidence for carcinogenicity based on animal studies, but not sufficient for assessment of human carcinogenic potential."

Oral and inhalation CSFs are presented on Tables 4-1 and 4-2, respectively.

4.2 Health Effects Criteria for Noncarcinogens

Oral RfDs and reference concentrations for inhalation (RfCs) are toxicity values developed by USEPA for chemicals exhibiting non-carcinogenic (systemic) effects. The RfD or RfC is an estimate of average daily exposure to an individual (including sensitive individuals) that is likely to be without appreciable risk of adverse effects even if exposure occurred continuously over a lifetime. These values are presented in units of mg/kg-day for comparison with estimated chronic daily intake into the body. The RfD is expressed in units of mg chemical per kg body weight per day (mg/kg-day), while the RfC is expressed in units of mg chemical per cubic meter of air (mg/m^3).

For chemicals that exhibit noncarcinogenic (e.g., systemic) effects, organisms have repair and detoxification capabilities that must be exceeded by some critical concentration (threshold) before the health effect is manifested. This threshold view holds that a range of exposures from just above zero to some finite value can be tolerated by the organism without an appreciable hazard of adverse effects. RfDs and RfCs are usually derived from no-observable-adverse-effect levels (NOAELs) taken either from human studies, often involving workplace exposures, or from animal studies and are adjusted downward using uncertainty or modifying factors.

Uncertainty factors are generally applied to adjust for the possibility that humans are more sensitive than experimental animals and that there may be sensitive subpopulations (e.g., children, pregnant women, individuals with hay fever or asthma). In addition, modifying factors are applied to address uncertainties related to the database. Uncertainty factors reflect scientific judgment regarding the various types of data used to estimate the RfD and RfC and generally consist of multiples of factors ranging from 1 to 10. For example, a factor of 10 may be introduced to account

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for possible differences in response between humans and animals in prolonged exposure studies. Other factors may be used to account for variation in susceptibility among individuals in the human population, use of data from a study with less-than-lifetime exposure, and/or use of data from a study that did not identify a NOAEL. For example, a modifying factor of 2 to 10 may be applied in instances where the database on a particular chemical lacks information on possible reproductive or developmental toxicity.

The quantitative relationship between the estimated chronic daily intake (dose) and the RfD (or RfC) is termed the hazard quotient (HQ). Doses that are significantly higher than the RfD or RfC may indicate an increased potential of hazard from the exposure, while doses that are less than the RfD or RfC are not likely to be associated with adverse health effects. It should be noted that an exceedance (i.e., HQ is greater than one) of the RfD or RfC does not predict a specific disease, just an increased potential hazard for non-cancer health effects.

RfDs and RfCs for COPCs are presented on Tables 4-3 and 4-4, respectively.

4.3 Toxicological Assessment

Tables 4-1 through 4-4 summarize the chronic oral, dermal, and inhalation RfDs and CSFs used to estimate noncarcinogenic effects and cancer risks for the COPCs. These criteria were the most current data, obtained from the April 2008 on-line version of IRIS (USEPA 2006c), USEPA's current PPRTVs and Health Effects Assessment Summary Tables (HEAST) (1997).

The use of surrogate toxicity values may be seen noted in Tables 4-1 through 4-4. The RfD for manganese of 2×10^{-2} mg/kg-day applies to nondietary exposures and was calculated from the RfD of 1.4×10^{-1} mg/kg-day as recommended by USEPA (2006c). IRIS has many values for the different salts of thallium. The RfD of 7×10^{-5} mg/kg-day recommended by USEPA Region 3 is used for thallium.

Qualitative information of noncarcinogens is also provided in these tables in the form of target organs for chronic exposures. Target organs are important for the evaluation of combined exposure to multiple chemicals, as discussed in the risk characterization.

4.4 Toxicity Profiles

The following sections summarize health effects for exposure to arsenic and lead.

4.4.1 Arsenic

Arsenic is a naturally occurring element widely distributed in the earth's crust. In the environment, arsenic is combined with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Naturally occurring arsenic in soil is part of the mineral matrix, often in association with iron. Inorganic arsenic compounds are now mainly used to preserve wood, and are also present in waste streams. For example, smelter emissions often contain arsenic present in ore. Arsenic used for wood treating or in waste

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streams is often more easily absorbed into the body and is more hazardous than arsenic that occurs naturally in soil.

Arsenic occurs naturally in soil and minerals and it therefore may enter the air, water, and land from wind-blown dust and may get into water from runoff and leaching. Arsenic cannot be destroyed in the environment. It can only change its form. Arsenic concentrations are naturally high in some rivers and streams as a result of large amounts of arsenic found in some minerals. Fish and shellfish can accumulate arsenic; however, most of this arsenic in these animals is in an organic form called arsenobetaine that is much less harmful.

Cancer

Several studies have shown that ingestion of inorganic arsenic can increase the risk of skin cancer and cancer in the lungs, bladder, liver, kidney, and prostate. Inhalation of inorganic arsenic can cause increase risk of lung cancer. The US Department of Health and Human Services (USDHHS) has determined that inorganic arsenic is a known human carcinogen. The International Agency for Research on Cancer (IARC), and the USEPA have determined that inorganic arsenic is carcinogenic to humans.

Studies of smelter workers have found an association between occupational arsenic exposure and lung cancer mortality. One study of a population residing near a pesticide manufacturing plant revealed that these residents were also at an excess risk of lung cancer. Case reports of arsenical pesticide applicators have also corroborated an association between arsenic exposure and lung cancer. Thus, risk assessment for exposure form breathing in dust that contains inorganic arsenic assumes that such exposure could cause lung cancer.

A study of 40,000 Taiwanese exposed to arsenic in drinking water found significant excess skin cancer by comparison to 7,500 residents of Taiwan and Matsu who consumed relatively arsenic-free water. Although this study demonstrated an association between arsenic exposure and development of skin cancer, it has several weaknesses and uncertainties that limit the study's usefulness in risk estimation, including poor nutritional status of the exposed populations, their genetic susceptibility, and their exposure to inorganic arsenic from non-water sources. Dietary inorganic arsenic was not considered nor was the potential contributions by contaminants other than arsenic in drinking water. There may have been bias of examiners in the original study since no skin cancer or preneoplastic lesions were seen in 7500 controls; prevalence rates rather than mortality rates are the endpoint; and furthermore there is concern of the applicability of extrapolating data from Taiwanese to the U.S. population because of different background rates of cancer, possibly genetically determined, and differences in diet other than arsenic (e.g., low protein and fat and high carbohydrate). Nevertheless, risk assessments performed for USEPA currently assume that exposure to inorganic arsenic can cause skin cancer.

Arsenic consumed by Taiwanese was dissolved in drinking water and therefore was in a form that was easily absorbed into the body. Arsenic in soil and/or wastes may

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be in a variety of forms that vary in their ability to be taken up into the body. In particular, arsenic that occurs naturally in the soil matrix may be very poorly absorbed. For the risk assessment for the Avoca Mine Site, arsenic was assumed to be in forms that are not highly available for absorption.

Non-Cancer

Arsenic is famous as a poison and relatively high doses can cause severe effects. Breathing high levels of inorganic arsenic can give you a sore throat or irritated lungs. Ingesting very high levels of arsenic can result in death. Such poisoning is, however, very unlikely at the levels of arsenic typically encountered in the environment. Chronic (long-term) exposure to lower levels of arsenic can cause nausea and vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels, and a sensation of "pins and needles" in hands and feet. Ingesting or breathing low levels of inorganic arsenic for a long time can cause a darkening of the skin and the appearance of small "corns" or "warts" on the palms, soles, and torso. Skin contact with inorganic arsenic may cause redness and swelling. In Taiwan, exposure to arsenic in drinking water resulted in a condition called Blackfoot disease. This disease of the blood vessels caused restriction in blood flow to the extremities. However, skin lesions were observed at even lower levels of exposure that Blackfoot disease. Thus, protection of people from skin lesions will also protect them from Blackfoot disease.

There is also some evidence that suggests that long-term exposure to arsenic in children may result in lower IQ scores. There is some information suggesting that children may be less efficient at converting inorganic arsenic to the less harmful organic forms. For this reason, children may be more susceptible to health effects from inorganic arsenic than adults. There is some evidence that inhaled or ingested arsenic can injure pregnant women or their unborn babies, although the studies are not definitive. Studies in animals show that large doses of arsenic that cause illness in pregnant females can also cause low birth weight, fetal malformations, and even fetal death. Arsenic can cross the placenta and has been found in fetal tissues. Arsenic is found at low levels in breast milk. Currently, information concerning effects on children and reproduction is not sufficient for direct incorporation into risk assessment. Risk assessment based on potential cancer effects and effects on the skin requires that arsenic exposures be kept very low. Thus, current risk assessment methods are likely to also protect from other effects where information is not sufficient yet to support quantitative risk assessment.

4.4.2 Lead

Lead is a naturally occurring, ubiquitous metal. Lead ores are often found with cadmium, zinc, and silver ores. Lead is commercially important because it is very soft, highly malleable, ductile, and is a poor conductor. In addition, it is resistant to corrosion, as well as being an effective sound absorber and an excellent radiation shield. Historically, lead has been used as pigments in paint, solders, gasoline additives, and in battery casings. Because of its extensive use and its ubiquitous distribution, exposure to lead is common.

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Quantitative Description of Health Effects

Oral absorption of inorganic lead in humans ranges from as low as 3 percent to as high as 80 percent (ATSDR 1991). The percentage of absorbed lead appears to be dependent on the solubility of the lead salt ingested, as well as age, nutritional status, and fasting time. Dietary absorption of lead in children has been reported at 50 percent as compared to 15 percent in adults (Chamberlain et al. 1978 in ATSDR 1991). Absorption from inhaled lead particles is thought to reach 100 percent; however, the particles must be deposited in the respiratory tract. Rate of deposition of lead-containing particles appears to be between 30 and 50 percent of the inhaled particles. Dermal absorption of lead is not considered a significant pathway.

Route of absorption does not affect distribution of lead. However, the toxicokinetics of lead alkyls are different from the toxicokinetics of inorganic lead and are not discussed. After absorption, lead is distributed among several physiologically distinct compartments (ATSDR 1991). The compartments are blood, soft tissue (particularly brain, kidney, and liver), and bone. Estimates of elimination half-times for lead from blood range from 15 to 35 days and elimination half-times from other soft tissues are probably similar (Harley and Kneip 1985 in ATSDR 1991). Elimination half-times for lead from mineralized bone are expressed in years. Because metabolic stress, such as pregnancy, may result in increased bone turnover or demineralization, there is potential for a portion of the parental bone lead-burden to be transferred to the fetus. In adults, approximately 94 percent of the total body burden is in bone (ATSDR 1991). Absorbed lead that is not retained is excreted by the kidney or through biliary clearance into the gastrointestinal tract. Infants retain approximately 32 percent of the lead absorbed (Ziegler et al. 1978 in ATSDR 1991), whereas, adults retain only about 1 percent of absorbed lead (Rabinowitz et al. 1977 in ATSDR 1991). Most toxicity endpoints associated with exposure to lead can be correlated with blood lead levels. Blood lead levels are, therefore, a useful index of toxicity.

Cases of severe lead encephalopathy have resulted in death in both adults and children. Blood lead levels associated with death in children ranged from approximately 125 µg/dL to 750 µg/dL. Systemic effects associated with lead include increased systolic and diastolic blood pressure (Harlan 1988; Pocock et al. 1984, 1985 in ATSDR 1991). Harlan's work, based on an analysis of National Health and Nutrition Examination Survey (NHANES II) data, estimated an increase in blood pressure of 7 mm Hg at blood lead levels between 14 and 30 µg/dL. Pirkle et al. (1985 in ATSDR 1991) evaluated the same data set for white males (ages 40 to 59) and found no discernible threshold for increased blood pressure associated with increased blood lead levels across the range of 7 to 34 µg/dL. Gastrointestinal symptoms, such as colic, abdominal pain, constipation, and anorexia, are typically seen at blood lead levels of 100 to 200 µg/dL but have been reported at blood lead levels as low as 40 µg/dL. Lead is known to depress heme synthesis and this effect also has no discernible threshold. Cytochrome P450 formation is also inhibited in the presence of lead. Kidney damage occurs with both acute and chronic exposures to lead. Acute renal toxicity has been reported in lead-intoxicated children and is considered reversible, whereas, chronic renal toxicity has been observed in lead-exposed workers

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and is considered irreversible. Lead interferes with vitamin D metabolism and may have some effect on the cellular component of the immune system.

The lowest observed effect level (LOEL) for overt neurotoxic toxicity in adults is 40 μg/dL (ATSDR 1991). Early symptoms include dullness, irritability, poor attention span, headache, muscular tremor, loss of memory, and hallucinations. As the condition worsens, symptoms include delirium, convulsions, paralysis, and coma and may lead to death. Decreased peripheral nerve conduction velocities have been seen in workers at blood lead levels ranging from 30 to 48 μg/dL; however, these effects are probably reversible.

Neurotoxicity in children is seen at much lower blood lead levels. Lead encephalopathy has been seen at blood lead levels of 60 to 300 μg/dL. Several studies have demonstrated a statistically significant decrement in children's IQ when correlated with blood lead levels and in some of the studies, results supported that there was no threshold level for this effect. There are also several well-designed and well-executed studies in the literature that have reported no statistically significant effects of lead exposure in IQ or other neurobehavioral measures.

Maternal blood lead levels appear to be correlated with birth weight and infant neurobehavioral deficits or delays.

Studies on the association of occupational exposure to lead with increased cancer risks are insufficient to determine the carcinogenicity of lead in humans. Ingestion of lead acetate and lead phosphate produced renal tumors in laboratory rats and mice.

It is difficult to briefly summarize the literature on lead. The Toxicological Profile for Lead (ATSDR 1991) contains over 1,000 references, and much of the brief synopsis above is taken from that profile.

Quantitative Description of Health Effects
Oral ingestion of certain lead salts (lead acetate, lead phosphate, lead subacetate) has been associated with increased renal tumor frequency in rats (Azar et al. 1973; Koller et al. 1985 both in ATSDR 1991), but no quantitative estimate of excess cancer risk has been performed by the Carcinogen Assessment Group of USEPA. USEPA has noted that the available data provide an insufficient basis on which to regulate lead acetate, lead phosphate, and lead subacetate as human carcinogens. However, applying the criteria described in USEPA's Guidelines for Carcinogenic Risk Assessment (USEPA 1986a in USEPA 1989), these lead salts have been classified by USEPA (1995b) in Group B2 - probable human carcinogen.

The USEPA Office of Drinking Water issued a draft health advisory of 20 μg/day for all extended periods of lead exposure (USEPA 1985 in ATSDR 1991). Blood lead levels above 15 μg/dL were identified as the level of concern, and fetuses and infants under 2 years of age are the sensitive subpopulation. In order to protect the fetus, it was considered advisable to limit the blood lead level in women of childbearing age to below 15 μg/dL (CDC 1990 in ATSDR 1991).

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USEPA has not published a reference dose (RfD) or acceptable intakes for chronic or subchronic periods of human exposure in IRIS (USEPA 2004) or HEAST (USEPA 1995a), because the general population is already accruing unavoidable background exposures through food, water, and dust. Any significant increase above background exposure would represent a cause for concern. In lieu of an acceptable intake for chronic exposure or RfDs, USEPA is currently refining a computer model for the prediction of blood lead levels in children exposed to lead from a variety of sources (USEPA 1991a, 1994a, b).

At present, human health criteria for lead in soil have not been established in the United States. The United Kingdom Directorate of the Environment has developed a tentative guideline of 550 ppm for lead in soil in residential areas (Smith et al. 1981 in ATSDR 1991). Vernon Houk of the Centers for Disease Control has been quoted as indicating that levels of 300 to 400 ppm lead in soil are acceptable based on studies of childhood lead poisoning (Mielke et al. 1984 in ATSDR 1991). The Ireland EPA has established an ESL of 1,000 mg/kg for soil

No reference concentration (RfC) is available for lead; and, as discussed above, it is not clear that there is a threshold below which there are no risks from exposure to lead. RfCs are based on the assumption that such a threshold exists; therefore, estimation of an RfC for lead is not appropriate at this time.

The impact of ingestion of lead in soils can be assessed using the IEUBK Lead Model, Version 1.0 (USEPA 2001). This model allows for the impact of lead in air on blood lead levels in children to be estimated. Thus, estimated blood lead levels can then be compared to target blood lead concentrations to assess potential risks.

The USEPA Technical Review Workgroup for Lead has developed an interim approach to assess risks associated with nonresidential adult exposures to lead in soil. The methodology consists of algorithms that concentrate on estimated fetal blood lead concentrations in pregnant women exposed to lead-contaminated soils on a daily basis. This approach can be used to back-calculate soil-lead Preliminary Remediation Goals (PRGs) that are protective of the developing fetus, the most susceptible receptor with adult exposures.

TABLE 4-1
CANCER TOXICITY DATA -- ORAL/DERMAL

Avoca Mining Site

Chemical of Potential Concern	Oral Cancer Slope Factor		Oral Absorption Efficiency for Dermal (1)	Absorbed Cancer Slope Factor for Dermal (1)		Weight of Evidence/ Cancer Guideline Description	Oral CSF	
	Value	Units		Value	Units		Source(s)	Date(s) (2) (MM/DD/YY)
INORGANICs								
Aluminum	NA	NA	--	NA	NA	D	--	05/01/08
Antimony	NA	NA	15.0%	NA	NA	D	--	10/11/07
Arsenic	1.5E+00	$(mg/kg/day)^{-1}$	95.0%	1.5E+00	$(mg/kg/day)^{-1}$	A	IRIS	05/01/08
Cadmium (3)	NA	NA	5.0%	NA	NA	D	IRIS	05/01/08
Chromium	NA	NA	1.3%	NA	NA	D	--	05/01/08
Chromium [+6] (3)	NA	NA	2.5%	NA	NA	D	IRIS	05/01/08
Cobalt	NA	NA	--	NA	NA	NA	--	05/01/08
Copper	NA	NA	--	NA	NA	D	--	05/01/08
Iron	NA	NA	--	NA	NA	NA	--	05/01/08
Lead	NA	NA	--	NA	NA	B2	--	05/01/08
Manganese	NA	NA	4.0%	NA	NA	D	--	05/01/08
Nickel (3)	NA	NA	4.0%	NA	NA	NA	IRIS / HEAST	05/01/08
Thallium	NA	NA	--	NA	NA	NA	--	05/01/08
Vanadium	NA	NA	2.6%	NA	NA	NA	--	05/01/08
Zinc	NA	NA	--	NA	NA	D	--	05/01/08

NCEA - National Center for Environmental Assessment

IRIS = Integrated Risk Information System; December 2005

HEAST = Health Effects Assessment Summary Tables; July 1997

CSF = Cancer slope factor

NA = Not Available

(1) The dermal Cancer Slope Factor was assumed to equal the oral Cancer Slope Factor.
   No adjustment factor was applied.
(2) IRIS values were confirmed against the USEPA's online database, May 2008.
   NCEA values were provided by USEPA Region 3 (2007)
(3) Not carcinogen by oral route.

USEPA Weight of Evidence:

A - Human Carcinogen

B1 - Probable human carcinogen - indicates that limited human data
   are available.

B2 - Probable human carcinogen - indicates sufficient evidence in
   animals and inadequate or no evidence in humans.

C - Possible human carcinogen

D - Not classifiable as human carcinogen

E - Evidence of noncarcinogenicity

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TABLE 4-2
CANCER TOXICITY DATA -- INHALATION
Avoca Mining Site

Chemical of Potential Concern	Unit Risk		Inhalation Cancer Slope Factor (1)		Weight of Evidence/ Cancer Guideline Description	Unit Risk: Inhalation CSF	
	Value	Units	Value	Units		Source(s)	Date(s) (2) (MM/DD/YYYY)
INORGANICs							
Aluminum	NA	NA	NA	NA	D	--	05/01/08
Antimony	NA	NA	NA	NA	D	--	05/01/08
Arsenic	4.3E-03	$(\mu g/m^3)^{-1}$	1.5E+01	$(mg/kg/day)^{-1}$	A	IRIS	05/01/08
Cadmium (3)	1.8E-03	$(\mu g/m^3)^{-1}$	6.3E+00	$(mg/kg/day)^{-1}$	B1	IRIS	05/01/08
Chromium	NA	NA	NA	NA	D	--	05/01/08
Chromium [+6]	1.2E-02	$(\mu g/m^3)^{-1}$	4.2E+01	$(mg/kg/day)^{-1}$	A	IRIS	05/01/08
Cobalt	2.8E-03	$(\mu g/m^3)^{-1}$	9.8E+00	$(mg/kg/day)^{-1}$	NA	PPRTV	10/11/07
Copper	NA	NA	NA	NA	D	--	05/01/08
Iron	NA	NA	NA	NA	NA	--	05/01/08
Lead	NA	NA	NA	NA	B2	--	05/01/08
Manganese	NA	NA	NA	NA	D	--	05/01/08
Nickel (4)	2.6E-04	$(\mu g/m^3)^{-1}$	9.1E-01	$(mg/kg/day)^{-1}$	A	OE	05/01/08
Thallium	NA	NA	NA	NA	NA	--	05/01/08
Vanadium	NA	NA	NA	NA	NA	--	05/01/08
Zinc	NA	NA	NA	NA	D	IRIS	05/01/08

IRIS = Integrated Risk Information System; March 2008

NCEA - National Center for Environmental Assessment

HEAST = Health Effects Assessment Summary Tables, July 1997

OE = OEHHA California Environmental Protection Agency
    Office of Environmental Health Hazard Assessment

NA = Not Available

PPRTV= EPA Provisional Peer Reviewed Toxicity Value

R = Route to route extrapolation (value used in Region 6 SLCs)

(1) Inhalation CSFs were calculated from unit risks assuming a 70 kg individual

(2) IRIS values were confirmed against the EPA's online database, May 2008.
    NCEA values were provided by USEPA Region 3 (2007).

(3) Cadmium is a B1 carcinogen by the inhalation route, but a D carcinogen by the oral route.

(4) Nickel and Nickel Compounds

USEPA Weight of Evidence:

A - Human Carcinogen

B1 - Probable human carcinogen - indicates that limited human data are available

B2 - Probable human carcinogen - indicates sufficient evidence in animals
    and inadequate or no evidence in humans.

C - Possible human carcinogen

D - Not classifiable as human carcinogen

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TABLE 4-3
NON-CANCER TOXICITY DATA -- ORAL/DERMAL

Chemical of Potential Concern	Chronic/ Subchronic	Oral RfD		Oral Absorption Efficiency for Dermal (1)	Absorbed RfD for Dermal (1)		Primary Target Organ(s)	Combined Uncertainty/ Modifying Factors	RfD: Target Organ(s)	
		Value	Units		Value	Units	Organ(s)		Source(s)	Date(s) (2) (MM/DD/YY)
INORGANICs										
Aluminum	Chronic	1.0E+00	mg/kg/day	--	1.0E+00	mg/kg/day	GI Tract/CNS	100	PPRTV	10/11/07
Antimony	Chronic	4.0E-04	mg/kg/day	15.0%	6.0E-05	mg/kg/day	Whole Body/Blood	1000	IRIS	05/01/08
Arsenic	Chronic	3.0E-04	mg/kg/day	95.0%	3.0E-04	mg/kg/day	Skin	3	IRIS	05/01/08
Cadmium (3)	Chronic	5.0E-04	mg/kg/day	5.0%	2.5E-05	mg/kg/day	Kidney	10	IRIS	05/01/08
Chromium (4)	Chronic	1.5E+00	mg/kg/day	1.3%	2.0E-02	mg/kg/day	NA	100	IRIS	05/01/08
Chromium [+6]	Chronic	3.0E-03	mg/kg/day	2.5%	7.5E-05	mg/kg/day	GI Tract	300	IRIS	05/01/08
Cobalt	Chronic	2.0E-02	mg/kg/day	--	2.0E-02	mg/kg/day	NA	NA	PPRTV	10/11/07
Copper	Chronic	4.0E-02	mg/kg/day	--	4.0E-02	mg/kg/day	GI Tract	--	HEAST	10/11/07
Iron	Chronic	7.0E-01	mg/kg/day	--	3.0E-01	mg/kg/day	GI Tract/Liver	1	PPRTV	10/11/07
Lead (6)	NA	NA	NA	--	NA	NA	NA	NA	--	05/01/08
Manganese (7)	Chronic	2.0E-02	mg/kg/day	4.0%	8.0E-04	mg/kg/day	CNS	1	IRIS	05/01/08
Nickel (8)	Chronic	2.0E-02	mg/kg/day	4.0%	8.0E-04	mg/kg/day	Body and Organ Weight	300	IRIS	05/01/08
Thallium	Chronic	7.0E-05	mg/kg/day	--	7.0E-05	mg/kg/day	Blood	NA	EPA Region 3	10/11/07
Vanadium	Chronic	1.0E-03	mg/kg/day	2.6%	2.6E-05	mg/kg/day	Metabolic	100	PPRTV	10/11/07
Zinc	Chronic	3.0E-01	mg/kg/day	--	3.0E-01	mg/kg/day	Blood	3	IRIS	05/01/08

NCEA - National Center for Environmental Assessment

IRIS = Integrated Risk Information System;May 2008

HEAST = Health Effects Assessment Summary Tables; July 1997

Region 3 = EPA Region 3 RBC Table; October 2007

PPRTV= EPA Provisional Peer Reviewed Toxicity Value

RfD = Reference dose

NA = Not Available

(1) The dermal RfD was assumed to equal the oral RfD, unless an adjustment factor was found in Exhibit 4.1 of USEPA 2004.

(2) IRIS values were confirmed against the USEPA's online database, March 2008.

(3) IRIS provides two RfDs for cadmium: 5×10^{-4} mg/kg/day for cadmium in drinking water and 1×10^{-3} mg/kg/day for cadmium in food.

(4) The RfD for trivalent chromium has been applied to total chromium.

(6) Lead is evaluated using the IEUBK model

(7) The RfD of 2×10^{-2} mg/kg/day applies to nondietary exposures, and was calculated from the IRIS RfD of 1.4×10^{-1} mg/kg/day as recommended in IRIS.
   Dietary exposure (5 mg/day) was subtracted and a modifying factor of 3 was applied.

(8) The RfD_o is for nickel, soluble salts

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TABLE 4-4
NON-CANCER TOXICITY DATA -- INHALATION
Avoca Mining Site

Chemical of Potential Concern	Chronic/ Subchronic	Inhalation RfC		Extrapolated RfD (1)		Primary Target Organ(s)	Combined Uncertainty/ Modifying Factors	RfC Target Organ(s)	
		Value	Units	Value	Units			Source(s)	Date(s) (2) (MM/DD/YY)
INORGANICs									
Aluminum	Chronic	3.5E-03	mg/m^3	1.0E-03	mg/kg/day	CNS	300	PPRTV	10/11/07
Antimony	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Arsenic	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Cadmium	Chronic	2.0E-04	mg/m^3	5.7E-05	mg/kg/day	NA	NA	NCEA	10/11/07
Chromium (3)	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Chromium [+6]	Chronic	1.0E-04	mg/m^3	2.9E-05	mg/kg/day	Lungs	300	IRIS	05/01/08
Cobalt	Chronic	2.0E-05	mg/m^3	5.7E-06	mg/kg/day	NA	NA	PPRTV	10/11/07
Copper	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Iron	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Lead	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Manganese	Chronic	5.0E-05	mg/m^3	1.4E-05	mg/kg/day	CNS	1,000	IRIS	05/01/08
Nickel	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Thallium	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Vanadium	NA	NA	NA	NA	NA	NA	NA	--	05/01/08
Zinc	NA	NA	NA	NA	NA	NA	NA	--	05/01/08

NCEA - National Center for Environmental Assessment

IRIS = Integrated Risk Information System; May 2008

HEAST = Health Effects Assessment Summary Tables; July 1997

RfC = Reference concentration

RfD = Reference dose

NA= Not Available

(1) Inhalation RfDs were calculated from Inhalation RfCs assuming a 70 kg individual has an inhalation rate of 20 m3/day.

(2) IRIS values were confirmed against the EPA's online database, March 2008.

(3) The RfC information for trivalent chromium has been applied to total chromium.

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Section 5
Risk Characterization

In this section of the risk assessment, human health risks associated with potentially complete human exposure pathways identified in Section 3 are characterized, integrating toxicity and exposure assessments into quantitative expressions of carcinogenic risk and non-carcinogenic hazard. Potential risks due to exposures to contaminants in soil and groundwater via ingestion, and dermal contact were quantitatively evaluated. Potential exposures and risks associated with contaminants resuspended from soil into air are quantitatively assessed via the inhalation pathway. Potential risks due to exposures to contaminants in sediment, and surface water are qualitatively evaluated. Potential consumption of homegrown produce and fish taken from the Avoca River are also addressed qualitatively.

Potential health hazards due to exposure to lead were evaluated independently because toxicity criteria, such as cancer slope factors and reference dose, are not available for this contaminant. Instead of standard risk and/or hazard calculations, the IEUBK model was used to estimate potential lead exposures for young children living in the study area and the Adult Lead Model is used to evaluate exposures for older children recreating in the area and adult workers. Quantitative results from the IEUBK model and Adult Lead Model and their interpretation for people living, working or recreating in the study area are presented separately.

Cancer risk and non-cancer hazard calculations for all COPCs are presented in Tables 1 through 37 included in Appendix C. Total risks and HIs for each area and receptor are summarized in Tables 5-1 through and 5-7 for the RME.

5.1 Overview of Cancer Risk Characterization

Cancer risk is estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a known, probable, or possible carcinogen. The upper-bound excess lifetime cancer risk is estimated by multiplying the exposure (lifetime average daily dose [LADD]) (Section 4.1) by cancer slope factors (CSF) (Section 4.1).

For potential carcinogens, cancer risks are thus obtained by the following equation:

$$\text{Risk} = \text{LADD x CSF}$$

Where:

Risk   =   Excess Lifetime Cancer Risk associated with exposure to the chemical via the specified route of exposure

LADD   =   Lifetime Average Daily Dose (in mg/kg/day)

CSF   =   Cancer Slope Factor (in $[\text{mg/kg/day}]^{-1}$)

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Excess lifetime cancer risks are generally expressed in scientific notation as incremental probabilities. An excess lifetime cancer risk of 1×10^{-6} (one in one million), for example, represents the incremental probability that an individual will develop cancer as a result of exposure to a carcinogenic chemical over a 70-year lifetime under specified exposure conditions. This increment is in addition to the risk of developing cancer from causes unrelated to the exposure.

The total excess lifetime cancer risk for each exposure pathway is obtained by summing chemical-specific risk estimates. In evaluating potential cancer risk, it is assumed that potential toxicity of chemical mixtures is additive. This approach is consistent with the USEPA guidelines for evaluating the effects of chemical mixtures (USEPA 1989). The risk summation methodology assumes that intakes of individual substances are small and that the independent action of each substance is independent (i.e., no synergistic or antagonistic chemical interactions exist, and that each substance causes the same effect, which is cancer). To the extent that these assumptions are not valid, the estimated total risk may overestimate or underestimate the actual risk.

As outlined in the OSWER directive (USEPA 1991), incremental cancer risks to an individual in the range of 1×10^{-4} (one cancer in an exposed population of ten thousand) to 1×10^{-6} (one cancer in an exposed population of one million) are generally considered acceptable by USEPA (1991). USEPA uses this target risk range (1×10^{-6} to 1×10^{-4}) to evaluate the need for remediation or mitigation at a site, but decisions on whether to remediate or mitigate risk that fall in this range are made on a site-specific basis. For sites where the cumulative carcinogenic risk is within this range, action may not be warranted unless a chemical specific standard is violated, there are significant non-carcinogenic risks, or an adverse environmental impact has been identified that warrants action (USEPA 1991). Cancer risk below 1×10^{-6} (1 in 1,000,000) are typically assumed to be *de minimis* and would require no remediation or mitigation. Risks that exceed 1 in 10,000 often require remediation and/or mitigation; however, no "bright line" has been established at the upper end of the risk range and risk management decisions are made on a site-by-site basis. Site-specific considerations, including types of exposure, uncertainties in estimating exposures, size of the affected population, and limitations of remedial activities, may determine the cancer risk level acceptable for a site.

Estimates of cancer risk are compared to the above targets as a means to put levels of cancer risk into perspective for the risk manager.

5.2 Overview of Non-carcinogenic Hazard Characterization

The potential for non-cancer health effects is evaluated by comparing average daily doses (ADD) with RfDs applicable for chronic (long-term) exposure. The ratio of exposure to toxicity is referred to as a hazard quotient (HQ). The HQ is a unitless ratio

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of a receptor's exposure level (or dose) to the "acceptable" (or allowable) exposure level.

The HQ is defined by the equation:

$$\textbf{HQ} = \textbf{ADD / RfD}$$

Where:

HQ   =   Hazard Quotient associated with the exposure via the specified exposure route (unitless)

ADD   =   Average Daily Dose (in mg/kg/day)

RfD   =   Reference Dose (in mg/kg/day)

A hazard index (HI) is a summation of HQs for a particular pathway or from several pathways. If the HI exceeds 1, further evaluation is required. Summation of HQs may overestimate hazards since chemicals may affect a variety of different organs or systems within the body. Chemicals affecting different organs or systems may act independently, and it is not appropriate to add HQs for such chemicals. Thus, if the HI for a pathway or a combination of pathways is 1 or above, HIs are further evaluated by grouping together those chemicals that affect the same organ. If the HI exceeds unity (1), the ADD is higher than a "safe" exposure level and some concern for potential non-cancer effects exists; however, this value should not be interpreted as a probability. Generally, the greater the HI above unity, the greater the level of concern.

Essentially all chemicals can cause adverse health effects if given at a high enough dose. However, when the dose is sufficiently low, typically no adverse effect is observed. Thus, in characterizing non-cancer effects of a chemical, the key parameter is the threshold dose at which an adverse effect first becomes evident. Doses below the threshold are considered to be safe, while doses above the threshold are could have some health impacts. The threshold dose is typically estimated from toxicological data (derived from studies of humans and/or animals) by finding the highest dose that does not produce an observable adverse effect, and the lowest dose that does produce an effect. These are referred to as the "No-observed-adverse-effect-level" (NOAEL) and the "Lowest-observed-adverse-effect-level" (LOAEL), respectively. The threshold is presumed to lie in the interval between the NOAEL and the LOAEL. However, in order to be conservative (protective), non-cancer risk evaluations are not based directly on the threshold exposure level, but on a value referred to as the RfD. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfD is derived from the NOAEL (or the LOAEL if a reliable NOAEL is not available) by dividing by an "uncertainty factor." If data are from studies in humans, and if observations are considered to be very reliable, the uncertainty factor may be as small as 1.0. However, the uncertainty factor is normally at least 10, and

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can be much higher if data are limited. The effect of dividing the NOAEL or the LOAEL by an uncertainty factor is to ensure that the RfD is not higher than the threshold level for adverse effects. Uncertainty factors are applied to correct for the possibilities that humans may be more sensitive than experimental animals, and that there may be sensitive subpopulations of humans (e.g., children, pregnant women, individuals with respiratory problems). Thus, there is always a "margin of safety" built into an RfD, and doses equal to or less than the RfD are nearly certain to be without any risk of adverse effect. Doses higher than the RfD may carry some risk, but because of the margin of safety, a dose above the RfD does not mean that an effect will necessarily occur.

For non-cancer hazards, USEPA typically uses a target HI of one, where HIs exceed this target, remediation and/or mitigation may be indicated. However, no bright line is established at an HI of 1, and risk management decisions are made on a site-by site basis. An HI of 1 or less for exposure via all chemicals and routes, or an HQ of 1 or less in the event that only one contaminant and/or exposure route is/are assessed, indicates that the receptor's exposure is equal to or less than an "allowable" exposure level, and adverse health effects are considered unlikely to occur. When the cumulative HI is less than or equal to 1, a conclusion of "no significant risk of harm to human health" based on non-cancer effects is appropriate. Chronic intakes that are greater than the RfD (i.e., an HI greater than 1) indicate a possibility for adverse effects, at least in sensitive populations and therefore may require further evaluation. However, whether such exposure actually produce adverse effects will (depending on the chemical) be a function of a number of factors such as the accuracy of uncertainty factors applied to the NOAEL, the appropriateness of animal model used in studies extrapolated to humans, and the potential for the chemical to cause effects in organs or systems (e.g., reproductive and immune systems) that have not been adequately studied. None of the above are quantifiable, such that it is not possible to discuss the risk of adverse effects in numerical terms. However, it is generally accepted that the protective assumptions made by USEPA in deriving RfDs will, in almost all cases, mean that exposures slightly in excess of the RfD will be associated with a low risk for adverse effects, with the probability of adverse effects increasing with increasing levels of exposure.

5.3 Results of Risk Calculations

Potential risks were estimated for the following receptors:

- Current/Future land use:
  (1)   Recreational visitors (current/future)
  (2)   Nearby residents (current/future)
  (3)   Commercial/Industrial Workers (future)
  (4)   Construction Workers (future)

USEPA guidance currently recommends a target range for cancer risk of 1×10^{-6} to 1×10^{-4}, and a target organ value of unity (1) for non-cancer health hazard as the threshold range of values for potential human health impact. Risks for all receptors

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were estimated using reasonable maximum exposure (RME) assumptions. Estimates based on RME generally form the basis for remedial decisions at a site. RME is considered high-end exposure that is still within a possible range. According to USEPA's Guidelines for Exposure Assessment (EPA 1992b), RME typically falls within the 90th to 99.9th percentile of possible exposures, and is the highest exposure that is reasonably expected to occur at a site. RME is estimated by combining average and upper range exposure assumptions. These calculations are made to arrive at an overall estimate that still falls within the realm of possible exposures.

Cancer risks and non-cancer health hazards associated with exposure to COPCs in spoils for recreational visitors and workers are presented in Table 5-1. Cancer risks and non-cancer health hazards associated with exposure to COPCs in soils for nearby residents are presented in Table 5-2. Using RME assumptions, the total excess lifetime cancer risks for all receptors exposed to contamination in soil/spoils, do not exceed the USEPA threshold of 1×10^{-4} for cancer risks. Cancer risk is due to exposure to arsenic. Site-specific bioavailability analyses have shown that arsenic in spoils at the Site is in a relatively inaccessible form. In addition, total HIs for receptors exposed to contaminants in spoils were below the USEPA threshold of one for recreational visitors. For the nearby child resident, the HI was slightly above one and was due to exposure to manganese and vanadium in soil. Maximum concentrations from all surface soil samples collected from fields and pastures in the vicinity of the site were used as exposure point concentrations to estimate hazards. Maximum concentrations of COPCs in surface soil were located in different exposure areas; the maximum concentration of manganese was located in Paddy's Field and the maximum concentration of vanadium was located in West Avoca. This assumption most likely overestimates risks and hazards for a randomly exposed receptor and since the HI of three is only slightly above one non-cancer health hazards for people exposed to nearby soils are not expected. For the future onsite commercial/industrial worker the total HI is slightly above one for EA-5 (Deep Adit Area); however, the HI based on toxic endpoints is below one.

Cancer risk and non-cancer health hazards associated with exposure to COPCs in groundwater are shown in Table 5-3. HIs for residents using groundwater from deep aquifers near the Site as a potable water source also were below the USEPA threshold of one for non-cancer effects at all locations sampled. Carcinogens were not reported above detection limits in homeowner wells. If shallow groundwater near the Site was used as a potable water source in the future cancer risk and non-cancer health hazards could exceed acceptable thresholds.

Exposure to more than one medium is possible at the Site and is evaluated for several receptors. Potential additive effects from different media are, however, not quantitatively evaluated, for the following reasons. Potential additive effects from different media are discussed in uncertainties. Combining risk estimates for media evaluated would not impact remedial decisions for the Site.

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5.3.1 Current/Future Recreational Visitors

In areas where exposures are possible for current recreational visitors, future exposure exposures are also estimated. Exposures for adults and older children (10 to 18 years of age) were evaluated. Recreational visitors are quantitatively evaluated for exposure to contaminants in soil via incidental ingestion, dermal contact and inhalation of particulates. Exposures to recreational visitors were evaluated for all onsite spoil exposure areas. Potential exposures to contaminants in surface water and sediment were qualitatively evaluated and are discussed in the Uncertainty Section (Section 7.3.1.4).

Cancer risk associated with exposures to soil for recreational adult and older child visitors is below or within the target cancer risk range of 1×10^{-6} to 1×10^{-4} for RME (Table 5-1) for all exposure areas. Cancer risk for the older child recreational visitor ranges from 2×10^{-7} to 1×10^{-5} (West Avoca). For the adult recreational visitor, cancer risk ranges from 4×10^{-7} to 4×10^{-5} (West Avoca). Cancer risk is due to exposure to arsenic in soil and the ingestion pathway contributes the majority of cancer risk estimate. As previously discussed arsenic in spoils at the site is not very bioaccessible resulting in low excess cancer estimates.

Non-cancer health hazards for COPCs other than lead are below the target threshold value of one suggesting that adverse non-cancer health effects are not expected resulting from exposure to COPCs in soil via a conservative recreational scenario (Table 5-1).

Table 5-1 Summary of Risks and Hazards for Avoca Spoil Exposure Areas

COPC	Recreational Scenario				Commercial/Industrial Worker		Construction Worker	
	Cancer Risk		Hazard Index		Cancer Risk	Hazard Index	Cancer Risk	Hazard Index
	Adult	Teen	Adult	Teen	Adult	Adult	Adult	Adult
EA-1	Connary							
Antimony	NC	NC	2.0E-02	2.6E-02	NC	4.9E-02	NC	8.5E-02
Arsenic	1.11E-06	3.88E-07	6.0E-03	7.8E-03	2.88E-06	2.6E-02	1.61E-07	2.9E-02
Cobalt	NC	NC	1.7E-05	2.2E-05	NC	6.1E-05	NC	8.1E-05
Copper	NC	NC	2.7E-02	3.5E-02	NC	6.5E-02	NC	1.1E-01
Iron	NC	NC	4.6E-06	5.9E-06	NC	1.1E-05	NC	1.9E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	5.1E-03	6.4E-03	NC	1.2E-02	NC	2.1E-02
Thallium	NC	NC	0.0E+00	NC	NC	0.0E+00	NC	NC
Vanadium	NC	NC	4.3E-03	5.4E-03	NC	1.0E-02	NC	1.8E-02
Total	1.E-06	4.E-07	0.06	0.08	3.E-06	0.16	2.E-07	0.27
EA-2	Mount Platt/ Cronebane							
Antimony	NC	NC	4.1E-03	5.3E-03	NC	1.0E-02	NC	1.7E-02
Arsenic	4.41E-07	1.53E-07	2.5E-03	3.2E-03	1.32E-06	1.4E-02	6.71E-08	1.4E-02
Cobalt	NC	NC	3.9E-05	4.9E-05	NC	1.4E-04	NC	1.8E-04
Copper	NC	NC	6.9E-03	8.8E-03	NC	1.7E-02	NC	2.9E-02
Iron	NC	NC	4.1E-06	5.2E-06	NC	9.8E-06	NC	1.7E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	3.4E-03	4.3E-03	NC	8.1E-03	NC	1.4E-02
Thallium	NC	NC	0.0E+00	0.0E+00	NC	0.0E+00	NC	NC
Vanadium	NC	NC	2.2E-03	2.8E-03	NC	5.4E-03	NC	9.4E-03
Total	4.E-07	2.E-07	0.02	0.02	1.E-06	0.05	7.E-08	0.08

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Table 5-1 Summary of Risks and Hazards for Avoca Spoil Exposure Areas

COPC	Recreational Scenario				Commercial/Industrial Worker		Construction Worker	
	Cancer Risk		Hazard Index		Cancer Risk	Hazard Index	Cancer Risk	Hazard Index
	Adult	Teen	Adult	Teen	Adult	Adult	Adult	Adult
EA-3	East Avoca/Tigroney West							
Antimony	NC	NC	2.5E-03	3.1E-03	NC	5.9E-03	NC	1.0E-02
Arsenic	4.64E-07	1.61E-07	2.6E-03	3.4E-03	1.40E-06	1.5E-02	7.07E-08	1.4E-02
Cobalt	NC	NC	7.3E-05	9.1E-05	NC	2.6E-04	NC	3.4E-04
Copper	NC	NC	2.3E-02	2.9E-02	NC	5.4E-02	NC	9.5E-02
Iron	NC	NC	8.3E-06	1.1E-05	NC	2.0E-05	NC	3.5E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	1.2E-02	1.6E-02	NC	2.9E-02	NC	5.1E-02
Thallium	NC	NC	0.0E+00	0.0E+00	NC	0.0E+00	NC	NC
Vanadium	NC	NC	8.0E-03	1.0E-02	NC	1.9E-02	NC	3.4E-02
Total	5.E-07	2.E-07	0.05	0.06	1.E-06	0.12	7.E-08	0.20
EA-4	Tigroney West Ore Bins							
Antimony	NC	NC	2.1E-02	2.7E-02	NC	5.0E-02	NC	8.8E-02
Arsenic	7.47E-06	2.62E-06	3.9E-02	5.2E-02	1.74E-05	1.3E-01	1.05E-06	1.7E-01
Cobalt	NC	NC	1.0E-04	1.3E-04	NC	3.6E-04	NC	4.8E-04
Copper	NC	NC	4.9E-02	6.2E-02	NC	1.2E-01	NC	2.0E-01
Iron	NC	NC	8.1E-06	1.0E-05	NC	1.9E-05	NC	3.4E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	8.6E-03	1.1E-02	NC	2.1E-02	NC	3.6E-02
Thallium	NC	NC	0.0E+00	0.0E+00	NC	0.0E+00	NC	NC
Vanadium	NC	NC	6.3E-03	8.0E-03	NC	1.5E-02	NC	2.6E-02
Total	7.E-06	3.E-06	0.12	0.16	2.E-05	0.33	1.E-06	0.53
EA-5	Deep Adit Area							
Antimony	NC	NC	2.1E-01	2.6E-01	NC	5.0E-01	NC	8.6E-01
Arsenic	5.98E-06	2.10E-06	3.2E-02	4.1E-02	1.40E-05	1.0E-01	8.43E-07	1.4E-01
Cobalt	NC	NC	2.6E-02	3.3E-02	NC	9.1E-02	NC	1.2E-01
Copper	NC	NC	1.7E-02	2.1E-02	NC	4.0E-02	NC	7.0E-02
Iron	NC	NC	1.3E-01	1.7E-01	NC	3.1E-01	NC	5.5E-01
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	1.6E-02	2.0E-02	NC	3.8E-02	NC	6.6E-02
Thallium	NC	NC	3.6E-02	4.6E-02	NC	8.7E-02	NC	1.5E-01
Vanadium	NC	NC	0.0E+00	0.0E+00	NC	NC	NC	NC
Total	6.E-06	2.E-06	0.46	0.59	1.E-05	1.17	8.E-07	**1.96**
EA-6	West Avoca							
Antimony	NC	NC	6.5E-03	8.3E-03	NC	1.6E-02	NC	2.7E-02
Arsenic	3.54E-05	1.24E-05	1.8E-01	2.4E-01	7.85E-05	5.1E-01	4.92E-06	7.8E-01
Cobalt	NC	NC	2.5E-04	3.2E-04	NC	8.9E-04	NC	1.2E-03
Copper	NC	NC	1.2E-02	1.5E-02	NC	2.9E-02	NC	5.0E-02
Iron	NC	NC	1.1E-05	1.4E-05	NC	2.6E-05	NC	4.5E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	1.7E-02	2.2E-02	NC	4.1E-02	NC	7.2E-02
Thallium	NC	NC	NC	NC	NC	0.0E+00	NC	NC
Vanadium	NC	NC	2.0E-02	2.5E-02	NC	4.7E-02	NC	8.2E-02
Total	4.E-05	1.E-05	0.24	0.31	8.E-05	0.64	5.E-06	1.01
EA-7	Shelton Abbey no surface data							

5.3.2 Current/Future Nearby Residents

Nearby residents may come into contact with contaminants in surface soil and interior dust through incidental ingestion, dermal contact, and inhalation of fugitive dust.

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Exposure to contaminants in soil for residents is estimated based on the maximum concentration of COPCs reported in surface soil samples collected from several fields and pastures sampled during the Phase 2 investigation.

In addition offsite residents may be exposed to contaminants in groundwater; however, as previously discussed few residents in the vicinity of the Site use groundwater as a drinking water source. Potential exposure routes include ingestion and dermal contact with contaminants in groundwater during washing, bathing, showering, laundering, and cooking. Residential groundwater wells sampled during the Phase II investigation draw water from the deep aquifer and appear not be impacted by site contamination.

USEPA guidance currently recommends a target range for carcinogenic risk of 1×10^{-6} to 1×10^{-4}, and a target organ value of unity (1) for non-carcinogenic health hazard as the threshold range of value for potential human health impact.

For residential exposures rather than evaluating cancer and non-cancer exposures for adults and children, children are evaluated for non-carcinogenic exposures and a combination of child and adult exposures are evaluated for carcinogens. Young children generally have high intake rates (food, water, incidentally ingested soil, etc.) and lower body weights compared to older children and adults and therefore tend to have higher chemical exposures per kilogram (kg) of body weight. Evaluating young children is therefore a conservative approach and yields the highest estimates for exposure to non-carcinogens.

5.3.2.1 Cancer Risk and Non-cancer Health Hazards Associated with Exposure to Soil

Soil at the Site includes outdoor soil and indoor dust. Risk estimates for residents are based on exposures to contaminants in surface soil; indoor dust estimates are based on COPC concentrations in soil. Cancer risks and non-cancer health hazards may exceed acceptable levels due to exposure to COPCs, which are common constituents in soil. Soil samples collected from areas unaffected by site contamination were collected to determine if calculated risks and hazards are associated with releases from the Site.

Cancer risks and non-cancer health hazards associated with exposure to COPCs in soils for nearby residents are presented in Table 5-2. Cancer risk associated with exposures to soil for nearby residents is 4×10^{-6} and is within the target cancer risk range of 1×10^{-6} to 1×10^{-4} for RME (Table 5-2). Cancer risk is due to exposure to arsenic in soil.

The HI associated with exposure to contaminants in soil by a nearby resident (young child 0 to 6 years in age) is slightly greater than the threshold of 1 (HI=3). These estimates are based on the maximum reported COPC concentrations from all fields/pastures sampled. HIs are greater than one for manganese and vanadium. These two COPCs affect different target organs; manganese affects the central

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nervous system and vanadium affects the metabolic system. Maximum concentrations of COPCs in surface soil were located in different exposure areas; the maximum concentration of manganese was located in Paddy's Field and the maximum concentration of vanadium was located in West Avoca. This assumption most likely overestimates risks and hazards for a randomly exposed receptor and since the HI of three is only slightly above one, non-cancer health hazards for people exposed to nearby soils are not expected. HIs for other COPCs are at least an order of magnitude below one.

Table 5-2 Summary of Risks and Hazards for Nearby Resident Exposed to Surface Soil

COPC	Cancer Risk	Hazard Index
	Adult/Child	Child
Antimony	NC	6.0E-02
Arsenic	4.37E-06	9.2E-02
Cobalt	NC	2.3E-02
Copper	NC	1.8E-01
Iron	NC	2.0E-04
Lead	NC	NC
Manganese	NC	**1.5E+00**
Thallium	NC	NC
Vanadium	NC	**1.6E+00**
Total	4.E-06	3

5.3.2.2 Cancer Risk and Non-cancer Health Hazards Associated with Exposure to Groundwater

Potential exposures to contaminants in groundwater were assessed for nearby residents who may use groundwater wells as potable water sources. Cancer risk and non-cancer hazards were estimated for ingestion and dermal contact with groundwater. Two types of groundwater wells were sampled in the Phase 2 investigation homeowner wells and monitoring wells. Most of the homeowner wells are completed in the deep bedrock aquifer while many of the monitoring wells are completed in the shallow alluvial aquifer near the Avoca River.

No carcinogens were selected as COPCs based on maximum concentrations of metals elevated in homeowner wells; therefore, no cancer risk estimates were calculated for this group of wells. Non-cancer health hazards were below the threshold of one which suggests that adverse non-cancer health hazards are not expected for homeowners who might use groundwater from bedrock aquifers (Table 5-3).

Risks and hazards were estimated assuming future residents may use shallow alluvial groundwater as a drinking water source. As discussed in Section 3.10, future use of this aquifer for drinking water is unlikely. Maximum concentration of COPCs from monitoring wells near the Avoca River are used as exposure point concentrations, Risk and hazard estimates are presented for both total and dissolved concentrations because total concentrations were not available for all wells. As shown in Table 5-3 domestic use of shallow alluvial groundwater in the vicinity of the site may pose unacceptable risks and hazards.

Water from Radio Tower Spring is used as drinking water source due to its alleged health benefits. Few chemicals were reported above detected limits and no carcinogens were detected. Non-cancer hazards are significantly below the USEPA threshold of one which suggests that adverse non-cancer health effects are not expected for people who drink water from Radio Tower Spring. Hazard calculations are presented in Table 3-38 in Appendix C.

Table 5-3 Summary of Risks and Hazards for Nearby Residents Exposed to Contaminants in Groundwater

	Homeowner Wells		Monitoring Wells (Total)		Monitoring Wells (Dissolved)	
COPC	Cancer Risk Adult	Hazard Index Child	Cancer Risk Adult	Hazard Index Child	Cancer Risk Adult	Hazard Index Child
Aluminum	NC	1.14E-01	NC	5.99E+00	NC	1.25E+02
Arsenic	NC	NC	NC	NC	3.09E-03	4.66E+01
Cadmium	NC	NC	NC	5.75E+00	NC	5.64E+01
Chromium III	NC	2.56E-04	NC	2.56E-04	NC	2.37E-02
Chromium IV	NC	2.56E-04	NC	2.56E-04	NC	2.37E-02
Copper	NC	1.94E-01	NC	1.92E+01	NC	2.05E+02
Iron	NC	6.88E-02	NC	1.45E-01	NC	1.86E+01
Lead	NC	NC	NC	NC	NC	NC
Manganese	NC	1.20E-01	NC	2.65E+01	NC	2.46E+02
Nickel	NC	3.84E-02	NC	2.78E-01	NC	2.76E+00
Zinc	NC	7.48E-02	NC	3.15E+00	NC	4.40E+01
Total	NC	0.6	NC	61	NC	744

5.3.3 Future Onsite Commercial/Industrial Workers

As a potential future use scenario, some areas of the site could be developed for commercial/industrial use or as a mining Heritage Park. Although redevelopment of all exposure areas on the Site is not likely, potential exposures via contact of contaminants in soil by future commercial/industrial workers was evaluated for all onsite exposure areas. Future workers may come into contact with contaminants in surface soil through incidental ingestion, dermal contact, and inhalation of fugitive dust.

Cancer risk associated with exposures to soil for future workers is within the USEPA target cancer risk range of 1×10^{-6} to 1×10^{-4} for RME and ranges from 9×10^{-7} (Mount/Platt/ Cronebane) to 5×10^{-5} (West Avoca)(Table 5-1). The majority of the cancer risk is due to ingestion of arsenic.

HIs for the future onsite commercial/industrial worker are below the non-cancer threshold of one for all EAs except EA-5 (Deep Adit Area); the HI for this EA is 2 and is mostly due to ingestion of antimony, arsenic and iron. For EA-5, XRF data were used to estimate EPCs. As discussed in Section 2.1, there is some uncertainty associated with the XRF data results. Since this HI is not significantly above the threshold and considering the uncertainties associated with the XRF data this slight exceedance likely does not indicate a potential for adverse health affects associated with exposure to soil for future commercial/industrial workers. Additionally the Deep Adit area is proposed to be used for construction of the water treatment building and all contaminated soils would be removed from the area before construction.

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5.3.4 Future Onsite Construction Workers

If areas of the Site are redeveloped for industrial or commercial use, recreational, or as a mining heritage park and museum workers involved with construction or preservation activities could be exposed to onsite soil during excavation for building foundations or utilities. Construction workers could be exposed to surface and subsurface soils through incidental ingestion, dermal contact, and inhalation of fugitive dust. Although redevelopment of all exposure areas on the Site is not likely, potential exposures via contact of contaminants in soil by construction workers was evaluated for all onsite exposure areas.

USEPA guidance currently recommends a target range for carcinogenic risk of 1×10^{-6} to 1×10^{-4}, and a target organ value of unity (1) for non-carcinogenic health hazard as the threshold range of value for potential human health impact.

Cancer risk associated with exposures to soil at the Site is due entirely to exposure to arsenic. Cancer risks for future construction workers range from 7×10^{-8} (EA-2, Mt. Platt/ Cronebane) to 5×10^{-6} (West Avoca). All cancer risks are below or within the USEPA target range for cancer risk (Tables 5-1 and Tables 21 through 26 in Appendix C).

The total HI for future construction workers is at or below the USEPA threshold of unity (1) for all exposure areas (Tables 5-1 and Tables 21 through 26 in Appendix C). These results suggest that non-cancer health effects due to exposure to contaminants other than lead in soil are not expected for future construction workers at the Site.

5.3.5 Sport Anglers

The fish community in the Avoca River is currently neither abundant nor diverse, primarily as a result of mine-related contamination. Ingestion of fish caught in the study area and subsequently eaten by anglers is not quantitatively evaluated at this time because there are insufficient numbers of fish in the sampled rivers and tributaries to support such an assessment. However, if there is a significant improvement in the numbers of fish in these waters following successful remediation, then the fish-ingestion pathway should be quantitatively assessed using site-specific fish tissue data.

5.4 Risks Associated with Exposure to Lead

Risks from exposure to lead cannot be assessed using standard methods because toxicological criteria for lead are not available. USEPA's position is that current data are insufficient to determine an RfD or RfC for lead. USEPA feels that the primary threat to human health from exposure to lead is subtle neurological effects in young children. For this reason, USEPA has not derived a CSF for lead.

The best available quantitative tool for evaluating health effects from exposure to lead is the IEUBK model (USEPA 2001). This model uses current information on the uptake of lead following exposure from different routes, the distribution of lead

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among various internal body compartments, and the excretion of lead, to predict impacts of lead exposure on blood lead concentrations in young children. The predicted blood lead concentrations can then be compared with target blood lead concentrations associated with subtle neurological effects in children. Because children are thought to be most susceptible to the adverse effects of lead, protection for this age group is assumed to also protect older individuals. Protection of young children is considered achieved when the model predicts that less than 5 percent of children will have blood lead levels greater than 10 µg/dL (USEPA 2001).

The IEUBK model (Version 1.0) is used to evaluate potential risks for nearby residents from exposure to lead associated with the Avoca Mining Site. Exposure to lead is evaluated for surface soil media for which lead was selected as a COPC. The Adult Lead Model was used to assess non-residential exposures to lead. Results of these analyses are discussed in the following sections.

5.4.1 Recreational User Lead Exposures

Recreational visitors to the Site may contact existing surface lead contamination in much of the Site spoil EAs. The adult lead model was used to assess lead exposures for older children and adults recreating in these areas. The 95th UCL and the mean absolute bioavailability estimate for each EA were used in the model along with the EPC for the area to predict blood lead levels. Target risks for lead are based on fetal blood lead level. A fetal blood lead level of 10 µg/dL is the goal for the 95th percentile blood lead concentration among fetuses born to women having exposures to the lead in soil. This means the likelihood of fetus blood lead concentration greater than 10 µg/dL would be 5 percent or less. Probabilities greater than 5 percent that the fetal blood level will exceed 10 µg/dL indicates a potential for adverse health effects associated with exposure to lead in soil.

The estimated average PbB for recreational users based on the 95th UCL estimate of absolute bioavailability ranged from 2 µg/dL to 12 µg/dL (EA-1 Connary). Estimates for potential effects on the fetus provided in Table 5-4 are presented for upper end of the age range for older children who recreate in the area. The Adult Lead Model predicts that the probability of fetal blood levels exceeding 10 µg/dL would range from less than 1 percent to 54 percent (EA-1 Connary) based on the 95th UCL absolute bioavailability estimate. Percentages greater than the target of no more than 5 percent probability of exceeding 10 µg/dL occur in two EAs, EA-1 (Connary) and EA-4 (Ore bins Tigroney West) (Table 5-4).

Table 5-4 Summary of Adult Lead Model for Recreational Visitors

Exposure Area		Statistic	EPC mg/kg	95th % UCL Absolute Bioavailability	PbB of adult worker, geometric mean	Probability that fetal PbB > PbB$_t$, assuming lognormal distribution
						GSDi = Hom
EA-1	Connary	95th UCL	34,525	6.64%	12.0	**53.9%**
		Mean	17,430	6.64%	6.8	**25.3%**
EA-2	Mount Platt/	95th UCL	13,768	1.00%	2.1	1.3%
	Cronebane	Mean	4,274	1.00%	1.7	0.6%
EA-3	East Avoca/	95th UCL	5,221	4.85%	2.7	2.7%
	Tigroney West	Mean	3,385	4.80%	2.2	1.6%
EA-4	Ore bins At Tigroney West	95th UCL	70,792	1.30%	5.7	**18.4%**
		Mean	19,675	1.30%	2.7	2.7%
EA-5	Deep Adit Area	95th UCL	10,834	1.30%	2.1	1.3%
		Mean	7,845	1.30%	2.0	1.0%
EA-6	West Avoca	95th UCL	3,808	13.94%	3.9	8.0%
	(1)	95th UCL	3,808	3.59%	1.9	0.8%
		Mean	2,165	13.94%	2.9	3.4%
EA-7	Shelton Abbey	95th UCL	NA	NA	NA	NA
		Mean	NA	NA	NA	NA

(1) 95TH UCL for absolute bioavailability excludes anomalous high absolute bioavailability value
GSDi = Hom Geometric Standard Deviation for homogenous populations

5.4.2 Residential Lead Exposures

The IEUBK model is run to evaluate potential exposures to lead in soil for nearby residents. The model was run using default values for all inputs, concentration of lead in paint, drinking water, diet, etc. except bioavailability. Five model computations were used to describe potential lead exposure, using a combination of default and site-specific input parameters. A range of site-specific bioavailability estimates (Table 5-5) for spoil piles were used to evaluate lead exposures for nearby residents. The assumption was made that the source of lead in nearby fields and pastures could potentially be from wind blown deposition of spoil material. The analyses also included the IEUBK default bioavailability estimate for lead of 30 percent. Using the range of absolute bioavailability estimates soil lead concentrations where no more than 5 percent of children were predicted to have blood lead levels above 10 μg/dL were developed. These values were then compared to maximum lead concentrations measure in soil samples collected from nearby fields and pastures. Several of the maximum lead concentrations in nearby surface soils are above the threshold level for lead exposure based on the IEUBK default value for bioavailability. Lead bioavailability for most of the spoil samples was low; comparing maximum lead concentrations in nearby surface soils to these more representative estimates of thresholds for adverse affects suggests that lead concentrations in nearby soils may be below levels of concern.

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Table 5-5 Summary of IEUBK Model

Total Percent Accessible in Soil and Dust (1)	Soil Lead Concentration (mg/kg) where no more than 5% of children (0 to 84 months) have blood lead levels above 10 µg/dL	Maximum Concentration (mg/kg) of Lead in Pastures Adjacent to Mine Areas		
1%	10,435	GMF	South of Cronebane (2)	818
3%	3,474	IFF	North of Cronebane (2)	117
6%	1,734	KF1	North of Cronebane (2)	219
14%	739	KF2	North of Cronebane (2)	346
30% (Default)	341	PHF	Paddy's Field (3)	766
		TMF1	West Avoca (4)	643
		TMF2	West Avoca (4)	225

(1) A range of site-specific bioavailability estimates for spoil piles were used to evaluate lead exposures for nearby residents. All other parameters are defaults for children 0- 84 months in age

(2) Absolute bioavailability in Cronebane Area 1 to 3%

(3) Assuming absolute bioavailability for Cronebane Area 1 to 3%

(4) Absolute bioavailability for West Avoca 1 to 14%

5.4.3 Commercial/Industrial Worker Lead Exposures

Future commercial/industrial workers could be exposed to lead contamination in surface soil. Although not all areas of the Site might be redeveloped in the future potential exposure to lead in all EAs was evaluated using the adult lead model for future commercial/industrial workers. The 95th UCL and the mean absolute bioavailability estimate for each EA were used in the model along with the EPC for the area to predict blood lead levels. The estimated average PbB for commercial/industrial workers based on the 95th UCL estimate of absolute bioavailability ranged from 3 µg/dL to 27µg/dL (EA-1 Connary). Estimates for potential effects on the fetus are also provided in Table 5-6.

Target risks for lead are based on fetal blood lead level. A fetal blood lead level of 10 µg/dL is the goal for the 95th percentile blood lead concentration among fetuses born to women having exposures to the lead in soil. This means the likelihood of fetus blood lead concentration greater than 10 µg/dL would be 5 percent or less. Probabilities greater than 5 percent that the fetal blood level will exceed 10 µg/dL indicates a potential for adverse health effects associated with exposure to lead in soil. The Adult Lead Model predicts that the probability of fetal blood levels exceeding 10 µg/dL could occur for workers exposed to lead in soil in EA-1 (Connary), EA-4 (Ore bins At Tigroney West), and EA-6 West Avoca.

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Table 5-6 Summary of Adult Lead Model For Commercial/Industrial Workers

Exposure Area		Statistic	EPC mg/kg	95th % UCL Absolute Bioavailability	PbB of Commercial/ /industrial worker, geometric mean	Probability that fetal PbB > PbB$_t$, assuming lognormal distribution
						GSDi = Hom
EA-1	Connary	95th UCL	34,525	6.64%	26.6	**88.1%**
		Mean	17,430	6.64%	14.2	**62.9%**
EA-2	Mount Platt/	95th UCL	13,768	1.00%	3.0	3.9%
	Cronebane	Mean	4,274	1.00%	2.0	1.0%
EA-3	East Avoca/	95th UCL	5,221	4.85%	4.3	9.9%
	Tigroney West	Mean	3,385	4.85%	3.3	5.1%
EA-4	Ore bins At Tigroney West	95th UCL	70,792	1.30%	11.6	**52.2%**
		Mean	19,675	1.30%	4.3	**10.1%**
EA-5	Deep Adit Area	95th UCL	10,834	1.30%	3.0	4.0%
		Mean	7,845	1.30%	2.6	2.6%
EA-6	West Avoca	95th UCL	3,808	13.94%	7.3	28.7%
		Mean	2,165	13.94%	4.8	**12.9%**
		95th UCL (1)	3,808	3.59%	3.0	3.9%
EA-7	Shelton Abbey	95th UCL	NA	NA	NA	NA
		Mean	NA	NA	NA	NA

GSDi = Hom Geometric Standard Deviation for homogenous populations

(1)   95TH UCL for absolute bioavailability excludes anomalous high absolute bioavailability value

5.4.4 Construction Worker Lead Exposures

Future development of the mine operations area would require some excavation during which construction workers could be exposed to lead contamination in surface and subsurface soil. The adult lead model was used to assess lead exposures for adult construction workers in the former mining operations area. The 95th UCL and the mean absolute bioavailability estimate for lead for each EA were used in the model along with the EPC for the area to predict blood lead levels. The estimated average PbB for construction workers based on the 95th UCL estimate of absolute bioavailability ranged from 4 µg/dL to 45 µg/dL (EA-1 Connary). Estimates for potential effects on the fetus are also provided in Table 5-7. The Adult Lead Model predicts that the probability of fetal blood levels exceeding 10 µg/dL could occur for workers exposed to lead in soil in EA-1 (Connary), EA-3 East Avoca/Tigroney West, EA-4 (Ore bins At Tigroney West), and EA-6 West Avoca. As discussed previously if the probability for fetal blood levels to exceed 10 µg/dL is greater than 5 percent a potential for adverse health effects associated with exposure to lead in soil is indicated.

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Table 5-7 Summary of Adult Lead Model For Construction Workers

Exposure Area		Statistic	EPC mg/kg	95th % UCL Absolute Bioavailability	PbB of Construction Worker, geometric mean	Probability that fetal PbB > PbBt, assuming lognormal distribution
						GSDi = Hom
EA-1	Connary	95th UCL	34,525	6.64%	44.6	**97.0%**
		Mean	17,430	6.64%	23.3	**84.0%**
EA-2	Mount Platt/	95th UCL	13,768	1.00%	4.1	8.9%
	Cronebane	Mean	4,274	1.00%	2.3	1.7%
EA-3	East Avoca/	95th UCL	5,221	4.85%	6.3	**22.0%**
	Tigroney West	Mean	3,385	4.85%	4.6	**11.7%**
EA-4	Ore bins Tigroney West	95th UCL	70,792	1.30%	18.8	**76.1%**
		Mean	19,675	1.30%	6.3	**22.3%**
EA-5	Deep Adit Area	95th UCL	10,834	1.30%	4.1	9.2%
		Mean	7,845	1.30%	3.4	5.6%
EA-6	West Avoca	95th UCL	3,808	13.94%	11.5	**51.8%**
		Mean	2,165	13.94%	7.2	**27.8%**
		95th UCL (1)	3,808	3.59%	4.1	8.8%
EA-7	Shelton Abbey	95th UCL	NA	NA	NA	NA
		Mean	NA	NA	NA	NA

GSDi = Hom Geometric Standard Deviation for homogenous populations

(1)   95TH UCL for absolute bioavailability excludes anomalous high absolute bioavailability value

5.4.5 Summary of Risk Characterization

Using RME assumptions, the total excess lifetime cancer risks for all receptors exposed to contamination in soil, do not exceed the USEPA threshold of 1×10^{-4} for cancer risks. Cancer risk is due to exposure to arsenic. Site-specific bioavailability analyses have shown that arsenic in soil at the Site is in a relatively inaccessible form. In addition, total non-cancer health hazards (HI) for receptors exposed to contaminants in soil were below the USEPA threshold of one for recreational visitors. For the nearby child resident the HI was slightly above one and was due to exposure to manganese and vanadium. For the future onsite commercial/industrial worker and construction workers the total HI is slightly above one for EA-5 (Deep Adit Area); however, the HI based on toxic endpoints is below one.

HIs for residents using groundwater from deep aquifers near the Site as a potable water source also were below the USEPA threshold of one for non-cancer effects at all locations sampled. Carcinogens were not reported above detection limits in homeowner wells. If shallow groundwater near the Site was used as a potable water source in the future cancer risk and non-cancer health hazards could exceed acceptable thresholds.

Recreational visitors (adults and children), future commercial/industrial workers, and future construction workers may be exposed to concentrations of lead in soil in some exposure areas at the Avoca Mining Site which may be associated with adverse

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health effects. For recreational visitors, these exposure areas include EA-1 (Connary) and EA-4 (Ore bins Tigroney West). Future commercial/industrial workers may be exposed to lead in spoil exposure areas EA-1 (Connary), EA-4 (Ore bins Tigroney West), and EA-6 (West Avoca) at levels associated with adverse health effects. Lead levels of concern for construction workers exposed to spoils may exist in EA-1 (Connary), EA-3 (East/Avoca/Tigroney West), EA-4 (Ore bins Tigroney West), and EA-6 (West Avoca).

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Section 6
Risk-Based Clean-up Levels for Soil/Spoils or Remediation Goals

Results of the HHRA indicate that the exposure to contaminants in spoils may be of concern for current and future receptors. Risk based clean-up levels or preliminary remediation goals (PRGs) were developed for carcinogenic risks and non-carcinogenic health hazards for all potential land uses (recreational, commercial, and residential), under RME exposure scenarios. PRGs for COPCs for spoils were estimated for adults and children recreating in the area currently and in the future, for future onsite commercial industrial workers and future onsite construction workers. PRGs for soils were estimated for current and future offsite residents.

By determining acceptable risk (i.e., 1×10^{-6} cancer risk or HI =1) and combining this with exposure assumptions presented previously in this report (Section 3), it is possible to calculate the average chemical concentration in a medium that results in the selected target risk. This chemical concentration, which represents the average concentration across the exposure unit, is the risk-based PRG. Selected targets for PRGs are 1×10^{-6} (i.e. one in a million) excess cancer incidents over a lifetime representing the lower bound of the USEPA acceptable cancer risk range, and a HQ of 1 for non-carcinogens. Risk managers might consider cleanup levels based on smaller target risks and hazards, for example, if relatively high exposures to multiple COPCs are anticipated.

PRGs represent the highest average concentrations of COPCs that could remain at the Site without risks or hazards exceeding a selected target value. PRG equations combine intakes from all major exposure pathways, and the resulting PRG levels should therefore be protective for total exposures within an exposure scenario. For all receptors, PRGs for all COPCs except lead take into account exposure via incidental ingestion of soil/spoils, dermal exposure to soil/spoils and inhalation of dust particles resuspended in air. PRGs developed for spoils to assess potential exposures associated with recreating in the area are based on very conservative assumptions since site specific data concerning the frequency of site visits by an individual are unavailable. Actual recreational activities were observed and evident (due to tracks) in both the Tigroney West (Ore bin) and Mount Platt areas.

Table 6-1 presents a summary of PRGs for spoils; PRGs for soils are summarized on Table 6-2. Calculations of PRGs are provided in Appendix E. Exposure point concentrations (EPCs) are presented on Tables 6-1 and 6-2 for comparison purposes. EPCs represent COPC concentrations to which receptors may be exposed within an exposure area. It is assumed that receptors will move randomly throughout an area. EPCs can be used, along with appropriate exposure assumptions, to reflect a range of potential exposures (average, reasonable upper range, worst case). Most often, and where data quantity allow, single EPCs are used to represent possible arithmetic average exposure concentrations. This average is often estimated using the 95% upper

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confidence level (UCL). Use of the 95% UCL helps ensure that the actual average concentration is not underestimated. The choice of the arithmetic mean as an appropriate statistic for characterizing exposure at an exposure point is based on the assumption of random exposure within the exposure area. EPCs presented in Table 6-1 for spoils represent maximum EPCs for all onsite areas. For offsite soils EPCs are maximum measured concentrations reported from all offsite areas sampled. EPCs were determined using statistical procedures recommended by USEPA, based on the findings of Singh, Singh, and Engelhardt (1997, 1999) (EPA 2004b).

PRGs for lead are estimated using USEPA lead models. PRGs for lead for nonresidential receptors are estimated using USEPA's Adult Lead Model (USEPA 1996). PRGs for lead for recreational visitors, commercial / industrial workers, and construction workers are presented Table 6-1. PRGs for lead are estimated for residents using USEPA's IEUBK model (USEPA 2001) and are summarized on Table 6-2. PRGs for lead were calculated based on the 95% UCL (3.95%) for absolute bioavailability estimated for all exposure areas. Bioavailability analyses were performed on spoil samples only. Calculations of PRGs for lead are presented in Appendix E.

Based on the conservative assumptions used to estimate PRGs, the maximum EPC for arsenic in spoils exceeds the 1×10^{-6} target cancer risk range site wide for recreational visitors and future commercial/industrial workers (Table 6-1). The maximum EPC for lead in spoils exceeds the PRG estimated for all receptors. The maximum EPC for thallium based on XRF data exceeds PRGs based on an HI of one for all receptor scenarios. Analytical results for thallium are available for the deep adit area only and are XRF measurements. XRF measurements are significantly higher for other chemicals for which there are also laboratory analyses which suggests that the EPC for thallium may be overestimated. Since the risk based PRG for iron for recreational visitors exceeds unity, the PRG for iron for recreational visitors is a ceiling limit equivalent to 10% by weight of the soil sample. EPCs for all areas except the deep adit area are orders of magnitude below this ceiling limit.

For offsite soils maximum reported concentrations of arsenic, manganese, and vanadium exceed their respective residential PRG. Neither manganese nor vanadium are expected to be associated with site-related contamination. Concentrations of arsenic in offsite surface soil are significantly below concentrations observed in onsite spoils and may not be elevated above background. Again it should be emphasized that PRGs for residents are very conservative.

Table 6-1 Human Health Risk-Based Cleanup Levels for Spoils. Avoca Mine Site

Chemical of Potential Concern	Target Risk or HI	Cleanup Level for Spoils (mg/kg)			Maximum Exposure Point Concentration for Onsite Areas [2]	Location of Maximum
		Recreational Visitor [1]	Commercial/ Industrial Worker	Construction Worker		
Arsenic	1×10^{-6}	571	221	3,925	1,622	West Avoca
Antimony	1	772	409	235	203	Deep Adit
Cobalt	1	37,348	13,345	10,103	1,217	Deep Adit
Copper	1	77,212	40,880	23,462	4,803	Ore Bins
Iron	1	100,000 (3)	715,400	410,583	224,969	Deep Adit
Lead	(4)	10,012	4,165	2,427	70,792	Ore Bins
Manganese	1	38,604	20,429	11,729	839	West Avoca
Thallium	1	147	78	45	404	Deep Adit (5)
Vanadium	1	1,930	1,022	587	48	West Avoca
(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children						
(2) The maximum exposure point concentration (mg/kg) is the maximum 95th UCL from all exposure areas.						
(3) PRG is a ceiling limit equivalent to a chemical representing 10% by weight of the soil sample. The risk based PRG exceeds unity (>1,000,000 mg/kg) which is not possible.						
(4) PRGs for receptors were calculated using the USEPA Adult Lead Model, based on 95%UCL of absolute bioavailability estimate for all exposure areas (3.95%)						
(5) Analytical results for thallium are available for the Deep Adit only and are XRF measurements						

Table 6-2 Human Health Risk-Based Cleanup Levels for Soils. Avoca Mine Site

Chemical of Potential Concern	Target Risk or HI	Cleanup Level for Soil Based on Offsite Resident [1] Scenario (mg/kg)	Maximum Exposure Point Concentration for Onsite Areas [2]	Location of Maximum
Arsenic	1×10^{-6}	134	276	TMF1
Antimony	1	31	2	TMF1
Cobalt	1	1,381	32	TMF2
Copper	1	3,129	575	TMF1
Iron	1	54,750	11	TMF2
Lead	(3)	2,671	818	GMF
Manganese	1	1,564	2,345	PHF
Thallium	1	6	NA	NA
Vanadium	1	78	128	TMF2

(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children

(2) The maximum exposure point concentration is the maximum concentration from all exposure areas.

(3) The PRG for lead for the offsite Resident was calculated using IEUBK Model for young children, and is based on 95%UCL of absolute bioavailability estimate for lead for the site (3.95%)

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Section 7
Evaluation of Uncertainties in the Human Health Risk Assessment

As in any risk assessment, estimates of potential health threats (cancer risks and non-cancer health effects) have numerous associated uncertainties. Uncertainties are inherent in the risk assessment process because of the numerous assumptions that are made in estimating exposure, toxicity, and potential risk. Conservative assumptions are made at every step of the process in the HHRA so as not to underestimate potential risk. As a result of the uncertainties, the risk assessment should not be construed as presenting absolute risks or hazards. Rather, it is a conservative analysis intended to indicate the potential for adverse impacts to occur based on reasonable maximum exposures.

An evaluation of uncertainties related to the risk assessment is important in order to place the Site risk estimates in perspective and to support risk managers in risk-based decision making. In addition, the uncertainty analysis identifies any additional data gaps, if any, that may affect the exposure and risk estimates.

The primary areas of uncertainty and limitations are qualitatively discussed here. In general, the main areas of uncertainty include the following:

- Environmental data (identification of COPCs, estimation of EPCs)
- Exposure assumptions
- Toxicological data
- Risk characterization

7.1 Environmental Data
Uncertainty is always involved in the estimation of chemical concentrations. Errors in the analytical data may stem from errors inherent in sampling and/or laboratory procedures. One of the most effective methods of minimizing procedural or systematic error is to subject the data to a QC review. This QC review procedure helps to eliminate many laboratory errors. However, it must be realized that error is inherent in all laboratory procedures. Based on the data and QA/QC procedures the data were considered usable for HHRA.

7.1.1 Data Biases
Uncertainty exists relative to the overall Site characterization in terms of whether the appropriate numbers of samples were taken from appropriate locations. For the Avoca Mining Site, a large number of soil and spoil samples were collected from areas where contamination was more likely to be present. This approach is appropriate to conservatively evaluate potential human exposures and to provide useful information for remedial options. Overall, the approach used to calculate EPCs from contaminated

sampling locations is anticipated to result in conservative EPCs for all exposure areas and therefore would not result in an underestimation of potential risk.

7.1.2 Spoil/Soil Data

As discussed in Section 2 analytical laboratory data for spoils were unavailable for EA-5; instead the HHRA used GSI XRF data to evaluate exposures for this EA. These data introduce uncertainty in the ability to compare exposures across the Site. A great deal of variability exists between XRF and analytical laboratory results for COPCs, more confidence is placed in laboratory analytical results.

Surface soil data were not available for EA-7 Shelton Abbey.

7.1.3 Groundwater Data

Groundwater data used in this assessment were collected over a relatively short period of time. For the most part, these data represent current groundwater quality for areas where residential wells are located and in the shallow alluvial zone near the Avoca River. However, prediction of future concentrations, especially over the long time periods is not possible. Groundwater data are used, without modification, to represent both current and potential future exposures. This approach could either under- or overestimate potential mine-related impacts.

This assessment used groundwater data collected in 2007, and for some monitoring wells only dissolved concentrations were available and these data were used to develop EPCs. Data collected in 2008 have been recently made available. Concentrations of COPCs have not changed substantially from November 2007 to February 2008; therefore, incorporating data from February 2008 would not change conclusions of the risk assessment.

7.1.4 Surface Water Data

Surface water sampling efforts focused on areas potentially affected by acid mine drainage. These data are not used to quantitatively evaluate human exposures since human exposure is expected to be infrequent and of short duration.

7.1.5 Air Data

Air data were not collected as part of the Phase 2 Investigation. Possible air concentrations used in the risk assessment were calculated from soil concentrations using a generic particle emission factor. Risk estimates for inhalation of particulates are presented in Appendix C. Risk estimates based on these calculated air concentrations were uniformly low and below levels of regulatory concern. This approach is subject to considerable uncertainty -- wind speeds and direction, dust sources other than the contaminated source, distance to receptors, seasonal variations in winds and temperatures, receptors activities etc. will all affect possible air concentrations. The generic particle emission factor is thought to be appropriate for fairly dusty environments and could substantially overestimate dust loading in Ireland where moist conditions predominate. On the other hand, this factor may

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underestimate dust generation during bicycle and quad bike riding. However, the dust loading factor would need to be orders of magnitude higher for exposure to a recreational visitor to exceed acceptable thresholds.

Surface soil data collected in fields and pastures downwind of spoil piles indicate that large quantities of spoil material have not been deposited in these fields as a result of dust blowing off the spoil piles. This observation suggests that under ambient conditions the inhalation pathway is not a significant exposure pathway for areas adjacent to the site.

7.2 Selection of COPCs

COPCs were selected based on toxicity, nutritional essentiality, and frequency of detection. The COPC screening process is conducted to limit the number of contaminants included in quantitative risk assessment, while also assuring that all significant contaminants are addressed. An initial risk screening was conducted by comparing maximum detected or upper bound chemical concentrations to EPA screening criteria when available and USEPA Region 3 risk-based screening criteria. Use of maximum or upper bound chemical concentrations is likely to result in the selection of chemicals with an overall low likelihood of posing unacceptable risk, rather than elimination of chemicals that could pose significant risk. COPCs retained for evaluation for HHRA were frequently-detected, toxic constituents whose maximum detected concentrations exceeded their respective screening levels. For non-carcinogens, COPCs were selected using a target HQ of 1. Chemicals present at concentrations that exceed screening criteria based on an HQ of 0.1 could, in theory, contribute to unacceptable non-cancer effects through combined exposure to multiple chemicals.

A number of COPCs were eliminated from the various media because they are essential nutrients (i.e., calcium, magnesium, potassium, phosphorous, sodium). Essential nutrients may be associated with adverse health effects, if they are present at high concentrations. There are no criteria that could be used to evaluate inorganic chemicals recognized as essential nutrients; quantitative risk assessment is therefore not possible for these chemicals. However, for the Avoca Mining Site, where relatively high concentrations of relatively toxic chemicals are present, it is considered unlikely that the essential nutrients would contribute significantly to overall risk.

7.3 Exposure Analysis

There are two major areas of uncertainty affecting exposure estimation. The first relates to estimation of EPCs. The second relates to parameter values used to estimate chemical intake (e.g., ingestion rate, exposure frequency).

7.3.1 Exposure Point Concentrations

The methods selected to determine EPCs were based on USEPA guidance (EPA 2007a). These approaches were based on recent recommendations for calculating exposure point concentrations and evaluating non-detect data made by leading

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statisticians in the field and USEPA. The methods used were chosen to provide the best possible estimate of exposure point concentrations for individual exposure areas.

Non-detects can be treated using several approaches for calculating EPC. Any approach dealing with non-detect chemical concentrations is associated with some uncertainty. A non-detect result does not indicate whether the chemical is absent from the medium, present at a concentration just above zero, or present at a concentration just below the detection limit. If sufficient data were available, the 95% UCL or 95th percentile was calculated depending on the frequency of non-detect data in a data set. For chemicals that were infrequently detected, many of the values used to estimate the EPCs were based on detection limits. Typically, in these cases, uncertainty may be high, but detection limits are low compared to concentrations that might be of concern. Thus, the impact of this uncertainty on the results of the risk assessment is minimal.

Due to limitations of the data, the approach used to calculate EPCs for some media may overestimate potential exposures and thus risks. Since the 95% UCL can be highly unstable from a mathematical standpoint, and is strongly influenced by the sample size and the variability of the chemical concentrations, the approach to estimating EPCs can result in the default use of the maximum detected concentration. This default was the case for groundwater and surface soil field/pasture EPCs. Use of maximum may have had a substantial impact on estimated risks or hazards for these exposure mediums.

7.3.1.1 Exposure Point Concentrations Based on Current Conditions Used to Estimate Future Exposures

Another assumption made in this assessment is that exposure to COPCs in various media remains constant over time. Thus, the assessment assumes that contaminant concentrations will neither increase nor decrease over time. In reality, COPC concentrations in dynamic systems change over time. Some processes, such as erosion and leaching, may lead to decreasing or increasing concentrations. Other processes, such increased acid rock drainage, could in theory cause some increases in concentrations. Future concentrations of COPCs in groundwater, surface water, and sediment in particular may vary substantially over time, which may result in exposures lower or higher than those calculated in this assessment. COPC concentrations in soil and waste piles may not be subject to as much uncertainty in the future, since many COPCs are relatively stable in soil and waste piles.

The magnitude of uncertainties associated with estimation of future EPCs cannot be ascertained with available data and analysis.

7.3.2 Exposure Assumptions

Exposure assumptions are generally a large source of uncertainty. Exposure parameters are selected using a combination of available guidance and professional judgment. Both sources of information include considerable uncertainty. Exposure assumptions that are used in the HHRA are generally conservative and are chosen to

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assure that human health is adequately protected. For example, assumptions made for exposure time, frequency, and duration of potential chemical exposures, as well as for the quantity of material ingested, inhaled, or absorbed are all on the high end of those possible; their combination in calculations of exposure is expected to provide an estimate of exposure well above the average. In general, assumptions were made based on RME and, in most cases, values were based on general USEPA guidance documents. RME is expected to fall within the high range of possible exposure and exposures estimated in this risk assessment are expected to have met that goal. In some cases, as discussed below, exposures can be viewed as ceiling values and may have exceeded the goal for RME.

7.3.2.1 Uncertainties Associated with Arsenic and Lead Bioavailability

Bioavailability of arsenic and lead in mine wastes is a critical issue for appropriate assessment of potential exposure. Site specific bioavailability measurements for arsenic and lead were conducted for spoils which reduces the uncertainty in exposure estimates for these COPCs.

The 95% UCL of relative bioavailability estimate for arsenic in each EA was used to estimate risk associated with exposure to arsenic in soil. The oral CSF and RfD for arsenic were derived based on an epidemiological study of a group of people who were exposed to high levels of soluble arsenic in food and water. Arsenic ingested from soil is less well absorbed and absorption in the GI tract can be adjusted with a lower bioavailability factor.

The 95% UCL of absolute bioavailability estimates for lead in each EA was used to evaluate exposure to lead in soil. For EA-6 one bioavailability estimate appears to be an anomaly; therefore, hazards were evaluated with and without this value.

7.3.2.2 Uncertainties Associated with Exposure Scenarios and Assumptions

Exposure assumptions are generally a large source of uncertainty. Exposure parameters are selected using a combination of available guidance and professional judgment. Both sources of information include considerable uncertainty. Exposure assumptions that are used in the HHRA are generally conservative and are chosen to assure that human health is adequately protected. For example, assumptions made for exposure time, frequency, and duration of potential chemical exposures, as well as for the quantity of material ingested, inhaled, or absorbed are all on the high end of those possible; their combination in calculations of exposure is expected to provide an estimate of exposure well above the average. In general, assumptions were made based on RME and, in most cases, values were based on general USEPA guidance documents. RME is expected to fall within the high range of possible exposure and exposures estimated in this risk assessment are expected to have met that goal. In some cases, as discussed below, exposures can be viewed as ceiling values and may have exceeded the goal for RME.

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Recreational Scenario

Exposure pathways potentially complete for recreational visitors which were evaluated quantitatively included: incidental ingestion of and dermal contact with soil and inhalation of particulates. Exposure pathways potentially complete for recreational visitors which were evaluated qualitatively include: incidental ingestion of and dermal contact with surface water and sediment, ingestion of fish, and ingestion of game.

Actual recreation activities are very difficult to predict, especially for future conditions. The assessment for possible recreational exposures is based on the concept of screening. In a screening evaluation, exposure parameters are chosen to assure that exposure estimates are at or above any exposures that are likely to actually occur. Risks and hazards for recreational visitors can be assumed to be ceiling values that will overestimate threats to human health. Where such estimates are below levels of concern, no action is necessary to protect visitors to the site.

Site observations indicate that recreational visitors are not generally exposed to surface water and sediment in the vicinity of the Avoca Mining Site. Many surface water bodies evaluated in this assessment would not be attractive for recreational activities, for example adits. Canoeing has been observed on the Avoca River; however, people are not expected to be exposed to contaminants in surface water for a significant period of time.

Recreational fishing occurs in some areas of the Avoca River; however, as discussed in Section 5.3.5, there are insufficient number of fish caught in the study area to support quantitative evaluation.

7.4 Toxicological Data

A potentially large source of uncertainty is inherent in the derivation of toxicity criteria (i.e., RfDs, and cancer slope factors). In many cases, data must be extrapolated from animals to sensitive humans by the application of uncertainty factors to an estimated no-observed-adverse-effect-level or lowest-observed adverse effects level for non-cancerous effects. While designed to be protective, in many cases uncertainty factors can overestimate the magnitude of differences that may exist between humans and animals, and among humans. Alternatively, toxicity criteria may be based on studies that did not detect the most sensitive adverse effects. For example, many past studies have not measured possible toxic effects on the immune system. Moreover, some chemicals may cause subtle effects not easily recognized in animal studies. The effects of lead on cognitive function and behavior at very low levels of exposure serve as examples.

Additional uncertainty exists in the derivation of cancer slope factors, which often involves linear extrapolation of effects at high doses to potential effects at lower doses commonly seen in environmental exposure settings. Currently, it is not known whether linear extrapolation is appropriate. In all likelihood, the shape of the dose response curve for carcinogenesis varies with different chemicals and mechanisms of

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action. The dose-response analysis involves the estimation of the toxicological effects of a compound on humans usually based upon laboratory animal studies. A potentially significant source of uncertainty occurs when dose-response relationships in humans are derived from animal to human via extrapolation. In addition, dose-response relationships are often a result from high-dose to low-dose extrapolations, which is also another source of uncertainty. It is not possible at this time to describe such differences in quantitative terms. It is likely that the assumption of linearity is conservative and yields CSFs that are unlikely to lead to underestimation of risks. Yet, for specific chemicals, current methodology could cause CSFs and, hence, risks to be underestimated.

Use of the USEPA toxicity criteria could either overestimate or underestimate potential risks, but it is difficult to determine either the direction or magnitude of any errors. In general, however, it is likely that the criteria err on the side of protectiveness for most chemicals. For example use of CSFs for arsenic, especially the oral CSF based on exposure of a large Taiwanese population to dissolved arsenic in drinking water, is controversial. Some evidence exists that metabolism of arsenic in the body may greatly reduce possible cancer risks at lower levels of exposure.

The ability to evaluate the risks associated with lead are limited because neither a CSF nor an RfD is available for lead. Instead, the accepted approach is to screen the lead results against established benchmarks. The IEUBK model is used to evaluate hazards for young children. The adult lead model is used to evaluate recreational exposures. Use of these models to evaluate exposure to lead in soil is considered protective for young children (residents) and older children and adults (recreational visitors).

7.5 Risk Characterization

Risk assessment guidance (USEPA 1989) stresses the importance of considering uncertainties in interpreting and applying results of any risk assessment. As a result of the uncertainties, this risk assessment should not be construed as presenting absolute risks or hazards. Rather, it is a conservative analysis intended to indicate the potential for adverse impacts to occur based on reasonable maximum and average exposures. Assumptions are made using best professional judgment and scientific literature on Site risk assessments. In general, assumptions made throughout this risk assessment are conservative in that they tend to overestimate exposure and resultant risk rather than underestimate it. The overall risk to public health attributable to the Site is an upper-bound probability of adverse health effects; true health effects may be lower.

Exposure to Chemical Mixtures
In this assessment, the effects of exposure to each COPC have initially been considered separately; however, these substances occur together at the Site, and individuals may be exposed to mixtures of the chemicals. Prediction of how these mixtures of chemicals will interact would best be based on an understanding of the mechanisms of such interactions. However, suitable data are not generally currently available to rigorously characterize the effects of chemical mixtures. Consequently, as

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recommended by USEPA (1989), chemicals present at the Site were assumed to act additively, and potential health risks were evaluated by summing excess lifetime cancer risks and calculating HIs for non-cancer health effects.

This approach to assessing risk associated with mixtures of chemicals assumes that there are no significant synergistic or antagonistic interactions among the chemicals, and that for non-cancer effects, chemicals that affect the same target organ or tissue will also target similar biochemical processes. To the extent that these assumptions are incorrect, actual risks could be either under- or overestimated.

Land Use

Uncertainty exists in the assumption of future recreational and commercial/industrial land use at the Site. Risk and hazards were conservatively developed for all exposure areas; some of these areas may never be redeveloped or used for the specific exposure scenario evaluated.

Homegrown produce is currently not a complete exposure pathway for nearby residents; there is a possibility for this pathway to be complete in the future. Plant bioaccumulation studies conducted for the ERA indicate that accumulation of mine-site related contaminants in nearby areas is not significant which suggests that if homeowners were to grow produce for consumption in the future unacceptable risks would not be expected.

7.6 Uncertainties Associated with PRGs

Uncertainties in the development of PRGs reflect uncertainties discussed above for other aspects of the risk assessment process. Overall, development of PRGs is intended to provide a range of possibilities that the risk manager can use to address risks and hazards at the site. This range allows the risk manager to select targets for remediation that reflect both quantitative and qualitative (uncertainty) aspects of the assessment. The calculations used for the risk calculations were designed to provide conservative RME risk and hazard estimates. Any of the calculated PRGs could be used with confidence to protect people potentially exposed to Site related contamination.

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Section 8
Summary

The Phase 2 HHRA performed for the Avoca Mining Site addresses potential hazards to human health associated with current conditions at the Site in the absence of any remedial actions. This Phase 2 HHRA builds upon the Preliminary Phase 1 HHRA data, assumptions, and results primarily by incorporating additional analytical data collected in order to perform quantitative risk assessment. The analysis, results, and conclusions presented in this assessment provide a basis for evaluating the nature and magnitude of human health risks potentially associated with exposure to mine related contamination at the Site. This information can, in turn, be used to identify areas or exposure pathways of potential concern and to determine the need for risk management measures. In general, this risk assessment is focused on providing a conservative estimate of risk for the Avoca Mining Site. A number of assumptions and uncertainties likely to overestimate rather than underestimate risks are made throughout the risk assessment process.

Risk Assessment Approach
Risk assessment is a tool used to evaluate the likelihood and degree of chemical exposure and the possible adverse health effects associated with such exposure. The overall approach for the HHRA follows guidance and recommendations provided in the Final Report of Expert group for Silvermines County Tipperary (EPA 2004) and in Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part A) (USEPA 1989), subsequent United States EPA (USEPA) supplemental risk assessment guidance documents and other guidance, literature, or site-specific information as appropriate. Based on site-specific data the HHRA:

- Identifies COPCs associated with historical releases at the site

- Evaluates potential exposure pathways by which people may contact COPCs at the site

- Assesses toxicity of COPCs

- Combines toxicity information with exposure assumptions to estimate potential carcinogenic and non-carcinogenic health risks

- Provides PRGs to assist in the preliminary evaluation of remedial alternatives

- Identifies important uncertainties that may influence the ability to assess human health risk

Steps conducted for the human health risk are summarized in the following sections. Conclusions and recommendations based on the HHRA findings are also discussed in this section.

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Selection of Chemicals of Potential Concern (COPCs)

This HHRA identifies COPCs associated with releases of mining-related contaminants that may result in adverse effects to people who live, work, or recreate in or near the study area currently or in the future. Identification of COPCs is based on comparison of measured concentrations of all constituents in the various Site media to conservative EPA or USEPA risk-based screening levels and/or commonly accepted benchmarks approved by EPA for screening purposes. Screening levels are conservative risk-based or other estimated concentrations that, if not exceeded, would be protective for human receptors under all possible chronic exposure conditions. Screening levels are generally based on potential cancer and non-cancer effects to humans and are constituent-specific and media-specific. COPCs are retained for further risk evaluation when measured maximum concentrations exceed their respective screening level.

COPCs were identified for surface soil/spoils, groundwater, surface water, and sediment. Surface soil/spoils COPCs are: antimony, arsenic, cobalt, copper, iron, lead, manganese, thallium, and vanadium. Groundwater COPCs for the homeowner wells are: aluminum and iron. COPCs for shallow alluvial groundwater are aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc. COPCs selected for sediment are: arsenic, iron, lead and manganese. COPCs for rivers and tributaries include: aluminum, iron, lead and manganese. In the second category of surface water (i.e., adits, etc.) COPCs include: aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc. Chemicals detected in surface water that are potential COPCs due to bioconcentration potential in fish include: cadmium, copper, lead, manganese, nickel, and zinc.

Assessment of Potential Receptors and Exposure Pathways

Potential receptor populations at or near the mine site and potential exposure pathways for these populations were identified based on current and potential future land use. Populations that could theoretically be exposed to contaminants from the mine site may include: current and future recreational visitors, nearby current and future residents, future onsite commercial/industrial workers, and future construction workers. Potential exposure pathways include: incidental ingestion of and dermal contact with soil, spoils, and inhalation of particulates in ambient air. Nearby residents may be exposed to contaminants in groundwater. Recreational visitors may also have limited exposure to contaminants in surface water and sediment.

Exposure Areas

Exposure areas were identified for the HHRA to estimate potential risks to receptors within specific areas based on concentrations of COPCs in media of concern. The primary criteria for designation of specific exposure areas (EAs) are the magnitude and distribution of COPCs, known or suspected contaminant source areas, as well as receptor behavior. Exposure areas were identified for soil/ spoils, groundwater, surface water and sediment.

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Seven EAs were identified for spoil piles including: EA-1 (Connary), EA-2 (Mount Platt/Cronebane), EA-3 (East Avoca/Tigroney West), EA-4 (Ore Bins, areas at Tigroney West), EA-5 (Deep Adit Area), EA-6 (West Avoca), and EA-7 (Shelton Abbey). Several fields and pastures in the vicinity of the site were designated as unique EAs. Some of these fields are downwind of spoil piles.

Groundwater is grouped into two exposure areas homeowner "wells" and shallow alluvial aquifer wells (monitoring wells).

Surface water is grouped into two major categories: 1) rivers and tributaries and 2) adits, springs, and miscellaneous surface waters. For the HHRA, the Avoca River and its tributaries are considered as one exposure unit from above Whitesbridge to Arklow. The reference area for the Avoca River includes from above Meeting of the Waters (Ballinacleish Bridge and Lions Bridge) downstream to above Whitesbridge. Adits, springs, and miscellaneous surface water bodies are evaluated as one exposure group. Sediment exposure areas follow the same grouping as surface water exposure areas.

Exposure Point Concentrations

Exposure point concentrations (EPCs) representative of concentrations of chemical at points of potential human contact with the environmental media of interest were calculated using ProUCL 4.0 and site specific data. In this assessment, ingestion, dermal contact, and inhalation exposures are estimated using soil and groundwater analytical data. EPCs for air are estimated from COPC concentrations in soil.

Toxicity Assessment

The toxicity assessment provides qualitative and quantitative descriptions of potential health impacts of COPCs. The toxicity assessment provides chemical-specific information that can be used along with estimates of exposure to estimate possible cancer risks and non-cancer health hazards.

Bioaccessibility Estimates

Bioavailability analyses for arsenic and lead were performed on representative spoil samples using (1) in vitro analysis of bioavailability of lead and arsenic in soils/mine waste, and (2) electron microprobe analysis of lead and arsenic speciation in soils/mine waste. Bioavailability is an estimate of the amount of lead or arsenic that might be absorbed from the GI tract after ingestion of soil. Bioavailability of arsenic and lead at the site was found to be relatively low and is not directly related to the soil concentration (i.e., a higher soil concentration does not equate with a higher bioavailability).

Bioavailability of lead as assessed in the in vitro assays for the Site show relatively low bioavailability, significantly below the IEUBK default (30 percent). Absolute bioavailability estimates for lead ranged from 1 to 13 percent and averaged about 3 percent. Arsenic bioavailability for mine wastes at the Site appear to be significantly

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less than the USEPA default value of 80 percent. In vitro bioavailability results for arsenic range from 0 to 8 percent.

Risk Characterization
Cancer Risk
Cancer risk is estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a known, probable, or possible carcinogen. Excess lifetime cancer risks are generally expressed in scientific notation as incremental probabilities. An excess lifetime cancer risk of 1×10^{-6} (one in one million), for example, represents the incremental probability that an individual will develop cancer as a result of exposure to a carcinogenic chemical over a 70-year lifetime under specified exposure conditions. This increment is in addition to the risk of developing cancer from causes unrelated to the exposure.

Using RME assumptions, the total excess lifetime cancer risks for all receptors exposed to contamination in soil, do not exceed the EPA threshold of 1×10^{-4} for cancer risks. Cancer risk is due to exposure to arsenic and site-specific bioavailability analyses have shown that arsenic in soil at the Site is in a relatively inaccessible form.

Carcinogens were not reported above detection limits in homeowner wells. If shallow groundwater near the Site was used as a potable water source in the future, cancer risk could exceed acceptable thresholds.

Non-cancer Health Hazards
The potential for non-cancer health effects is evaluated by comparing average daily doses with reference doses (RfDs) applicable for chronic (long-term) exposure. The ratio of exposure to toxicity is referred to as a hazard quotient (HQ). The HQ is a unitless ratio of a receptor's exposure level (or dose) to the "acceptable" (or allowable) exposure level. A hazard index (HI) is a summation of HQs for a particular pathway or from several pathways. If the HI exceeds 1, further evaluation is required. Generally, the greater the HI above unity, the greater the level of concern.

Total HIs for receptors exposed to contaminants in soil were below the USEPA threshold of one for all receptors except the nearby child resident. For this receptor, the HI was only slightly above one and was due to exposure to manganese and vanadium at background levels. For the future commercial/industrial workers, the total HI is slightly above one for EA-5 (Deep Adit Area); however, the HI based on toxic endpoints is below one.

HIs for residents using groundwater from homeowner's wells near the Site as a potable water source also were below the EPA threshold of one for non-cancer effects at all locations sampled. If shallow groundwater near the Site was used as a potable water source in the future, non-cancer health hazards could exceed acceptable thresholds.

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Lead Exposures

Risks from exposure to lead cannot be assessed using standard methods because toxicological criteria for lead are not available. USEPA's position is that current data are insufficient to determine an RfD or RfC for lead. USEPA feels that the primary threat to human health from exposure to lead is subtle neurological effects in young children. For this reason, USEPA has not derived a CSF for lead.

The IEUBK model (Version 1.0) is used to evaluate potential risks for nearby residents from exposure to lead associated with the Avoca Mining Site. Exposure to lead is evaluated for surface soil media for which lead was selected as a COPC. The Adult Lead Model was used to assess non-residential (i.e., recreational, commercial/ industrial workers and construction workers) exposures to lead. Results of these analyses are discussed in the following sections.

Site–specific bioavailability estimates for lead are relatively low for all EAs suggesting that exposure to lead in soil may not be of concern in most EAs. However potential exposure to lead in soil by recreational visitors may be of concern in two EAs, EA-1 (Connary) and EA-4 (Ore bins Tigroney West). Future commercial/industrial workers may be exposed to lead in spoil exposure areas EA-1 (Connary), EA-4 (Ore bins Tigroney West) and EA-6 (West Avoca) at levels associated with adverse health effects. Lead levels of concern for future construction workers exposed to spoils may exist in EA-1 (Connary), EA-3 (East/Avoca/Tigroney West), EA-4 (Ore bins Tigroney West) and EA-6 (West Avoca).

A range of site-specific bioavailability estimates for spoil piles were used to evaluate lead exposures for nearby residents. The assumption was made that the source of lead in nearby fields and pastures could potentially be from wind blown deposition of spoil material. The analyses also included the IEUBK default bioavailability estimate for lead of 30 percent. Results of this analysis using more representative bioavailability estimates indicate that lead levels in nearby soils are below levels of concern for a young child based on the available data.

Uncertainties

Uncertainties are inherent in the risk assessment process because of the numerous assumptions that are made in estimating exposure, toxicity, and potential risk. Conservative assumptions are made at every step of the process in the HHRA so as not to underestimate potential risk. As a result of the uncertainties, the risk assessment should not be construed as presenting absolute risks or hazards. Rather, it is a conservative analysis intended to indicate the potential for adverse impacts to occur based on reasonable maximum and typical (central tendency) exposures.

Remediation Goals

Remediation goals were estimated for recreational exposures to help address community concerns for children recreating on the site. The analysis indicates that exposure to lead in soil in some areas of the Avoca Mining Site may be of concern for recreational visitors. A summary of remediation goals is provided in Table 8-1.

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Table 8-1 Summary of Human Health Risk-Based Cleanup Levels for Spoils/Soils. Avoca Mine Site

Chemical of Potential Concern	Target Risk or HI	Cleanup Level for Spoils (mg/kg)			Cleanup Level for Soils (mg/kg)
		Recreational Visitor [1]	Commercial/ Industrial Worker	Construction Worker	Resident
Arsenic	1×10^{-6}	571	221	3,925	134
Antimony	1	772	409	235	31
Cobalt	1	37,348	13,345	10,103	1,381
Copper	1	77,212	40,880	23,462	3,129
Iron	1	100,000 (2)	715,400	410,583	54,750
Lead	(3)	10,012	4,165	2,427	2,671
Manganese	1	38,604	20,429	11,729	1,564
Thallium	1	147	78	45	6
Vanadium	1	1,930	1,022	587	78

(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children

(2) PRG is a ceiling limit equivalent to a chemical representing 10% by weight of the soil sample. The risk based PRG exceeds unity (>1,000,000 mg/kg) which is not possible.

(3) PRGs for all receptors except residents were calculated using the USEPA Adult Lead Model, based on 95%UCL of absolute bioavailability estimate for all exposure areas (3.95%). The PRG for residents was calculated using the USEPA IEUBK model for young children.

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Appendix A
Bioavailability Analyses

TABLE 1. Preliminary Summary Of In Vitro Bioassay Results for Arsenic

Exposure Area	Sample ID	As in <250u bulk soil ug/kg	As in <250u bulk soil mg/kg	mass soil (g)	calc As #1	ICP As (mg/l)	solution amt (l)	% Relative As Bioavailability	mg/kg
EA-1	SP25 (0,0)	1189387.202	1,189	1.00628	1196.86	5.648	0.1	0.05	**0.561**
EA-1	SP25 (0,1)	625219	625	1.00627	629.14	37.559	0.1	0.60	**3.732**
EA-1	SP25 (0,-1)	1038130.689	1,038	1.00359	1041.86	44.6755	0.1	0.43	**4.452**
EA-1	SP25 (0,-2)	2525360.993	2,525	1.00601	2540.54	38.6	0.1	0.15	**3.837**
EA-1	SP25 (1,0)	1452031.794	1,452	1.00506	1459.38	19.683	0.1	0.13	**1.958**
EA-1	SP25 (-1,0)	975154.4255	975	1.00847	983.41	-2.023	0.1	-0.02	**-0.201**
EA-1	SP31 (0,1)	2169502.922	2,170	1.00429	2178.81	34.875	0.1	0.16	**3.473**
EA-1	SP31 (0,2)	2560135.908	2,560	1.00284	2567.41	30.3435	0.1	0.12	**3.026**
EA-1	SP31 (1,1)	2007579.456	2,008	1.00079	2009.17	23.956	0.1	0.12	**2.394**
EA-2	SP20 (0,0)	538537.9036	539	1.00169	539.45	7.968	0.1	0.15	**0.795**
EA-2	SP20 (0,-1)	487966.0342	488	1.00633	491.05	-8.839	0.1	-0.18	**-0.878**
EA-2	SP20 (0,2)	653996.443	654	1.00794	659.19	1.7855	0.1	0.03	**0.177**
EA-2	SP20 (0,-2)	676687.6291	677	1.00699	681.42	-0.476	0.1	-0.01	**-0.047**
EA-2	SP20 (0.5, 2)	800936.1427	801	1.00638	806.05	8.1305	0.1	0.10	**0.808**
EA-2	SP20 (1,0.5)	581588.2135	582	1.00223	582.89	3.4475	0.1	0.06	**0.344**
EA-2	SP20 (-1,-2)	461902	462	1.00286	463.22	14.0475	0.1	0.30	**1.401**
EA-2	SP20A (-3,1)	407303.5402	407	1.00885	410.91	5.186	0.1	0.13	**0.514**
EA-3	SP10 (0,2)	130121.0049	130	1.00057	130.20	3.821	0.1	0.29	**0.382**
EA-3	SP4 (0,0)	427236.0426	427	1.00478	429.28	11.4685	0.1	0.27	**1.141**
EA-3	SP5 (0,0)	1035073.915	1,035	1.00705	1042.37	18.9125	0.1	0.18	**1.878**
EA-3	SP5 (0,1)	789057.8	789	1.00262	791.13	0.0965	0.1	0.00	**0.010**
EA-3	SP5 (0,-1)	336143.0797	336	1.00753	338.67	9.1775	0.1	0.27	**0.911**
EA-3	SP5 (-1,0)	706482.5249	706	1.00701	711.43	4.1085	0.1	0.06	**0.408**
EA-4	SP2 (0,0)	1053108.522	1,053	1.00224	1055.47	176.054	0.1	1.67	**17.566**
EA-4	SP2 (1,1)	1122460.664	1,122	1.00619	1129.41	0.499	0.1	0.00	**0.050**
EA-6	SP34 (0,0)	1424211.027	1,424	1.00302	1428.51	1.4315	0.1	0.01	**0.143**
EA-6	SP34 (1,0)	159945.0157	160	1.00557	160.84	4.4345	0.1	0.28	**0.441**
EA-6	SP34 (1,-4)	1611333.549	1,611	1.00068	1612.43	29.639	0.1	0.18	**2.962**
EA-6	SP37 (0,3)	14790.72857	15	1.00366	14.84	11.25	0.1	7.58	**1.121**
EA-6	SP37 (-1,1)	418010.7266	418	1.00509	420.14	36.307	0.1	0.86	**3.612**
EA-6	SP37A (0,0)	346105.8813	346	1.00756	348.72	0.9375	0.1	0.03	**0.093**

Preliminary Summary Of In Vitro Bioassay Results for Lead

Sample ID	Pb in <250u bulk soil ug/kg	Pb in <250u bulk soil mg/kg	mass soil (g)	calc Pb #1	ICP Pb (mg/l)	solution amt (l)	% Relative Pb Bioavailability	% Absolute Pb Bioavailability
SP25 (0,0)	28,755,373	28,755	1.00628	28,936	6418	0.1	2.22	1.1
SP25 (0,1)	7,896,351	7,896	1.00627	7,946	7531	0.1	9.48	4.7
SP25 (0,-1)	55,523,413	55,523	1.00359	55,723	122530	0.1	21.99	11.0
SP25 (0,-2)	56,021,770	56,022	1.00601	56,358	59675	0.1	10.59	5.3
SP25 (1,0)	35,527,421	35,527	1.00506	35,707	42919	0.1	12.02	6.0
SP25 (-1,0)	29,192,732	29,193	1.00847	29,440	8925	0.1	3.03	1.5
SP31 (0,1)	41,434,927	41,435	1.00429	41,613	50365	0.1	12.10	6.1
SP31 (0,2)	37,514,033	37,514	1.00284	37,621	7455	0.1	1.98	1.0
SP31 (1,1)	35,590,883	35,591	1.00079	35,619	37735	0.1	10.59	5.3
SP20 (0,0)	3,301,832	3,302	1.00169	3,307	418	0.1	1.26	0.6
SP20 (0,-1)	3,151,451	3,151	1.00633	3,171	181	0.1	0.57	0.3
SP20 (0,2)	5,523,848	5,524	1.00794	5,568	1128	0.1	2.03	1.0
SP20 (0,-2)	4,773,881	4,774	1.00699	4,807	1235	0.1	2.57	1.3
SP20 (0.5, 2)	8,061,220	8,061	1.00638	8,113	1781	0.1	2.20	1.1
SP20 (1,0.5)	2,877,101	2,877	1.00223	2,884	237	0.1	0.82	0.4
SP20 (-1,-2)	5,397,076	5,397	1.00286	5,413	244	0.1	0.45	0.2
SP20A (-3,1)	3,404,644	3,405	1.00885	3,435	409	0.1	1.19	0.6
SP10 (0,2)	548,547	549	1.00057	549	700	0.1	12.75	6.4
SP4 (0,0)	2,657,083	2,657	1.00478	2,670	1189	0.1	4.45	2.2
SP5 (0,0)	9,815,539	9,816	1.00705	9,885	1825	0.1	1.85	0.9
SP5 (0,1)	9,322,856	9,323	1.00262	9,347	3301	0.1	3.53	1.8
SP5 (0,-1)	2,648,849	2,649	1.00753	2,669	1234	0.1	4.63	2.3
SP5 (-1,0)	7,331,026	7,331	1.00701	7,382	2751	0.1	3.73	1.9
SP2 (0,0)	17,170,325	17,170	1.00224	17,209	4479	0.1	2.60	1.3
SP2 (1,1)	49,540,694	49,541	1.00619	49,847	6360	0.1	1.28	0.6
SP34 (0,0)	1,250,503	1,251	1.00302	1,254	361	0.1	2.88	1.4
SP34 (1,0)	289,392	289	1.00557	291	42	0.1	1.45	0.7
SP34 (1,-4)	1,764,060	1,764	1.00068	1,765	1268	0.1	7.18	3.6
SP37 (0,3)	58,578	59	1.00366	59	164	0.1	27.89	13.9
SP37 (-1,1)	2,452,470	2,452	1.00509	2,465	440	0.1	1.78	0.9
SP37A (0,0)	2,203,550	2,204	1.00756	2,220	32	0.1	0.15	0.1

Appendix B
Exposure Point Concentrations and ProUCL Results

Table 1
Exposure Point Concentration Summary for Surface Spoils and Surface Soil
Avoca Mining Site

| COPC | Exposure Area | | | | | | | Avoca Surface Soil |
| | Avoca Spoils | | | | | | | |
	EA-1	EA-2	EA-3	EA-4	EA-5	EA-6	EA-7 (1)	(Fields and Pastures)
Antimony	19.9	4.1	2.4	20.6	203	6.4	NA	1.9
Arsenic	631	493	535	1,545	1,237	1,622	NA	275.5
Cobalt	0.815	1.84	3.4	5	1,217	12	NA	32.0
Copper	2,673	678	2,227	4,803	1,637	1,174	NA	574.7
Iron	8	7	14	14	224,969	19	NA	11.1
Lead	34,525	13,768	5,221	70,792	10,834	3,808	NA	818.0
Manganese	248	165	601	423	775	839	NA	2,345.0
Thallium	NA	NA	NA	NA	404	NA	NA	NA
Vanadium	10.5	5.5	19.7	15.5	NA	48.2	NA	128.3

Units are mg/Kg

NA= Not available, data are not available to estimate EPC

(1) Surface Data for Spoils were not available for EA-7

Table 2
Exposure Point Concentration Summary for Groundwater (1)
Avoca Mining Site

Chemical		EPC = Maximum Concentration in Homeowner Well Total	EPC = Maximum Concentration in Monitoring Well Total (2) Only 3 results for total	EPC = Maximum Concentration in Monitoring Well Dissolved (3) 12 results for dissolved
Aluminum		1,186	62,440	1,300,000
Arsenic		ND	ND	27
Cadmium		ND	30	294
Chromium		4	4	370
	Chromium III	4	4	370
	Chromium IV	4	4	370
Cobalt		ND	116	1,087
Copper		81	8,028	85,460
Iron		502	1,058	136,000
Lead		3	10	231
Manganese		25	5,537	51,310
Nickel		8	58	575
Zinc		234	9,855	137,700

Units are ug/L

(1) risks and hazards were evaluated based on maximum concentration for all of the above groups of data; due to the small sample the maximum detected concentration is the EPC

(2) Monitoring wells were evaluated separately from homeowner wells since these samples are from shallow groundwater in contaminated areas

(3) Total concentrations in water are normally used to evaluate human health, since so few total results were available form monitoring wells potential risks were also evaluated using dissolved concentrations. (Refer to uncertainty Section of HHRA)

Table 3
Avoca Spoils
Exposure Point Concentration Summary for Surface Spoils

COPC	Number of Detects	Number of Samples	FOD %	Minimum Detected Concentration	Arithmetic Average	Maximum Detected Concentration	95% UCL	Rationale
EA-1	Connnary							
Antimony	18	18	100	0.7	12.8	39.4	19.9	95% Approximate Gamma UCL
Arsenic	18	18	100	64.7	422	962	631	95% Approximate Gamma UCL
Cobalt	13	18	72	0.4	0.8	1.4	0.815	95% KM (Percentile Bootstrap) UCL
Copper	18	18	100	12.6	1,485	6,426	2,673	95% Approximate Gamma UCL
Lead	18	18	100	24.9	17,430	78,441	34,525	95% Approximate Gamma UCL
Vanadium	7	18	39	8.4	14.9	10.9	10.5	95% KM (Percentile Bootstrap) UCL
EA-2	Mount Platt/ Cronebane							
Antimony	24	24	100	1.3	3.6	7.4	4.1	95% Student's-t UCL
Arsenic	24	24	100	5.6	412	747	493	95% Student's-t UCL
Cobalt	22	24	92	0.4	1.6	3.7	1.84	95% KM (BCA) UCL
Copper	24	24	100	149.7	574	1,337	678	95% Student's-t UCL
Lead	24	24	100	156.2	4,274	24,266	13,768	99% Chebyshev (Mean, Sd) UCL
Vanadium	7	24	29	1.2	8.2	15.7	5.5	95% KM (Percentile Bootstrap) UCL
EA-3	East Avoca	Tigroney West						
Antimony	10	10	100	0.9	1.9	3.2	2.4	95% Student's-t UCL
Arsenic	10	10	100	8.1	364	886	535	95% Student's-t UCL
Cobalt	10	10	100	0.6	2	6	3.4	95% Student's-t UCL
Copper	10	10	100	74.0	991	2,912	2,227	95% Approximate Gamma UCL
Lead	10	10	100	58.3	3,385	7,974	5,221	95% Student's-t UCL
Vanadium	4	10	40	1.9	13.1	23.0	19.7	95% KM (Percentile Bootstrap) UCL
EA-4	Ore Bins at	Tigroney West						
Antimony	10	10	100	0.9	9.7	44.1	20.6	95% Approximate Gamma UCL
Arsenic	10	10	100	118.7	814	2,893	1,545	95% Approximate Gamma UCL
Cobalt	10	10	100	0.5	3	9	5	95% Approximate Gamma UCL
Copper	10	10	100	213.6	2,196	11,116	4,803	95% Approximate Gamma UCL
Lead	10	10	100	19.8	19,675	74,877	70,792	95% Adjusted Gamma UCL
Vanadium	7	10	70	2.7	13.3	26.3	15.5	95% KM (Percentile Bootstrap) UCL
EA-5	Deep Adit Area	XRF Data						
Antimony	6	16	38	0.0	67.2	229	203	95% KM (Percentile Bootstrap) UCL
Arsenic	16	16	100	371.91	981.7	2,940	1,237	Use 95% Approximate Gamma UCL
Cobalt	5	16	31	0.0	389.9	1,774	1,217	95% KM (Percentile Bootstrap) UCL
Copper	16	16	100	410.12	1,209.9	3,404	1,637	95% Approximate Gamma UCL
Lead	16	16	100	1128.21	7,845.6	22,877	10,834	95% Approximate Gamma UCL
Thallium	13	16	81	0.0	278.5	949	404	95% KM (BCA) UCL
Vanadium	NA	NA	NA	NA	NA	NA	NA	NA
EA-6	West Avoca							
Antimony	10	10	100	0.2	4.0	19.9	6.4	95% KM (Chebyshev) UCL
Arsenic	36	36	100	12.7	552	1,798	1,622	99% Chebyshev (Mean, Sd) UCL
Cobalt	35	36	97	0.566	6.233	17.64	12	97.5% KM (Chebyshev) UCL
Copper	36	36	100	2.493	399.8	2822	1,174	Use 95% Chebyshev (MVUE) UCL
Lead	36	36	100	5.4	2,165	28,363	3,808	95% Adjusted Gamma UCL
Vanadium	7	10	70	2.7	27.8	179.9	48.2	95% KM (Chebyshev) UCL
EA-7	Shelton Abbey							
	no data	only samples at depth						

Appendix B-1
Exposure Point Concentrations and ProUCL Results
Exposure Area 1, Connary

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 1	General UCL Statistics for Data Sets with Non-Detects, EA-1 Spoils Antimony							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4		Full Precision		OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Sb											
10												
11						General Statistics						
12				Number of Valid Samples		18			Number of Unique Samples		18	
13												
14			Raw Statistics						Log-transformed Statistics			
15				Minimum		0.747			Minimum of Log Data		-0.292	
16				Maximum		39.42			Maximum of Log Data		3.674	
17				Mean		12.8			Mean of log Data		2.048	
18				Median		7.2			SD of log Data		1.118	
19				SD		12.22						
20			Coefficient of Variation			0.955						
21				Skewness		1.119						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test						Lognormal Distribution Test			
25			Shapiro Wilk Test Statistic			0.831			Shapiro Wilk Test Statistic		0.959	
26			Shapiro Wilk Critical Value			0.897			Shapiro Wilk Critical Value		0.897	
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution						Assuming Lognormal Distribution			
30			95% Student's-t UCL			17.81			95% H-UCL		31.22	
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL			31.57	
32			95% Adjusted-CLT UCL			18.35			97.5% Chebyshev (MVUE) UCL		39.28	
33			95% Modified-t UCL			17.94			99% Chebyshev (MVUE) UCL		54.42	
34												
35			Gamma Distribution Test						Data Distribution			
36			k star (bias corrected)			0.983		Data appear Gamma Distributed at 5% Significance Level				
37				Theta Star		13.02						
38				nu star		35.38						
39		Approximate Chi Square Value (.05)				22.77			Nonparametric Statistics			
40			Adjusted Level of Significance			0.0357			95% CLT UCL		17.54	
41			Adjusted Chi Square Value			21.8			95% Jackknife UCL		17.81	
42									95% Standard Bootstrap UCL		17.49	
43			Anderson-Darling Test Statistic			0.405			95% Bootstrap-t UCL		19.2	
44			Anderson-Darling 5% Critical Value			0.764			95% Hall's Bootstrap UCL		18.4	
45			Kolmogorov-Smirnov Test Statistic			0.153			95% Percentile Bootstrap UCL		17.46	
46			Kolmogorov-Smirnov 5% Critical Value			0.209			95% BCA Bootstrap UCL		18.36	
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL		25.35	
48									97.5% Chebyshev(Mean, Sd) UCL		30.78	
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL		41.45	
50			95% Approximate Gamma UCL			19.89						
51			95% Adjusted Gamma UCL			20.77						
52												
53		Potential UCL to Use							Use 95% Approximate Gamma UCL		19.89	
54												

Table 2 | General UCL Statistics for Data Sets with Non-Detects, EA-1 Spoils Arsenic

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

As

General Statistics

Number of Valid Samples	18	Number of Unique Samples	18

Raw Statistics		Log-transformed Statistics	
Minimum	64.68	Minimum of Log Data	4.17
Maximum	961.7	Maximum of Log Data	6.869
Mean	421.6	Mean of log Data	5.626
Median	318.3	SD of log Data	1.013
SD	344.9		
Coefficient of Variation	0.818		
Skewness	0.521		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.845	Shapiro Wilk Test Statistic	0.89
Shapiro Wilk Critical Value	0.897	Shapiro Wilk Critical Value	0.897
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	563.1	95% H-UCL	894.1
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	960.7
95% Adjusted-CLT UCL	566	97.5% Chebyshev (MVUE) UCL	1184
95% Modified-t UCL	564.7	99% Chebyshev (MVUE) UCL	1622

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.152	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	365.9		
nu star	41.48		
Approximate Chi Square Value (.05)	27.72	Nonparametric Statistics	
Adjusted Level of Significance	0.0357	95% CLT UCL	555.4
Adjusted Chi Square Value	26.64	95% Jackknife UCL	563.1
		95% Standard Bootstrap UCL	555.1
Anderson-Darling Test Statistic	0.7	95% Bootstrap-t UCL	576
Anderson-Darling 5% Critical Value	0.76	95% Hall's Bootstrap UCL	553.6
Kolmogorov-Smirnov Test Statistic	0.156	95% Percentile Bootstrap UCL	552.1
Kolmogorov-Smirnov 5% Critical Value	0.208	95% BCA Bootstrap UCL	553.1
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	776
		97.5% Chebyshev(Mean, Sd) UCL	929.4
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1231
95% Approximate Gamma UCL	631		
95% Adjusted Gamma UCL	656.5		
Potential UCL to Use		Use 95% Approximate Gamma UCL	631

		Table 3	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-1 Cobalt				
	User Selected Options						
	From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProUC					
	Full Precision	OFF					
	Confidence Coefficient	95%					
	Number of Bootstrap Operations	2000					

Co

General Statistics

Number of Valid Samples	18	
Number of Unique Samples	13	
Number of Detected Data	13	
Number of Non-Detect Data	5	
Percent Non-Detects	27.78%	

Raw Statistics		Log-transformed Statistics	
Minimum Detected	0.414	Minimum Detected	-0.882
Maximum Detected	1.37	Maximum Detected	0.315
Mean of Detected	0.787	Mean of Detected	-0.29
SD of Detected	0.27	SD of Detected	0.329
Minimum Non-Detect	0.4	Minimum Non-Detect	-0.916
Maximum Non-Detect	0.4	Maximum Non-Detect	-0.916

UCL Statistics

Normal Distribution Test with Detected Values Only		Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.914	Shapiro Wilk Test Statistic	0.974
5% Shapiro Wilk Critical Value	0.866	5% Shapiro Wilk Critical Value	0.866
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
DL/2 Substitution Method		DL/2 Substitution Method	
Mean	0.624	Mean	-0.657
SD	0.353	SD	0.668
95% DL/2 (t) UCL	0.769	95% H-Stat (DL/2) UCL	0.676
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	
Mean	0.617	Mean in Log Scale	-0.514
SD	0.365	SD in Log Scale	0.473
95% MLE (t) UCL	0.767	Mean in Original Scale	0.663
95% MLE (Tiku) UCL	0.776	SD in Original Scale	0.309
		95% Percentile Bootstrap UCL	0.788
		95% BCA Bootstrap UCL	0.798

Gamma Distribution Test with Detected Values Only		Data Distribution Test with Detected Values Only	
k star (bias corrected)	7.733	Data appear Normal at 5% Significance Level	
Theta Star	0.102		
nu star	201.1		
A-D Test Statistic	0.281	Nonparametric Statistics	
5% A-D Critical Value	0.734	Kaplan-Meier (KM) Method	
K-S Test Statistic	0.734	Mean	0.684
5% K-S Critical Value	0.237	SD	0.277
Data appear Gamma Distributed at 5% Significance Level		SE of Mean	0.068
		95% KM (t) UCL	0.802
Assuming Gamma Distribution		95% KM (z) UCL	0.795
Gamma ROS Statistics using Extrapolated Data		95% KM (jackknife) UCL	0.792
Minimum	0.319	95% KM (bootstrap t) UCL	0.807
Maximum	1.37	95% KM (BCA) UCL	0.833
Mean	0.717	95% KM (Percentile Bootstrap) UCL	0.815
Median	0.683	95% KM (Chebyshev) UCL	0.98
SD	0.265	97.5% KM (Chebyshev) UCL	1.108
k star	7.044	99% KM (Chebyshev) UCL	1.36
Theta star	0.102		
Nu star	253.6	Potential UCLs to Use	
AppChi2	217.7	95% KM (t) UCL	0.802
95% Gamma Approximate UCL	0.836	95% KM (Percentile Bootstrap) UCL	0.815
95% Adjusted Gamma UCL	0.848		

Note: DL/2 is not a recommended method.

Table 4 General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-1, Copper

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Cu

General Statistics

Number of Valid Samples	18	Number of Unique Samples	18

Raw Statistics		Log-transformed Statistics	
Minimum	12.64	Minimum of Log Data	2.537
Maximum	6426	Maximum of Log Data	8.768
Mean	1485	Mean of log Data	6.393
Median	966.4	SD of log Data	1.72
SD	1727		
Coefficient of Variation	1.163		
Skewness	1.761		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.801	Shapiro Wilk Test Statistic	0.937
Shapiro Wilk Critical Value	0.897	Shapiro Wilk Critical Value	0.897
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	2193	95% H-UCL	13062
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	6884
95% Adjusted-CLT UCL	2335	97.5% Chebyshev (MVUE) UCL	8905
95% Modified-t UCL	2221	99% Chebyshev (MVUE) UCL	12875

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.594	Data appear Gamma Distributed at 5% Significance Level	
Theta Star	2500		
nu star	21.38		
Approximate Chi Square Value (.05)	11.87	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0357	95% CLT UCL	2154
Adjusted Chi Square Value	11.2	95% Jackknife UCL	2193
		95% Standard Bootstrap UCL	2151
Anderson-Darling Test Statistic	0.186	95% Bootstrap-t UCL	2604
Anderson-Darling 5% Critical Value	0.785	95% Hall's Bootstrap UCL	3355
Kolmogorov-Smirnov Test Statistic	0.12	95% Percentile Bootstrap UCL	2205
Kolmogorov-Smirnov 5% Critical Value	0.213	95% BCA Bootstrap UCL	2330
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	3258
		97.5% Chebyshev(Mean, Sd) UCL	4026
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	5534
95% Approximate Gamma UCL	2673		
95% Adjusted Gamma UCL	2835		
Potential UCL to Use		Use 95% Approximate Gamma UCL	2673

	Table 5	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-1, Iron	

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Fe

General Statistics

Number of Valid Samples	18	Number of Unique Samples	18

Raw Statistics		Log-transformed Statistics	
Minimum	0.979	Minimum of Log Data	-0.0215
Maximum	11.15	Maximum of Log Data	2.411
Mean	6.826	Mean of log Data	1.788
Median	7.524	SD of log Data	0.618
SD	2.838		
Coefficient of Variation	0.416		
Skewness	-0.542		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.959	Shapiro Wilk Test Statistic	0.815
Shapiro Wilk Critical Value	0.897	Shapiro Wilk Critical Value	0.897
Data appear Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	7.989	95% H-UCL	9.984
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	11.91
95% Adjusted-CLT UCL	7.835	97.5% Chebyshev (MVUE) UCL	13.97
95% Modified-t UCL	7.975	99% Chebyshev (MVUE) UCL	18.01

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	3.308	Data appear Normal at 5% Significance Level	
Theta Star	2.063		
nu star	119.1		
Approximate Chi Square Value (.05)	94.89	Nonparametric Statistics	
Adjusted Level of Significance	0.0357	95% CLT UCL	7.926
Adjusted Chi Square Value	92.82	95% Jackknife UCL	7.989
		95% Standard Bootstrap UCL	7.892
Anderson-Darling Test Statistic	0.775	95% Bootstrap-t UCL	7.843
Anderson-Darling 5% Critical Value	0.743	95% Hall's Bootstrap UCL	7.83
Kolmogorov-Smirnov Test Statistic	0.195	95% Percentile Bootstrap UCL	7.894
Kolmogorov-Smirnov 5% Critical Value	0.205	95% BCA Bootstrap UCL	7.832
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	9.741
		97.5% Chebyshev(Mean, Sd) UCL	11
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	13.48
95% Approximate Gamma UCL	8.566		
95% Adjusted Gamma UCL	8.757		
Potential UCL to Use		Use 95% Student's-t UCL	7.989

Table 6 General UCL Statistics for Data Sets with Non-Detects, EA-1 Spoils Lead

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Data.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Pb

General Statistics

Number of Valid Samples	18	Number of Unique Samples	18

Raw Statistics		Log-transformed Statistics	
Minimum	24.92	Minimum of Log Data	3.216
Maximum	78441	Maximum of Log Data	11.27
Mean	17430	Mean of log Data	8.518
Median	6994	SD of log Data	2.12
SD	22219		
Coefficient of Variation	1.275		
Skewness	1.609		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.781	Shapiro Wilk Test Statistic	0.932
Shapiro Wilk Critical Value	0.897	Shapiro Wilk Critical Value	0.897
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	26540	95% H-UCL	497288
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	125241
95% Adjusted-CLT UCL	28166	97.5% Chebyshev (MVUE) UCL	164468
95% Modified-t UCL	26871	99% Chebyshev (MVUE) UCL	241523

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.46	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	37875		
nu star	16.57		
Approximate Chi Square Value (.05)	8.364	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0357	95% CLT UCL	26044
Adjusted Chi Square Value	7.808	95% Jackknife UCL	26540
		95% Standard Bootstrap UCL	25917
Anderson-Darling Test Statistic	0.241	95% Bootstrap-t UCL	30833
Anderson-Darling 5% Critical Value	0.799	95% Hall's Bootstrap UCL	31617
Kolmogorov-Smirnov Test Statistic	0.147	95% Percentile Bootstrap UCL	26303
Kolmogorov-Smirnov 5% Critical Value	0.215	95% BCA Bootstrap UCL	28353
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	40258
		97.5% Chebyshev(Mean, Sd) UCL	50136
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	69538
95% Approximate Gamma UCL	34525		
95% Adjusted Gamma UCL	36982		
Potential UCL to Use		Use 95% Approximate Gamma UCL	34525

Table 7 General UCL Statistics for Data Sets with Non-Detects, Spoils EA-1 Manganese

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Mn

General Statistics

Number of Valid Samples	18	Number of Unique Samples	18

Raw Statistics		Log-transformed Statistics	
Minimum	13.68	Minimum of Log Data	2.616
Maximum	443.4	Maximum of Log Data	6.095
Mean	192.1	Mean of log Data	4.887
Median	178.5	SD of log Data	1.044
SD	137.3		
Coefficient of Variation	0.715		
Skewness	0.578		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.923	Shapiro Wilk Test Statistic	0.884
Shapiro Wilk Critical Value	0.897	Shapiro Wilk Critical Value	0.897
Data appear Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	248.4	95% H-UCL	455.2
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	481.2
95% Adjusted-CLT UCL	250.1	97.5% Chebyshev (MVUE) UCL	594.7
95% Modified-t UCL	249.2	99% Chebyshev (MVUE) UCL	817.5

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.282	Data appear Normal at 5% Significance Level	
Theta Star	149.9		
nu star	46.14		
Approximate Chi Square Value (.05)	31.55	Nonparametric Statistics	
Adjusted Level of Significance	0.0357	95% CLT UCL	245.4
Adjusted Chi Square Value	30.4	95% Jackknife UCL	248.4
		95% Standard Bootstrap UCL	242.2
Anderson-Darling Test Statistic	0.394	95% Bootstrap-t UCL	253.3
Anderson-Darling 5% Critical Value	0.756	95% Hall's Bootstrap UCL	249.5
Kolmogorov-Smirnov Test Statistic	0.127	95% Percentile Bootstrap UCL	244.5
Kolmogorov-Smirnov 5% Critical Value	0.207	95% BCA Bootstrap UCL	251.6
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	333.2
		97.5% Chebyshev(Mean, Sd) UCL	394.2
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	514.1
95% Approximate Gamma UCL	280.9		
95% Adjusted Gamma UCL	291.6		
Potential UCL to Use		Use 95% Student's-t UCL	248.4

	Table7	General UCL Statistics for Data Sets with Non-Detects, EA-1 Spoils Vanadium								

Table7 General UCL Statistics for Data Sets with Non-Detects, EA-1 Spoils Vanadium

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

V

General Statistics

Number of Valid Samples	18	Number of Detected Data	7
Number of Unique Samples	7	Number of Non-Detect Data	11
		Percent Non-Detects	61.11%

Raw Statistics		Log-transformed Statistics	
Minimum Detected	8.43	Minimum Detected	2.132
Maximum Detected	14.89	Maximum Detected	2.701
Mean of Detected	10.89	Mean of Detected	2.363
SD of Detected	2.704	SD of Detected	0.237
Minimum Non-Detect	8	Minimum Non-Detect	2.079
Maximum Non-Detect	8	Maximum Non-Detect	2.079

UCL Statistics

Normal Distribution Test with Detected Values Only		Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.831	Shapiro Wilk Test Statistic	0.851
5% Shapiro Wilk Critical Value	0.803	5% Shapiro Wilk Critical Value	0.803
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
DL/2 Substitution Method		DL/2 Substitution Method	
Mean	6.681	Mean	1.766
SD	3.813	SD	0.51
95% DL/2 (t) UCL	8.245	95% H-Stat (DL/2) UCL	7.5
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	
Mean	6.73	Mean in Log Scale	1.878
SD	4.28	SD in Log Scale	0.479
95% MLE (t) UCL	8.485	Mean in Original Scale	7.283
95% MLE (Tiku) UCL	9.261	SD in Original Scale	3.531
		95% Percentile Bootstrap UCL	8.691
		95% BCA Bootstrap UCL	8.864

Gamma Distribution Test with Detected Values Only		Data Distribution Test with Detected Values Only	
k star (bias corrected)	11.68	Data appear Normal at 5% Significance Level	
Theta Star	0.933		
nu star	163.5		
A-D Test Statistic	0.586	Nonparametric Statistics	
5% A-D Critical Value	0.707	Kaplan-Meier (KM) Method	
K-S Test Statistic	0.707	Mean	9.388
5% K-S Critical Value	0.311	SD	1.97
Data appear Gamma Distributed at 5% Significance Level		SE of Mean	0.502
		95% KM (t) UCL	10.26
Assuming Gamma Distribution		95% KM (z) UCL	10.21
Gamma ROS Statistics using Extrapolated Data		95% KM (jackknife) UCL	10.13
Minimum	6.972	95% KM (bootstrap t) UCL	11.2
Maximum	15.55	95% KM (BCA) UCL	10.72
Mean	11.77	95% KM (Percentile Bootstrap) UCL	10.5
Median	11.8	95% KM (Chebyshev) UCL	11.57
SD	2.719	97.5% KM (Chebyshev) UCL	12.52
k star	15.59	99% KM (Chebyshev) UCL	14.38
Theta star	0.755		
Nu star	561.3	Potential UCLs to Use	
AppChi2	507.4	95% KM (t) UCL	10.26
95% Gamma Approximate UCL	13.02	95% KM (Percentile Bootstrap) UCL	10.5
95% Adjusted Gamma UCL	13.15		

Note: DL/2 is not a recommended method.

Appendix B-2
Exposure Point Concentrations and ProUCL Results
Exposure Area 2, Mount Platt/Cronebane

Table 1	General UCL Statistics for Data Sets with Non-Detects, EA-2, Spoils, Antimony

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Sb

General Statistics

Number of Valid Samples	24	Number of Unique Samples	24

Raw Statistics		Log-transformed Statistics	
Minimum	1.29	Minimum of Log Data	0.255
Maximum	7.445	Maximum of Log Data	2.008
Mean	3.58	Mean of log Data	1.194
Median	3.691	SD of log Data	0.43
SD	1.417		
Coefficient of Variation	0.396		
Skewness	0.667		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.952	Shapiro Wilk Test Statistic	0.944
Shapiro Wilk Critical Value	0.916	Shapiro Wilk Critical Value	0.916
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	4.075	95% H-UCL	4.295
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	5.023
95% Adjusted-CLT UCL	4.097	97.5% Chebyshev (MVUE) UCL	5.637
95% Modified-t UCL	4.082	99% Chebyshev (MVUE) UCL	6.844

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	5.538	Data appear Normal at 5% Significance Level	
Theta Star	0.646		
nu star	265.8		
Approximate Chi Square Value (.05)	229.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0392	95% CLT UCL	4.055
Adjusted Chi Square Value	226.7	95% Jackknife UCL	4.075
		95% Standard Bootstrap UCL	4.053
Anderson-Darling Test Statistic	0.405	95% Bootstrap-t UCL	4.123
Anderson-Darling 5% Critical Value	0.746	95% Hall's Bootstrap UCL	4.195
Kolmogorov-Smirnov Test Statistic	0.125	95% Percentile Bootstrap UCL	4.069
Kolmogorov-Smirnov 5% Critical Value	0.178	95% BCA Bootstrap UCL	4.122
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	4.84
		97.5% Chebyshev(Mean, Sd) UCL	5.386
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	6.457
95% Approximate Gamma UCL	4.154		
95% Adjusted Gamma UCL	4.198		
Potential UCL to Use		Use 95% Student's-t UCL	4.075

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 2	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-2 Arsenic							
2	User Selected Options											
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	As											
10												
11						General Statistics						
12				Number of Valid Samples		24			Number of Unique Samples			24
13												
14			Raw Statistics						Log-transformed Statistics			
15				Minimum		5.594			Minimum of Log Data			1.722
16				Maximum		746.5			Maximum of Log Data			6.615
17				Mean		411.9			Mean of log Data			5.666
18				Median		450.3			SD of log Data			1.154
19				SD		231.2						
20			Coefficient of Variation			0.561						
21				Skewness		-0.444						
22												
23						Relevant UCL Statistics						
24		Normal Distribution Test							Lognormal Distribution Test			
25			Shapiro Wilk Test Statistic			0.92			Shapiro Wilk Test Statistic			0.742
26			Shapiro Wilk Critical Value			0.916			Shapiro Wilk Critical Value			0.916
27		Data appear Normal at 5% Significance Level							Data not Lognormal at 5% Significance Level			
28												
29		Assuming Normal Distribution							Assuming Lognormal Distribution			
30			95% Student's-t UCL			492.7			95% H-UCL			1084
31		95% UCLs (Adjusted for Skewness)							95% Chebyshev (MVUE) UCL			1182
32			95% Adjusted-CLT UCL			484.9			97.5% Chebyshev (MVUE) UCL			1460
33			95% Modified-t UCL			492			99% Chebyshev (MVUE) UCL			2007
34												
35		Gamma Distribution Test							Data Distribution			
36			k star (bias corrected)			1.388			Data appear Normal at 5% Significance Level			
37			Theta Star			296.7						
38			nu star			66.63						
39		Approximate Chi Square Value (.05)				48.85			Nonparametric Statistics			
40		Adjusted Level of Significance				0.0392			95% CLT UCL			489.5
41		Adjusted Chi Square Value				47.78			95% Jackknife UCL			492.7
42									95% Standard Bootstrap UCL			486.5
43		Anderson-Darling Test Statistic				1.634			95% Bootstrap-t UCL			485.6
44		Anderson-Darling 5% Critical Value				0.761			95% Hall's Bootstrap UCL			481.4
45		Kolmogorov-Smirnov Test Statistic				0.251			95% Percentile Bootstrap UCL			488.1
46		Kolmogorov-Smirnov 5% Critical Value				0.181			95% BCA Bootstrap UCL			481.9
47		Data not Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL			617.6
48									97.5% Chebyshev(Mean, Sd) UCL			706.6
49		Assuming Gamma Distribution							99% Chebyshev(Mean, Sd) UCL			881.4
50			95% Approximate Gamma UCL			561.8						
51			95% Adjusted Gamma UCL			574.4						
52												
53		Potential UCL to Use							Use 95% Student's-t UCL			492.7
54												

	Table 3	**General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-2, Copper**							
	User Selected Options								
	From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProUC							
	Full Precision	OFF							
	Confidence Coefficient	95%							
	Number of Bootstrap Operations	2000							
Co									
			General Statistics						
	Number of Valid Samples	24			Number of Detected Data	22			
	Number of Unique Samples	21			Number of Non-Detect Data	2			
					Percent Non-Detects	8.33%			
	Raw Statistics				**Log-transformed Statistics**				
	Minimum Detected	0.423			Minimum Detected	-0.86			
	Maximum Detected	3.676			Maximum Detected	1.302			
	Mean of Detected	1.588			Mean of Detected	0.304			
	SD of Detected	0.912			SD of Detected	0.588			
	Minimum Non-Detect	0.4			Minimum Non-Detect	-0.916			
	Maximum Non-Detect	0.4			Maximum Non-Detect	-0.916			
			UCL Statistics						
	Normal Distribution Test with Detected Values Only				**Lognormal Distribution Test with Detected Values Only**				
	Shapiro Wilk Test Statistic	0.91			Shapiro Wilk Test Statistic	0.979			
	5% Shapiro Wilk Critical Value	0.911			5% Shapiro Wilk Critical Value	0.911			
	Data not Normal at 5% Significance Level				**Data appear Lognormal at 5% Significance Level**				
	Assuming Normal Distribution				**Assuming Lognormal Distribution**				
	DL/2 Substitution Method				DL/2 Substitution Method				
	Mean	1.472			Mean	0.145			
	SD	0.955			SD	0.78			
	95% DL/2 (t) UCL	1.807			95% H-Stat (DL/2) UCL	2.048			
	Maximum Likelihood Estimate(MLE) Method				Log ROS Method				
	Mean	1.447			Mean in Log Scale	0.188			
	SD	0.98			SD in Log Scale	0.687			
	95% MLE (t) UCL	1.79			Mean in Original Scale	1.484			
	95% MLE (Tiku) UCL	1.785			SD in Original Scale	0.94			
					95% Percentile Bootstrap UCL	1.803			
					95% BCA Bootstrap UCL	1.847			
	Gamma Distribution Test with Detected Values Only				**Data Distribution Test with Detected Values Only**				
	k star (bias corrected)	2.896			**Data appear Gamma Distributed at 5% Significance Level**				
	Theta Star	0.548							
	nu star	127.4							
	A-D Test Statistic	0.187			**Nonparametric Statistics**				
	5% A-D Critical Value	0.749			Kaplan-Meier (KM) Method				
	K-S Test Statistic	0.749			Mean	1.491			
	5% K-S Critical Value	0.187			SD	0.911			
	Data appear Gamma Distributed at 5% Significance Level				SE of Mean	0.19			
					95% KM (t) UCL	1.817			
	Assuming Gamma Distribution				95% KM (z) UCL	1.804			
	Gamma ROS Statistics using Extrapolated Data				95% KM (jackknife) UCL	1.809			
	Minimum	0			95% KM (bootstrap t) UCL	1.859			
	Maximum	3.676			95% KM (BCA) UCL	1.838			
	Mean	1.459			95% KM (Percentile Bootstrap) UCL	1.815			
	Median	1.242			95% KM (Chebyshev) UCL	2.321			
	SD	0.974			97.5% KM (Chebyshev) UCL	2.68			
	k star	0.538			99% KM (Chebyshev) UCL	3.386			
	Theta star	2.713							
	Nu star	25.82			**Potential UCLs to Use**				
	AppChi2	15.24			95% KM (BCA) UCL	1.838			
	95% Gamma Approximate UCL	2.472							
	95% Adjusted Gamma UCL	2.569							
	Note: DL/2 is not a recommended method.								

Table 4 General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-2, Copper

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Cu

General Statistics

Number of Valid Samples	24	Number of Unique Samples	24

Raw Statistics		Log-transformed Statistics	
Minimum	149.7	Minimum of Log Data	5.009
Maximum	1337	Maximum of Log Data	7.198
Mean	574.2	Mean of log Data	6.221
Median	537.2	SD of log Data	0.541
SD	297.9		
Coefficient of Variation	0.519		
Skewness	1.028		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.926	Shapiro Wilk Test Statistic	0.98
Shapiro Wilk Critical Value	0.916	Shapiro Wilk Critical Value	0.916
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	678.4	95% H-UCL	731
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	870.6
95% Adjusted-CLT UCL	687.9	97.5% Chebyshev (MVUE) UCL	996.9
95% Modified-t UCL	680.6	99% Chebyshev (MVUE) UCL	1245

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	3.489	Data appear Normal at 5% Significance Level	
Theta Star	164.6		
nu star	167.5		
Approximate Chi Square Value (.05)	138.5	Nonparametric Statistics	
Adjusted Level of Significance	0.0392	95% CLT UCL	674.2
Adjusted Chi Square Value	136.7	95% Jackknife UCL	678.4
		95% Standard Bootstrap UCL	671.1
Anderson-Darling Test Statistic	0.139	95% Bootstrap-t UCL	695.5
Anderson-Darling 5% Critical Value	0.749	95% Hall's Bootstrap UCL	711.9
Kolmogorov-Smirnov Test Statistic	0.0711	95% Percentile Bootstrap UCL	677.1
Kolmogorov-Smirnov 5% Critical Value	0.179	95% BCA Bootstrap UCL	685.7
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	839.3
		97.5% Chebyshev(Mean, Sd) UCL	954
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1179
95% Approximate Gamma UCL	694.1		
95% Adjusted Gamma UCL	703.4		
Potential UCL to Use		Use 95% Student's-t UCL	678.4

Table 5 General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-2

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Fe

General Statistics

Number of Valid Samples	24	Number of Unique Samples	24

Raw Statistics		Log-transformed Statistics	
Minimum	1.692	Minimum of Log Data	0.526
Maximum	14.56	Maximum of Log Data	2.678
Mean	5.69	Mean of log Data	1.58
Median	5.588	SD of log Data	0.58
SD	3.381		
Coefficient of Variation	0.594		
Skewness	1.23		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.88	Shapiro Wilk Test Statistic	0.971
Shapiro Wilk Critical Value	0.916	Shapiro Wilk Critical Value	0.916
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	6.873	95% H-UCL	7.354
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	8.794
95% Adjusted-CLT UCL	7.011	97.5% Chebyshev (MVUE) UCL	10.13
95% Modified-t UCL	6.902	99% Chebyshev (MVUE) UCL	12.77

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	2.915	Data appear Gamma Distributed at 5% Significance Level	
Theta Star	1.952		
nu star	139.9		
Approximate Chi Square Value (.05)	113.6	Nonparametric Statistics	
Adjusted Level of Significance	0.0392	95% CLT UCL	6.825
Adjusted Chi Square Value	111.9	95% Jackknife UCL	6.873
		95% Standard Bootstrap UCL	6.779
Anderson-Darling Test Statistic	0.356	95% Bootstrap-t UCL	7.157
Anderson-Darling 5% Critical Value	0.75	95% Hall's Bootstrap UCL	7.134
Kolmogorov-Smirnov Test Statistic	0.128	95% Percentile Bootstrap UCL	6.833
Kolmogorov-Smirnov 5% Critical Value	0.179	95% BCA Bootstrap UCL	6.951
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	8.698
		97.5% Chebyshev(Mean, Sd) UCL	10
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	12.56
95% Approximate Gamma UCL	7.01		
95% Adjusted Gamma UCL	7.114		

Potential UCL to Use		Use 95% Approximate Gamma UCL	7.01

Table 6 General UCL Statistics for Data Sets with Non-Detects, Spoils EA-2, Lead

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Pb

General Statistics

Number of Valid Samples	24	Number of Unique Samples	24

Raw Statistics		Log-transformed Statistics	
Minimum	156.2	Minimum of Log Data	5.051
Maximum	24266	Maximum of Log Data	10.1
Mean	4274	Mean of log Data	7.919
Median	3552	SD of log Data	1.075
SD	4675		
Coefficient of Variation	1.094		
Skewness	3.595		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.599	Shapiro Wilk Test Statistic	0.877
Shapiro Wilk Critical Value	0.916	Shapiro Wilk Critical Value	0.916
Data not Normal at 5% Significance Level		**Data not Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	5909	95% H-UCL	8816
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	9921
95% Adjusted-CLT UCL	6591	97.5% Chebyshev (MVUE) UCL	12168
95% Modified-t UCL	6026	99% Chebyshev (MVUE) UCL	16582

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.143	**Data do not follow a Discernable Distribution (0.05)**	
Theta Star	3738		
nu star	54.88		
Approximate Chi Square Value (.05)	38.86	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0392	95% CLT UCL	5843
Adjusted Chi Square Value	37.91	95% Jackknife UCL	5909
		95% Standard Bootstrap UCL	5876
Anderson-Darling Test Statistic	1.053	95% Bootstrap-t UCL	7464
Anderson-Darling 5% Critical Value	0.766	95% Hall's Bootstrap UCL	12652
Kolmogorov-Smirnov Test Statistic	0.186	95% Percentile Bootstrap UCL	6018
Kolmogorov-Smirnov 5% Critical Value	0.182	95% BCA Bootstrap UCL	6944
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	8433
		97.5% Chebyshev(Mean, Sd) UCL	10233
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	13768
95% Approximate Gamma UCL	6036		
95% Adjusted Gamma UCL	6187		
Potential UCL to Use		Use 99% Chebyshev (Mean, Sd) UCL	13768

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 7	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-2 Manganese							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Mn											
10												
11					General Statistics							
12			Number of Valid Samples	24					Number of Unique Samples	24		
13												
14		Raw Statistics						Log-transformed Statistics				
15			Minimum	2					Minimum of Log Data	0.693		
16			Maximum	416.9					Maximum of Log Data	6.033		
17			Mean	115.3					Mean of log Data	4.265		
18			Median	69.08					SD of log Data	1.131		
19			SD	113.7								
20			Coefficient of Variation	0.986								
21			Skewness	1.479								
22												
23					Relevant UCL Statistics							
24		Normal Distribution Test						Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic	0.792					Shapiro Wilk Test Statistic	0.909		
26			Shapiro Wilk Critical Value	0.916					Shapiro Wilk Critical Value	0.916		
27		Data not Normal at 5% Significance Level						Data not Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30			95% Student's-t UCL	155.1					95% H-UCL	254.9		
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL	280.7			
32			95% Adjusted-CLT UCL	160.9					97.5% Chebyshev (MVUE) UCL	346.1		
33			95% Modified-t UCL	156.2					99% Chebyshev (MVUE) UCL	474.6		
34												
35		Gamma Distribution Test						Data Distribution				
36			k star (bias corrected)	1.055			Data appear Gamma Distributed at 5% Significance Level					
37			Theta Star	109.3								
38			nu star	50.64								
39		Approximate Chi Square Value (.05)		35.3				Nonparametric Statistics				
40		Adjusted Level of Significance		0.0392					95% CLT UCL	153.5		
41		Adjusted Chi Square Value		34.4					95% Jackknife UCL	155.1		
42									95% Standard Bootstrap UCL	153.4		
43		Anderson-Darling Test Statistic		0.602					95% Bootstrap-t UCL	169.4		
44		Anderson-Darling 5% Critical Value		0.768					95% Hall's Bootstrap UCL	159.4		
45		Kolmogorov-Smirnov Test Statistic		0.139					95% Percentile Bootstrap UCL	153.5		
46		Kolmogorov-Smirnov 5% Critical Value		0.182					95% BCA Bootstrap UCL	160.8		
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL	216.4			
48									97.5% Chebyshev(Mean, Sd) UCL	260.2		
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL	346.1			
50			95% Approximate Gamma UCL	165.4								
51			95% Adjusted Gamma UCL	169.8								
52												
53		Potential UCL to Use						Use 95% Approximate Gamma UCL				165.4
54												

	Table 8	General UCL Statistics for Data Sets with Non-Detects, EA-2 Spoils, Vanadium						

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

V

General Statistics

Number of Valid Samples	24	Number of Detected Data	7
Number of Unique Samples	7	Number of Non-Detect Data	17
		Percent Non-Detects	70.83%

Raw Statistics		Log-transformed Statistics	
Minimum Detected	1.187	Minimum Detected	0.171
Maximum Detected	15.7	Maximum Detected	2.753
Mean of Detected	8.167	Mean of Detected	1.562
SD of Detected	6.807	SD of Detected	1.272
Minimum Non-Detect	8	Minimum Non-Detect	2.079
Maximum Non-Detect	8	Maximum Non-Detect	2.079

UCL Statistics

Normal Distribution Test with Detected Values Only		Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.809	Shapiro Wilk Test Statistic	0.753
5% Shapiro Wilk Critical Value	0.803	5% Shapiro Wilk Critical Value	0.803
Data appear Normal at 5% Significance Level		Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
DL/2 Substitution Method		DL/2 Substitution Method	
Mean	5.215	Mean	1.437
SD	3.979	SD	0.655
95% DL/2 (t) UCL	6.607	95% H-Stat (DL/2) UCL	8.53
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	
Mean	13.6	Mean in Log Scale	0.699
SD	2.559	SD in Log Scale	1.128
95% MLE (t) UCL	14.49	Mean in Original Scale	3.75
95% MLE (Tiku) UCL	15.78	SD in Original Scale	4.688
		95% Percentile Bootstrap UCL	5.362
		95% BCA Bootstrap UCL	5.681

Gamma Distribution Test with Detected Values Only		Data Distribution Test with Detected Values Only	
k star (bias corrected)	0.703	Data appear Normal at 5% Significance Level	
Theta Star	11.61		
nu star	9.849		
A-D Test Statistic	0.835	Nonparametric Statistics	
5% A-D Critical Value	0.727	Kaplan-Meier (KM) Method	
K-S Test Statistic	0.727	Mean	3.262
5% K-S Critical Value	0.319	SD	4.636
Data follow Appr. Gamma Distribution at 5% Significance Level		SE of Mean	1.023
		95% KM (t) UCL	5.015
Assuming Gamma Distribution		95% KM (z) UCL	4.944
Gamma ROS Statistics using Extrapolated Data		95% KM (jackknife) UCL	4.921
Minimum	0	95% KM (bootstrap t) UCL	5.459
Maximum	15.7	95% KM (BCA) UCL	9.921
Mean	5.968	95% KM (Percentile Bootstrap) UCL	5.493
Median	5.445	95% KM (Chebyshev) UCL	7.72
SD	5.3	97.5% KM (Chebyshev) UCL	9.649
k star	0.168	99% KM (Chebyshev) UCL	13.44
Theta star	35.52		
Nu star	8.064	Potential UCLs to Use	
AppChi2	2.772	95% KM (t) UCL	5.015
95% Gamma Approximate UCL	17.36	95% KM (Percentile Bootstrap) UCL	5.493
95% Adjusted Gamma UCL	18.81		

Note: DL/2 is not a recommended method.

Appendix B-3
Exposure Point Concentrations and ProUCL Results
Exposure Area 3, East Avoca Tigroney West

Table1 General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-3 Antimony

User Selected Options	
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Sb

General Statistics

Number of Valid Samples	10	Number of Unique Samples	10

Raw Statistics		Log-transformed Statistics	
Minimum	0.885	Minimum of Log Data	-0.122
Maximum	3.225	Maximum of Log Data	1.171
Mean	1.874	Mean of log Data	0.511
Median	1.552	SD of log Data	0.512
SD	0.942		
Coefficient of Variation	0.503		
Skewness	0.479		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.855	Shapiro Wilk Test Statistic	0.882
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	2.42	95% H-UCL	2.785
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	3.221
95% Adjusted-CLT UCL	2.413	97.5% Chebyshev (MVUE) UCL	3.804
95% Modified-t UCL	2.428	99% Chebyshev (MVUE) UCL	4.95

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	3.172	**Data appear Normal at 5% Significance Level**	
Theta Star	0.591		
nu star	63.43		
Approximate Chi Square Value (.05)	46.11	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	2.364
Adjusted Chi Square Value	43.55	95% Jackknife UCL	2.42
		95% Standard Bootstrap UCL	2.342
Anderson-Darling Test Statistic	0.564	95% Bootstrap-t UCL	2.52
Anderson-Darling 5% Critical Value	0.729	95% Hall's Bootstrap UCL	2.316
Kolmogorov-Smirnov Test Statistic	0.193	95% Percentile Bootstrap UCL	2.329
Kolmogorov-Smirnov 5% Critical Value	0.268	95% BCA Bootstrap UCL	2.368
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	3.173
		97.5% Chebyshev(Mean, Sd) UCL	3.735
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	4.839
95% Approximate Gamma UCL	2.578		
95% Adjusted Gamma UCL	2.73		
Potential UCL to Use		Use 95% Student's-t UCL	2.42

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 2	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-3, Arsenic							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	As											
10												
11						General Statistics						
12			Number of Valid Samples	10				Number of Unique Samples				10
13												
14		Raw Statistics					Log-transformed Statistics					
15			Minimum	8.136				Minimum of Log Data				2.096
16			Maximum	885.8				Maximum of Log Data				6.786
17			Mean	364.2				Mean of log Data				5.36
18			Median	287.2				SD of log Data				1.403
19			SD	294.5								
20		Coefficient of Variation		0.808								
21			Skewness	0.58								
22												
23						Relevant UCL Statistics						
24		Normal Distribution Test					Lognormal Distribution Test					
25		Shapiro Wilk Test Statistic		0.938				Shapiro Wilk Test Statistic				0.868
26		Shapiro Wilk Critical Value		0.842				Shapiro Wilk Critical Value				0.842
27		Data appear Normal at 5% Significance Level					Data appear Lognormal at 5% Significance Level					
28												
29		Assuming Normal Distribution					Assuming Lognormal Distribution					
30		95% Student's-t UCL		534.9				95% H-UCL				3670
31		95% UCLs (Adjusted for Skewness)					95% Chebyshev (MVUE) UCL					1479
32		95% Adjusted-CLT UCL		535.6				97.5% Chebyshev (MVUE) UCL				1909
33		95% Modified-t UCL		537.8				99% Chebyshev (MVUE) UCL				2753
34												
35		Gamma Distribution Test					Data Distribution					
36		k star (bias corrected)		0.813				Data appear Normal at 5% Significance Level				
37		Theta Star		448.1								
38		nu star		16.26								
39		Approximate Chi Square Value (.05)		8.144				Nonparametric Statistics				
40		Adjusted Level of Significance		0.0267				95% CLT UCL				517.4
41		Adjusted Chi Square Value		7.168				95% Jackknife UCL				534.9
42								95% Standard Bootstrap UCL				509.7
43		Anderson-Darling Test Statistic		0.231				95% Bootstrap-t UCL				568.2
44		Anderson-Darling 5% Critical Value		0.747				95% Hall's Bootstrap UCL				536.9
45		Kolmogorov-Smirnov Test Statistic		0.146				95% Percentile Bootstrap UCL				507
46		Kolmogorov-Smirnov 5% Critical Value		0.273				95% BCA Bootstrap UCL				517
47		Data appear Gamma Distributed at 5% Significance Level					95% Chebyshev(Mean, Sd) UCL					770.1
48								97.5% Chebyshev(Mean, Sd) UCL				945.7
49		Assuming Gamma Distribution					99% Chebyshev(Mean, Sd) UCL					1291
50		95% Approximate Gamma UCL		727.1								
51		95% Adjusted Gamma UCL		826.1								
52												
53		Potential UCL to Use						Use 95% Student's-t UCL				534.9
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 3	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-3, Copper							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU(								
4			Full Precision	OFF								
5			Confidence Coefficient	95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Cu											
10												
11						General Statistics						
12				Number of Valid Samples		10			Number of Unique Samples			10
13												
14			Raw Statistics					Log-transformed Statistics				
15					Minimum	73.96				Minimum of Log Data		4.303
16					Maximum	2912				Maximum of Log Data		7.977
17					Mean	990.5				Mean of log Data		6.154
18					Median	430.8				SD of log Data		1.394
19					SD	1060						
20				Coefficient of Variation		1.07						
21					Skewness	0.82						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test					Lognormal Distribution Test				
25				Shapiro Wilk Test Statistic		0.823			Shapiro Wilk Test Statistic			0.867
26				Shapiro Wilk Critical Value		0.842			Shapiro Wilk Critical Value			0.842
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution					Assuming Lognormal Distribution				
30					95% Student's-t UCL	1605				95% H-UCL		7845
31			95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL			3226
32				95% Adjusted-CLT UCL		1635			97.5% Chebyshev (MVUE) UCL			4161
33				95% Modified-t UCL		1619			99% Chebyshev (MVUE) UCL			5999
34												
35			Gamma Distribution Test					Data Distribution				
36				k star (bias corrected)		0.625		Data appear Gamma Distributed at 5% Significance Level				
37					Theta Star	1584						
38					nu star	12.51						
39			Approximate Chi Square Value (.05)			5.564			Nonparametric Statistics			
40			Adjusted Level of Significance			0.0267				95% CLT UCL		1542
41			Adjusted Chi Square Value			4.783				95% Jackknife UCL		1605
42										95% Standard Bootstrap UCL		1505
43			Anderson-Darling Test Statistic			0.698				95% Bootstrap-t UCL		1789
44			Anderson-Darling 5% Critical Value			0.755				95% Hall's Bootstrap UCL		1533
45			Kolmogorov-Smirnov Test Statistic			0.275				95% Percentile Bootstrap UCL		1539
46			Kolmogorov-Smirnov 5% Critical Value			0.276				95% BCA Bootstrap UCL		1599
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL			2451
48									97.5% Chebyshev(Mean, Sd) UCL			3083
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL			4325
50				95% Approximate Gamma UCL		2227						
51				95% Adjusted Gamma UCL		2590						
52												
53			Potential UCL to Use						Use 95% Approximate Gamma UCL			2227
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 4	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-3, Cobalt							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProUC								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Co											
10												
11						General Statistics						
12			Number of Valid Samples	10					Number of Unique Samples	10		
13												
14			Raw Statistics						Log-transformed Statistics			
15				Minimum	0.581					Minimum of Log Data	-0.543	
16				Maximum	5.918					Maximum of Log Data	1.778	
17				Mean	2.499					Mean of log Data	0.74	
18				Median	1.864					SD of log Data	0.645	
19				SD	1.575							
20			Coefficient of Variation	0.63								
21				Skewness	1.245							
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test						Lognormal Distribution Test			
25			Shapiro Wilk Test Statistic	0.883					Shapiro Wilk Test Statistic	0.953		
26			Shapiro Wilk Critical Value	0.842					Shapiro Wilk Critical Value	0.842		
27		Data appear Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30			95% Student's-t UCL	3.412						95% H-UCL	4.36	
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL		4.82		
32			95% Adjusted-CLT UCL	3.528					97.5% Chebyshev (MVUE) UCL		5.816		
33			95% Modified-t UCL	3.445					99% Chebyshev (MVUE) UCL		7.771		
34												
35		Gamma Distribution Test						Data Distribution				
36			k star (bias corrected)	2.158				Data appear Normal at 5% Significance Level				
37			Theta Star	1.158								
38			nu star	43.17								
39		Approximate Chi Square Value (.05)		29.1					Nonparametric Statistics			
40		Adjusted Level of Significance		0.0267					95% CLT UCL	3.319		
41		Adjusted Chi Square Value		27.11					95% Jackknife UCL	3.412		
42									95% Standard Bootstrap UCL	3.275		
43		Anderson-Darling Test Statistic		0.33					95% Bootstrap-t UCL	3.944		
44		Anderson-Darling 5% Critical Value		0.732					95% Hall's Bootstrap UCL	4.202		
45		Kolmogorov-Smirnov Test Statistic		0.189					95% Percentile Bootstrap UCL	3.297		
46		Kolmogorov-Smirnov 5% Critical Value		0.268					95% BCA Bootstrap UCL	3.447		
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL		4.67		
48								97.5% Chebyshev(Mean, Sd) UCL		5.609		
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL		7.454		
50			95% Approximate Gamma UCL	3.707								
51			95% Adjusted Gamma UCL	3.98								
52												
53		Potential UCL to Use							Use 95% Student's-t UCL	3.412		
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 5	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-3, Iron							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProUC								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	Fe											
10												
11						General Statistics						
12			Number of Valid Samples			10				Number of Unique Samples		10
13												
14			Raw Statistics						Log-transformed Statistics			
15				Minimum		0.377				Minimum of Log Data		-0.976
16				Maximum		16.97				Maximum of Log Data		2.832
17				Mean		10.74				Mean of log Data		1.985
18				Median		12.64				SD of log Data		1.255
19				SD		5.939						
20			Coefficient of Variation			0.553						
21				Skewness		-0.922						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test						Lognormal Distribution Test			
25			Shapiro Wilk Test Statistic			0.868				Shapiro Wilk Test Statistic		0.703
26			Shapiro Wilk Critical Value			0.842				Shapiro Wilk Critical Value		0.842
27		Data appear Normal at 5% Significance Level						Data not Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30				95% Student's-t UCL		14.19				95% H-UCL		73.59
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				40.15
32			95% Adjusted-CLT UCL			13.25			97.5% Chebyshev (MVUE) UCL			51.38
33			95% Modified-t UCL			14.09			99% Chebyshev (MVUE) UCL			73.44
34												
35		Gamma Distribution Test						Data Distribution				
36			k star (bias corrected)			1.065		Data appear Normal at 5% Significance Level				
37				Theta Star		10.08						
38				nu star		21.31						
39		Approximate Chi Square Value (.05)				11.82			Nonparametric Statistics			
40		Adjusted Level of Significance				0.0267				95% CLT UCL		13.83
41		Adjusted Chi Square Value				10.61				95% Jackknife UCL		14.19
42										95% Standard Bootstrap UCL		13.67
43		Anderson-Darling Test Statistic				1.159				95% Bootstrap-t UCL		13.55
44		Anderson-Darling 5% Critical Value				0.741				95% Hall's Bootstrap UCL		13.17
45		Kolmogorov-Smirnov Test Statistic				0.332			95% Percentile Bootstrap UCL			13.5
46		Kolmogorov-Smirnov 5% Critical Value				0.272				95% BCA Bootstrap UCL		13.23
47		Data not Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL				18.93
48								97.5% Chebyshev(Mean, Sd) UCL				22.47
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL				29.43
50			95% Approximate Gamma UCL			19.37						
51			95% Adjusted Gamma UCL			21.57						
52												
53		Potential UCL to Use							Use 95% Student's-t UCL			14.19
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				**Table 6**	**General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-3 Lead**							
2		**User Selected Options**										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat								
4			Full Precision	OFF								
5			Confidence Coefficient	95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	**Pb**											
10												
11						**General Statistics**						
12				Number of Valid Samples	10				Number of Unique Samples			10
13												
14			**Raw Statistics**						**Log-transformed Statistics**			
15				Minimum	58.26				Minimum of Log Data			4.065
16				Maximum	7974				Maximum of Log Data			8.984
17				Mean	3385				Mean of log Data			7.094
18				Median	2509				SD of log Data			2.018
19				SD	3167							
20			Coefficient of Variation		0.936							
21				Skewness	0.321							
22												
23						**Relevant UCL Statistics**						
24			**Normal Distribution Test**						**Lognormal Distribution Test**			
25			Shapiro Wilk Test Statistic		0.866				Shapiro Wilk Test Statistic			0.811
26			Shapiro Wilk Critical Value		0.842				Shapiro Wilk Critical Value			0.842
27		**Data appear Normal at 5% Significance Level**						**Data not Lognormal at 5% Significance Level**				
28												
29		**Assuming Normal Distribution**						**Assuming Lognormal Distribution**				
30				95% Student's-t UCL	5221				95% H-UCL			358932
31		**95% UCLs (Adjusted for Skewness)**						95% Chebyshev (MVUE) UCL				23142
32			95% Adjusted-CLT UCL		5141				97.5% Chebyshev (MVUE) UCL			30558
33			95% Modified-t UCL		5238				99% Chebyshev (MVUE) UCL			45125
34												
35			**Gamma Distribution Test**						**Data Distribution**			
36			k star (bias corrected)		0.485			**Data appear Normal at 5% Significance Level**				
37				Theta Star	6975							
38				nu star	9.706							
39		Approximate Chi Square Value (.05)			3.759				**Nonparametric Statistics**			
40			Adjusted Level of Significance		0.0267				95% CLT UCL			5032
41			Adjusted Chi Square Value		3.143				95% Jackknife UCL			5221
42									95% Standard Bootstrap UCL			4927
43			Anderson-Darling Test Statistic		0.636				95% Bootstrap-t UCL			5371
44			Anderson-Darling 5% Critical Value		0.769				95% Hall's Bootstrap UCL			4745
45			Kolmogorov-Smirnov Test Statistic		0.214				95% Percentile Bootstrap UCL			4962
46			Kolmogorov-Smirnov 5% Critical Value		0.279				95% BCA Bootstrap UCL			4988
47		**Data appear Gamma Distributed at 5% Significance Level**						95% Chebyshev(Mean, Sd) UCL				7750
48									97.5% Chebyshev(Mean, Sd) UCL			9639
49		**Assuming Gamma Distribution**						99% Chebyshev(Mean, Sd) UCL				13350
50			95% Approximate Gamma UCL		8741							
51			95% Adjusted Gamma UCL		10453							
52												
53		**Potential UCL to Use**						Use 95% Student's-t UCL				5221
54												

	Table 7	General UCL Statistics for Data Sets with Non-Detects,Spoils EA-3 Manganese									
User Selected Options											
From File			C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProUC									
Full Precision			OFF									
Confidence Coefficient			95%									
Number of Bootstrap Operations			2000									

Mn

General Statistics

Number of Valid Samples	10		Number of Unique Samples	10

Raw Statistics		**Log-transformed Statistics**	
Minimum	34.53	Minimum of Log Data	3.542
Maximum	968.5	Maximum of Log Data	6.876
Mean	410.8	Mean of log Data	5.572
Median	311.7	SD of log Data	1.16
SD	327.2		
Coefficient of Variation	0.797		
Skewness	0.565		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Shapiro Wilk Test Statistic	0.921	Shapiro Wilk Test Statistic	0.898
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	600.5	95% H-UCL	1948
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1256
95% Adjusted-CLT UCL	600.8	97.5% Chebyshev (MVUE) UCL	1597
95% Modified-t UCL	603.6	99% Chebyshev (MVUE) UCL	2267

Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	0.95	**Data appear Normal at 5% Significance Level**	
Theta Star	432.4		
nu star	19		
Approximate Chi Square Value (.05)	10.12	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	581
Adjusted Chi Square Value	9.012	95% Jackknife UCL	600.5
		95% Standard Bootstrap UCL	570.5
Anderson-Darling Test Statistic	0.287	95% Bootstrap-t UCL	631.9
Anderson-Darling 5% Critical Value	0.744	95% Hall's Bootstrap UCL	602.3
Kolmogorov-Smirnov Test Statistic	0.147	95% Percentile Bootstrap UCL	573.2
Kolmogorov-Smirnov 5% Critical Value	0.272	95% BCA Bootstrap UCL	587.1
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	861.9
		97.5% Chebyshev(Mean, Sd) UCL	1057
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1440
95% Approximate Gamma UCL	771.5		
95% Adjusted Gamma UCL	866.2		
Potential UCL to Use		Use 95% Student's-t UCL	600.5

Appendix B-4
Exposure Point Concentrations and ProUCL Results
Exposure Area 4, Ore Bins at Tigroney West

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 1	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-4, Arsenic							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	As											
10												
11						General Statistics						
12				Number of Valid Samples	10				Number of Unique Samples	10		
13												
14			Raw Statistics					Log-transformed Statistics				
15				Minimum	118.7				Minimum of Log Data	4.776		
16				Maximum	2893				Maximum of Log Data	7.97		
17				Mean	814				Mean of log Data	6.24		
18				Median	545.1				SD of log Data	1.034		
19				SD	844.9							
20			Coefficient of Variation		1.038							
21				Skewness	1.852							
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test					Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic		0.789				Shapiro Wilk Test Statistic	0.955		
26			Shapiro Wilk Critical Value		0.842				Shapiro Wilk Critical Value	0.842		
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution					Assuming Lognormal Distribution				
30			95% Student's-t UCL		1304				95% H-UCL	2613		
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL		2033		
32			95% Adjusted-CLT UCL		1421				97.5% Chebyshev (MVUE) UCL	2560		
33			95% Modified-t UCL		1330				99% Chebyshev (MVUE) UCL	3596		
34												
35			Gamma Distribution Test					Data Distribution				
36			k star (bias corrected)		0.923		Data appear Gamma Distributed at 5% Significance Level					
37				Theta Star	882.1							
38				nu star	18.46							
39		Approximate Chi Square Value (.05)			9.721			Nonparametric Statistics				
40		Adjusted Level of Significance			0.0267				95% CLT UCL	1253		
41		Adjusted Chi Square Value			8.64				95% Jackknife UCL	1304		
42									95% Standard Bootstrap UCL	1231		
43		Anderson-Darling Test Statistic			0.344				95% Bootstrap-t UCL	1639		
44		Anderson-Darling 5% Critical Value			0.744				95% Hall's Bootstrap UCL	2929		
45		Kolmogorov-Smirnov Test Statistic			0.209				95% Percentile Bootstrap UCL	1265		
46		Kolmogorov-Smirnov 5% Critical Value			0.273				95% BCA Bootstrap UCL	1449		
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL	1979		
48									97.5% Chebyshev(Mean, Sd) UCL	2483		
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL	3473		
50			95% Approximate Gamma UCL		1545							
51			95% Adjusted Gamma UCL		1739							
52												
53			Potential UCL to Use						Use 95% Approximate Gamma UCL	1545		
54												

	Table 2	General UCL Statistics for Data Sets with Non-Detects,Spoils, EA-4,Copper

User Selected Options

From File	WorkSheet.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Cu

General Statistics

Number of Valid Samples	10	Number of Unique Samples	10

Raw Statistics		Log-transformed Statistics	
Minimum	213.6	Minimum of Log Data	5.364
Maximum	11116	Maximum of Log Data	9.316
Mean	2196	Mean of log Data	7.002
Median	1018	SD of log Data	1.193
SD	3283		
Coefficient of Variation	1.495		
Skewness	2.687		

Relevant UCL Statistics

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.62	Shapiro Wilk Test Statistic	0.972
Shapiro Wilk Critical Value	0.842	Shapiro Wilk Critical Value	0.842
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	4099	95% H-UCL	9050
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	5517
95% Adjusted-CLT UCL	4846	97.5% Chebyshev (MVUE) UCL	7032
95% Modified-t UCL	4246	99% Chebyshev (MVUE) UCL	10007

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.662	**Data appear Gamma Distributed at 5% Significance Level**	
Theta Star	3318		
nu star	13.24		
Approximate Chi Square Value (.05)	6.051	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0267	95% CLT UCL	3904
Adjusted Chi Square Value	5.231	95% Jackknife UCL	4099
		95% Standard Bootstrap UCL	3823
Anderson-Darling Test Statistic	0.469	95% Bootstrap-t UCL	9002
Anderson-Darling 5% Critical Value	0.753	95% Hall's Bootstrap UCL	10985
Kolmogorov-Smirnov Test Statistic	0.194	95% Percentile Bootstrap UCL	4088
Kolmogorov-Smirnov 5% Critical Value	0.275	95% BCA Bootstrap UCL	5043
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	6722
		97.5% Chebyshev(Mean, Sd) UCL	8680
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	12527
95% Approximate Gamma UCL	4803		
95% Adjusted Gamma UCL	5556		
Potential UCL to Use		Use 95% Approximate Gamma UCL	4803

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 3	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-4, Cobalt							
2	User Selected Options											
3			From File	WorkSheet.wst								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	Co											
10												
11					General Statistics							
12		Number of Valid Samples			10				Number of Unique Samples			10
13												
14		Raw Statistics						Log-transformed Statistics				
15			Minimum		0.471				Minimum of Log Data			-0.752
16			Maximum		8.544				Maximum of Log Data			2.145
17			Mean		3.121				Mean of log Data			0.927
18			Median		2.726				SD of log Data			0.74
19			SD		2.15							
20		Coefficient of Variation			0.689							
21			Skewness		1.905							
22												
23					Relevant UCL Statistics							
24		Normal Distribution Test						Lognormal Distribution Test				
25		Shapiro Wilk Test Statistic			0.807				Shapiro Wilk Test Statistic			0.893
26		Shapiro Wilk Critical Value			0.842				Shapiro Wilk Critical Value			0.842
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30		95% Student's-t UCL			4.367				95% H-UCL			6.312
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				6.606
32		95% Adjusted-CLT UCL			4.677			97.5% Chebyshev (MVUE) UCL				8.073
33		95% Modified-t UCL			4.436			99% Chebyshev (MVUE) UCL				10.95
34												
35		Gamma Distribution Test						Data Distribution				
36		k star (bias corrected)			1.829			Data appear Gamma Distributed at 5% Significance Level				
37			Theta Star		1.706							
38			nu star		36.58							
39		Approximate Chi Square Value (.05)			23.74				Nonparametric Statistics			
40		Adjusted Level of Significance			0.0267				95% CLT UCL			4.239
41		Adjusted Chi Square Value			21.96				95% Jackknife UCL			4.367
42									95% Standard Bootstrap UCL			4.197
43		Anderson-Darling Test Statistic			0.477				95% Bootstrap-t UCL			5.063
44		Anderson-Darling 5% Critical Value			0.734				95% Hall's Bootstrap UCL			9.912
45		Kolmogorov-Smirnov Test Statistic			0.194				95% Percentile Bootstrap UCL			4.293
46		Kolmogorov-Smirnov 5% Critical Value			0.269				95% BCA Bootstrap UCL			4.795
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL				6.085
48									97.5% Chebyshev(Mean, Sd) UCL			7.367
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL				9.886
50		95% Approximate Gamma UCL			4.81							
51		95% Adjusted Gamma UCL			5.201							
52												
53		Potential UCL to Use						Use 95% Approximate Gamma UCL				4.81
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 4	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-4, Iron							
2	User Selected Options											
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	Fe											
10												
11						General Statistics						
12			Number of Valid Samples			10			Number of Unique Samples			10
13												
14		Raw Statistics						Log-transformed Statistics				
15				Minimum		2.116			Minimum of Log Data			0.75
16				Maximum		17.52			Maximum of Log Data			2.863
17				Mean		11.08			Mean of log Data			2.266
18				Median		12.56			SD of log Data			0.639
19				SD		4.848						
20			Coefficient of Variation			0.438						
21				Skewness		-0.615						
22												
23						Relevant UCL Statistics						
24		Normal Distribution Test						Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic			0.951			Shapiro Wilk Test Statistic			0.823
26			Shapiro Wilk Critical Value			0.842			Shapiro Wilk Critical Value			0.842
27		Data appear Normal at 5% Significance Level						Data not Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30			95% Student's-t UCL			13.89			95% H-UCL			19.86
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				22.01
32			95% Adjusted-CLT UCL			13.28			97.5% Chebyshev (MVUE) UCL			26.54
33			95% Modified-t UCL			13.84			99% Chebyshev (MVUE) UCL			35.43
34												
35		Gamma Distribution Test						Data Distribution				
36			k star (bias corrected)			2.701			Data appear Normal at 5% Significance Level			
37				Theta Star		4.101						
38				nu star		54.02						
39		Approximate Chi Square Value (.05)				38.14			Nonparametric Statistics			
40			Adjusted Level of Significance			0.0267			95% CLT UCL			13.6
41			Adjusted Chi Square Value			35.83			95% Jackknife UCL			13.89
42									95% Standard Bootstrap UCL			13.45
43			Anderson-Darling Test Statistic			0.554			95% Bootstrap-t UCL			13.52
44			Anderson-Darling 5% Critical Value			0.73			95% Hall's Bootstrap UCL			13.21
45			Kolmogorov-Smirnov Test Statistic			0.255			95% Percentile Bootstrap UCL			13.38
46			Kolmogorov-Smirnov 5% Critical Value			0.268			95% BCA Bootstrap UCL			13.26
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL				17.76
48									97.5% Chebyshev(Mean, Sd) UCL			20.65
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL				26.33
50			95% Approximate Gamma UCL			15.69						
51			95% Adjusted Gamma UCL			16.7						
52												
53		Potential UCL to Use							Use 95% Student's-t UCL			13.89
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 5	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-4 Lead							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4			Full Precision	OFF								
5			Confidence Coefficient	95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Pb											
10												
11						General Statistics						
12				Number of Valid Samples	10				Number of Unique Samples	10		
13												
14			Raw Statistics					Log-transformed Statistics				
15				Minimum	19.76				Minimum of Log Data	2.983		
16				Maximum	74877				Maximum of Log Data	11.22		
17				Mean	19675				Mean of log Data	8.537		
18				Median	11110				SD of log Data	2.588		
19				SD	23795							
20			Coefficient of Variation		1.209							
21				Skewness	1.663							
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test					Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic		0.807				Shapiro Wilk Test Statistic	0.857		
26			Shapiro Wilk Critical Value		0.842				Shapiro Wilk Critical Value	0.842		
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution					Assuming Lognormal Distribution				
30			95% Student's-t UCL		33469				95% H-UCL	52929033		
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL		269731		
32			95% Adjusted-CLT UCL		36281				97.5% Chebyshev (MVUE) UCL	360047		
33			95% Modified-t UCL		34129				99% Chebyshev (MVUE) UCL	537455		
34												
35			Gamma Distribution Test					Data Distribution				
36			k star (bias corrected)		0.399		Data appear Gamma Distributed at 5% Significance Level					
37			Theta Star		49349							
38			nu star		7.974							
39		Approximate Chi Square Value (.05)			2.72			Nonparametric Statistics				
40		Adjusted Level of Significance			0.0267				95% CLT UCL	32052		
41		Adjusted Chi Square Value			2.216				95% Jackknife UCL	33469		
42									95% Standard Bootstrap UCL	31687		
43		Anderson-Darling Test Statistic			0.244				95% Bootstrap-t UCL	51041		
44		Anderson-Darling 5% Critical Value			0.782				95% Hall's Bootstrap UCL	97303		
45		Kolmogorov-Smirnov Test Statistic			0.173				95% Percentile Bootstrap UCL	32324		
46		Kolmogorov-Smirnov 5% Critical Value			0.282				95% BCA Bootstrap UCL	34933		
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL	52475		
48									97.5% Chebyshev(Mean, Sd) UCL	66667		
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL	94546		
50			95% Approximate Gamma UCL		57681							
51			95% Adjusted Gamma UCL		70792							
52												
53			Potential UCL to Use						Use 95% Adjusted Gamma UCL	70792		
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 6	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-4 Manganese							
2	User Selected Options											
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU								
4		Full Precision		OFF								
5	Confidence Coefficient			95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	Mn											
10												
11					General Statistics							
12			Number of Valid Samples			10			Number of Unique Samples			10
13												
14		Raw Statistics						Log-transformed Statistics				
15				Minimum		97.65				Minimum of Log Data		4.581
16				Maximum		471.3				Maximum of Log Data		6.155
17				Mean		359.6				Mean of log Data		5.814
18				Median		376.8				SD of log Data		0.459
19				SD		109.1						
20			Coefficient of Variation			0.303						
21				Skewness		-1.598						
22												
23					Relevant UCL Statistics							
24		Normal Distribution Test						Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic			0.845			Shapiro Wilk Test Statistic			0.675
26			Shapiro Wilk Critical Value			0.842			Shapiro Wilk Critical Value			0.842
27		Data appear Normal at 5% Significance Level						Data not Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30			95% Student's-t UCL			422.8				95% H-UCL		518.4
31		95% UCLs (Adjusted for Skewness)							95% Chebyshev (MVUE) UCL			604.6
32			95% Adjusted-CLT UCL			397.7			97.5% Chebyshev (MVUE) UCL			706.9
33			95% Modified-t UCL			419.9			99% Chebyshev (MVUE) UCL			907.9
34												
35		Gamma Distribution Test						Data Distribution				
36			k star (bias corrected)			5.136		Data appear Normal at 5% Significance Level				
37				Theta Star		70.01						
38				nu star		102.7						
39		Approximate Chi Square Value (.05)				80.34		Nonparametric Statistics				
40		Adjusted Level of Significance				0.0267			95% CLT UCL			416.3
41			Adjusted Chi Square Value			76.9			95% Jackknife UCL			422.8
42									95% Standard Bootstrap UCL			414.4
43		Anderson-Darling Test Statistic				1.032			95% Bootstrap-t UCL			408.8
44		Anderson-Darling 5% Critical Value				0.727			95% Hall's Bootstrap UCL			403.5
45		Kolmogorov-Smirnov Test Statistic				0.301			95% Percentile Bootstrap UCL			408.4
46		Kolmogorov-Smirnov 5% Critical Value				0.267			95% BCA Bootstrap UCL			399.1
47		Data not Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL			509.9
48									97.5% Chebyshev(Mean, Sd) UCL			575
49		Assuming Gamma Distribution							99% Chebyshev(Mean, Sd) UCL			702.8
50			95% Approximate Gamma UCL			459.8						
51			95% Adjusted Gamma UCL			480.3						
52												
53		Potential UCL to Use							Use 95% Student's-t UCL			422.8
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 7	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-4 Antimony							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4			Full Precision	OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Sb											
10												
11						General Statistics						
12				Number of Valid Samples		10			Number of Unique Samples			10
13												
14			Raw Statistics					Log-transformed Statistics				
15				Minimum		0.871			Minimum of Log Data			-0.138
16				Maximum		44.11			Maximum of Log Data			3.787
17				Mean		9.73			Mean of log Data			1.64
18				Median		5.138			SD of log Data			1.208
19				SD		12.87						
20			Coefficient of Variation			1.323						
21				Skewness		2.506						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test					Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic			0.675			Shapiro Wilk Test Statistic			0.971
26			Shapiro Wilk Critical Value			0.842			Shapiro Wilk Critical Value			0.842
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution					Assuming Lognormal Distribution				
30			95% Student's-t UCL			17.19			95% H-UCL			44.52
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				26.47
32			95% Adjusted-CLT UCL			19.87			97.5% Chebyshev (MVUE) UCL			33.77
33			95% Modified-t UCL			17.73			99% Chebyshev (MVUE) UCL			48.11
34												
35			Gamma Distribution Test					Data Distribution				
36			k star (bias corrected)			0.709		Data appear Gamma Distributed at 5% Significance Level				
37				Theta Star		13.72						
38				nu star		14.19						
39		Approximate Chi Square Value (.05)				6.701			Nonparametric Statistics			
40			Adjusted Level of Significance			0.0267			95% CLT UCL			16.42
41			Adjusted Chi Square Value			5.83			95% Jackknife UCL			17.19
42									95% Standard Bootstrap UCL			16.09
43			Anderson-Darling Test Statistic			0.327			95% Bootstrap-t UCL			29.2
44			Anderson-Darling 5% Critical Value			0.751			95% Hall's Bootstrap UCL			41.07
45			Kolmogorov-Smirnov Test Statistic			0.165			95% Percentile Bootstrap UCL			16.99
46			Kolmogorov-Smirnov 5% Critical Value			0.274			95% BCA Bootstrap UCL			20.29
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL				27.47
48									97.5% Chebyshev(Mean, Sd) UCL			35.15
49			Assuming Gamma Distribution					99% Chebyshev(Mean, Sd) UCL				50.23
50			95% Approximate Gamma UCL			20.6						
51			95% Adjusted Gamma UCL			23.68						
52												
53		Potential UCL to Use						Use 95% Approximate Gamma UCL				20.6
54												

Table 8	**General UCL Statistics for Data Sets with Non-Detects, Spoils EA-4 Vanadium**		

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

V

General Statistics

Number of Valid Samples	10	Number of Detected Data	7
Number of Unique Samples	7	Number of Non-Detect Data	3
		Percent Non-Detects	30.00%

Raw Statistics		Log-transformed Statistics	
Minimum Detected	2.686	Minimum Detected	0.988
Maximum Detected	26.28	Maximum Detected	3.269
Mean of Detected	13.29	Mean of Detected	2.419
SD of Detected	7.133	SD of Detected	0.707
Minimum Non-Detect	8	Minimum Non-Detect	2.079
Maximum Non-Detect	8	Maximum Non-Detect	2.079

UCL Statistics

Normal Distribution Test with Detected Values Only		Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.927	Shapiro Wilk Test Statistic	0.851
5% Shapiro Wilk Critical Value	0.803	5% Shapiro Wilk Critical Value	0.803
Data appear Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
DL/2 Substitution Method		DL/2 Substitution Method	
Mean	10.5	Mean	2.109
SD	7.351	SD	0.763
95% DL/2 (t) UCL	14.76	95% H-Stat (DL/2) UCL	22.4
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	
Mean	9.912	Mean in Log Scale	2.062
SD	8.08	SD in Log Scale	0.832
95% MLE (t) UCL	14.6	Mean in Original Scale	10.37
95% MLE (Tiku) UCL	15.19	SD in Original Scale	7.504
		95% Percentile Bootstrap UCL	14.26
		95% BCA Bootstrap UCL	14.64

Gamma Distribution Test with Detected Values Only		Data Distribution Test with Detected Values Only	
k star (bias corrected)	1.885	**Data appear Normal at 5% Significance Level**	
Theta Star	7.05		
nu star	26.38		
A-D Test Statistic	0.453	Nonparametric Statistics	
5% A-D Critical Value	0.712	Kaplan-Meier (KM) Method	
K-S Test Statistic	0.712	Mean	10.11
5% K-S Critical Value	0.314	SD	7.357
Data appear Gamma Distributed at 5% Significance Level		SE of Mean	2.513
		95% KM (t) UCL	14.71
Assuming Gamma Distribution		95% KM (z) UCL	14.24
Gamma ROS Statistics using Extrapolated Data		95% KM (jackknife) UCL	14.79
Minimum	2.686	95% KM (bootstrap t) UCL	15.32
Maximum	26.28	95% KM (BCA) UCL	16.52
Mean	12.03	95% KM (Percentile Bootstrap) UCL	15.52
Median	11.77	95% KM (Chebyshev) UCL	21.06
SD	6.355	97.5% KM (Chebyshev) UCL	25.8
k star	2.572	99% KM (Chebyshev) UCL	35.11
Theta star	4.678		
Nu star	51.44	**Potential UCLs to Use**	
AppChi2	35.97	95% KM (t) UCL	14.71
95% Gamma Approximate UCL	17.21	95% KM (Percentile Bootstrap) UCL	15.52
95% Adjusted Gamma UCL	18.35		

Note: DL/2 is not a recommended method.

Appendix B-5
Exposure Point Concentrations and ProUCL Results
Exposure Area 5, Deep Adit Area

			Table 1	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-5 Antimony							
		User Selected Options									
		From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils								
		Full Precision	OFF								
		Confidence Coefficient	95%								
	Number of Bootstrap Operations		2000								
Sb											
			General Statistics								
		Number of Valid Samples	16			Number of Detected Data					6
		Number of Unique Samples	6			Number of Non-Detect Data					10
						Percent Non-Detects					62.50%
		Raw Statistics				Log-transformed Statistics					
		Minimum Detected	110.4		Log Statistics Not Avaliable						
		Maximum Detected	228.9								
		Mean of Detected	179.3								
		Mean of Detected	179.3								
		Mean of Detected	179.3								
		Maximum Non-Detect	0								
			UCL Statistics								
	Normal Distribution Test with Detected Values Only					Lognormal Distribution Test with Detected Values Only					
		Shapiro Wilk Test Statistic	0.85			Not Available					
		5% Shapiro Wilk Critical Value	0.788								
	Data appear Normal at 5% Significance Level										
	Assuming Normal Distribution					Assuming Lognormal Distribution					
		DL/2 Substitution Method				DL/2 Substitution Method					N/A
		Mean	67.22								
		SD	93.62								
		95% DL/2 (t) UCL	108.2								
	Maximum Likelihood Estimate(MLE) Method					Log ROS Method					N/A
		Mean	-46.77								
		SD	205.8								
		95% MLE (t) UCL	43.41								
		95% MLE (Tiku) UCL	84.12								
	Gamma Distribution Test with Detected Values Only					Data Distribution Test with Detected Values Only					
	Gamma Statistics Not Available					Data appear Normal at 5% Significance Level					
	Potential UCLs to Use					Nonparametric Statistics					
		95% KM (t) UCL	156.6			Kaplan-Meier (KM) Method					
	95% KM (Percentile Bootstrap) UCL		202.8			Mean					136.2
						SD					42.4
						SE of Mean					11.61
						95% KM (t) UCL					156.6
						95% KM (z) UCL					155.3
						95% KM (jackknife) UCL					155.4
						95% KM (bootstrap t) UCL					153.5
						95% KM (BCA) UCL					204.7
						95% KM (Percentile Bootstrap) UCL					202.8
						95% KM (Chebyshev) UCL					186.8
						97.5% KM (Chebyshev) UCL					208.7
						99% KM (Chebyshev) UCL					251.7
Note: DL/2 is not a recommended method.											

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 2	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-5 Arsenic							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils								
4		Full Precision		OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	As											
10												
11					General Statistics							
12				Number of Valid Samples	16				Number of Unique Samples	16		
13												
14			Raw Statistics					Log-transformed Statistics				
15				Minimum	371.9				Minimum of Log Data	5.919		
16				Maximum	2940				Maximum of Log Data	7.986		
17				Mean	981.7				Mean of log Data	6.771		
18				Median	835.1				SD of log Data	0.473		
19				SD	591.9							
20			Coefficient of Variation		0.603							
21				Skewness	2.635							
22												
23					Relevant UCL Statistics							
24		Normal Distribution Test						Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic		0.721				Shapiro Wilk Test Statistic	0.947		
26			Shapiro Wilk Critical Value		0.887				Shapiro Wilk Critical Value	0.887		
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30				95% Student's-t UCL	1241				95% H-UCL	1250		
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL		1482		
32			95% Adjusted-CLT UCL		1329				97.5% Chebyshev (MVUE) UCL	1704		
33			95% Modified-t UCL		1257				99% Chebyshev (MVUE) UCL	2140		
34												
35		Gamma Distribution Test						Data Distribution				
36			k star (bias corrected)		3.61			Data appear Gamma Distributed at 5% Significance Level				
37			Theta Star		272							
38			nu star		115.5							
39		Approximate Chi Square Value (.05)			91.69				Nonparametric Statistics			
40		Adjusted Level of Significance			0.0335				95% CLT UCL	1225		
41		Adjusted Chi Square Value			89.28				95% Jackknife UCL	1241		
42									95% Standard Bootstrap UCL	1211		
43		Anderson-Darling Test Statistic			0.599				95% Bootstrap-t UCL	1480		
44		Anderson-Darling 5% Critical Value			0.742				95% Hall's Bootstrap UCL	2375		
45		Kolmogorov-Smirnov Test Statistic			0.183				95% Percentile Bootstrap UCL	1239		
46		Kolmogorov-Smirnov 5% Critical Value			0.216				95% BCA Bootstrap UCL	1381		
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL		1627		
48								97.5% Chebyshev(Mean, Sd) UCL		1906		
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL		2454		
50		95% Approximate Gamma UCL			1237							
51		95% Adjusted Gamma UCL			1270							
52												
53		Potential UCL to Use						Use 95% Approximate Gamma UCL		1237		
54												

	Table 3	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-5 Cobalt						
User Selected Options								
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils							
Full Precision	OFF							
Confidence Coefficient	95%							
Number of Bootstrap Operations	2000							

Co

General Statistics				
Number of Valid Samples	16	Number of Detected Data	5
Number of Unique Samples	5	Number of Non-Detect Data	11
		Percent Non-Detects	68.75%

Raw Statistics		**Log-transformed Statistics**	
Minimum Detected	873.6	Log Statistics Not Avaliable	
Maximum Detected	1774		
Mean of Detected	1248		
Mean of Detected	1248		
Mean of Detected	1248		
Maximum Non-Detect	0		

UCL Statistics			
Normal Distribution Test with Detected Values Only		**Lognormal Distribution Test with Detected Values Only**	
Shapiro Wilk Test Statistic	0.919	Not Available	
5% Shapiro Wilk Critical Value	0.762		
Data appear Normal at 5% Significance Level			
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
DL/2 Substitution Method		DL/2 Substitution Method	N/A
Mean	389.9		
SD	628		
95% DL/2 (t) UCL	665.1		
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	N/A
Mean	1248		
SD	335.9		
95% MLE (t) UCL	1395		
95% MLE (Tiku) UCL	1511		
Gamma Distribution Test with Detected Values Only		**Data Distribution Test with Detected Values Only**	
Gamma Statistics Not Available		Data appear Normal at 5% Significance Level	
Potential UCLs to Use		**Nonparametric Statistics**	
95% KM (t) UCL	1116	Kaplan-Meier (KM) Method	
95% KM (Percentile Bootstrap) UCL	1217	Mean	990.5
		SD	255.6
		SE of Mean	71.43
		95% KM (t) UCL	1116
		95% KM (z) UCL	1108
		95% KM (jackknife) UCL	1102
		95% KM (bootstrap t) UCL	1113
		95% KM (BCA) UCL	1529
		95% KM (Percentile Bootstrap) UCL	1217
		95% KM (Chebyshev) UCL	1302
		97.5% KM (Chebyshev) UCL	1437
		99% KM (Chebyshev) UCL	1701

Note: DL/2 is not a recommended method.

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 4	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-5 Copper							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils								
4			Full Precision	OFF								
5			Confidence Coefficient	95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Cu											
10												
11					General Statistics							
12			Number of Valid Samples	16					Number of Unique Samples	16		
13												
14		Raw Statistics					Log-transformed Statistics					
15				Minimum	410.1				Minimum of Log Data	6.016		
16				Maximum	3404				Maximum of Log Data	8.133		
17				Mean	1210				Mean of log Data	6.897		
18				Median	920				SD of log Data	0.622		
19				SD	897.8							
20			Coefficient of Variation	0.742								
21				Skewness	1.684							
22												
23					Relevant UCL Statistics							
24		Normal Distribution Test					Lognormal Distribution Test					
25			Shapiro Wilk Test Statistic	0.77				Shapiro Wilk Test Statistic		0.935		
26			Shapiro Wilk Critical Value	0.887				Shapiro Wilk Critical Value		0.887		
27		Data not Normal at 5% Significance Level					Data appear Lognormal at 5% Significance Level					
28												
29		Assuming Normal Distribution					Assuming Lognormal Distribution					
30			95% Student's-t UCL	1603					95% H-UCL	1707		
31		95% UCLs (Adjusted for Skewness)					95% Chebyshev (MVUE) UCL			2024		
32			95% Adjusted-CLT UCL	1680				97.5% Chebyshev (MVUE) UCL		2387		
33			95% Modified-t UCL	1619				99% Chebyshev (MVUE) UCL		3101		
34												
35		Gamma Distribution Test					Data Distribution					
36			k star (bias corrected)	2.188			Data appear Gamma Distributed at 5% Significance Level					
37			Theta Star	552.9								
38			nu star	70.03								
39			Approximate Chi Square Value (.05)	51.76			Nonparametric Statistics					
40			Adjusted Level of Significance	0.0335					95% CLT UCL	1579		
41			Adjusted Chi Square Value	49.98					95% Jackknife UCL	1603		
42									95% Standard Bootstrap UCL	1566		
43			Anderson-Darling Test Statistic	0.719					95% Bootstrap-t UCL	1863		
44			Anderson-Darling 5% Critical Value	0.746					95% Hall's Bootstrap UCL	2036		
45			Kolmogorov-Smirnov Test Statistic	0.203					95% Percentile Bootstrap UCL	1587		
46			Kolmogorov-Smirnov 5% Critical Value	0.217					95% BCA Bootstrap UCL	1669		
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL	2188		
48									97.5% Chebyshev(Mean, Sd) UCL	2612		
49		Assuming Gamma Distribution							99% Chebyshev(Mean, Sd) UCL	3443		
50			95% Approximate Gamma UCL	1637								
51			95% Adjusted Gamma UCL	1695								
52												
53		Potential UCL to Use						Use 95% Approximate Gamma UCL		1637		
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 5	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-5 Iron							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils								
4		Full Precision		OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Fe											
10												
11						General Statistics						
12				Number of Valid Samples		16			Number of Unique Samples			16
13												
14				Raw Statistics					Log-transformed Statistics			
15				Minimum		93685			Minimum of Log Data			11.45
16				Maximum		363041			Maximum of Log Data			12.8
17				Mean		191976			Mean of log Data			12.11
18				Median		169098			SD of log Data			0.342
19				SD		70183						
20				Coefficient of Variation		0.366						
21				Skewness		1.186						
22												
23						Relevant UCL Statistics						
24				Normal Distribution Test					Lognormal Distribution Test			
25				Shapiro Wilk Test Statistic		0.887			Shapiro Wilk Test Statistic			0.957
26				Shapiro Wilk Critical Value		0.887			Shapiro Wilk Critical Value			0.887
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30				95% Student's-t UCL		222735			95% H-UCL			227605
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				264088
32				95% Adjusted-CLT UCL		226394			97.5% Chebyshev (MVUE) UCL			295454
33				95% Modified-t UCL		223602			99% Chebyshev (MVUE) UCL			357066
34												
35				Gamma Distribution Test					Data Distribution			
36				k star (bias corrected)		7.354		Data appear Gamma Distributed at 5% Significance Level				
37				Theta Star		26105						
38				nu star		235.3						
39				Approximate Chi Square Value (.05)		200.8			Nonparametric Statistics			
40				Adjusted Level of Significance		0.0335			95% CLT UCL			220837
41				Adjusted Chi Square Value		197.2			95% Jackknife UCL			222735
42									95% Standard Bootstrap UCL			220357
43				Anderson-Darling Test Statistic		0.553			95% Bootstrap-t UCL			233579
44				Anderson-Darling 5% Critical Value		0.739			95% Hall's Bootstrap UCL			232615
45				Kolmogorov-Smirnov Test Statistic		0.214			95% Percentile Bootstrap UCL			220735
46				Kolmogorov-Smirnov 5% Critical Value		0.215			95% BCA Bootstrap UCL			226565
47		Data appear Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL				268456
48									97.5% Chebyshev(Mean, Sd) UCL			301549
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL				366554
50				95% Approximate Gamma UCL		224969						
51				95% Adjusted Gamma UCL		229108						
52												
53		Potential UCL to Use						Use 95% Approximate Gamma UCL				224969
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 6		General UCL Statistics for Full Data Sets, Spoils, EA-5 Lead						
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils								
4		Full Precision		OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Pb											
10												
11						General Statistics						
12				Number of Valid Samples		16				Number of Unique Samples		16
13												
14			Raw Statistics						Log-transformed Statistics			
15					Minimum	1128				Minimum of Log Data		7.028
16					Maximum	22877				Maximum of Log Data		10.04
17					Mean	7846				Mean of log Data		8.739
18					Median	7442				SD of log Data		0.749
19					SD	5331						
20				Coefficient of Variation		0.679						
21					Skewness	1.494						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test						Lognormal Distribution Test			
25				Shapiro Wilk Test Statistic		0.883				Shapiro Wilk Test Statistic		0.956
26				Shapiro Wilk Critical Value		0.887				Shapiro Wilk Critical Value		0.887
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30				95% Student's-t UCL		10182				95% H-UCL		13018
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				15108
32			95% Adjusted-CLT UCL			10570			97.5% Chebyshev (MVUE) UCL			18147
33			95% Modified-t UCL			10265			99% Chebyshev (MVUE) UCL			24116
34												
35		Gamma Distribution Test						Data Distribution				
36				k star (bias corrected)		1.939		Data appear Gamma Distributed at 5% Significance Level				
37					Theta Star	4045						
38					nu star	62.06						
39			Approximate Chi Square Value (.05)			44.94			Nonparametric Statistics			
40			Adjusted Level of Significance			0.0335				95% CLT UCL		10038
41			Adjusted Chi Square Value			43.29				95% Jackknife UCL		10182
42										95% Standard Bootstrap UCL		9963
43			Anderson-Darling Test Statistic			0.248				95% Bootstrap-t UCL		11070
44			Anderson-Darling 5% Critical Value			0.748				95% Hall's Bootstrap UCL		12965
45			Kolmogorov-Smirnov Test Statistic			0.111				95% Percentile Bootstrap UCL		10047
46			Kolmogorov-Smirnov 5% Critical Value			0.217				95% BCA Bootstrap UCL		10544
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL			13655
48										97.5% Chebyshev(Mean, Sd) UCL		16168
49		Assuming Gamma Distribution							99% Chebyshev(Mean, Sd) UCL			21106
50			95% Approximate Gamma UCL			10834						
51			95% Adjusted Gamma UCL			11249						
52												
53		Potential UCL to Use							Use 95% Approximate Gamma UCL			10834
54												

	Table 7	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-5 Manganese									
	User Selected Options										
	From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils									
	Full Precision	OFF									
	Confidence Coefficient	95%									
	Number of Bootstrap Operations	2000									
Mn											
			General Statistics								
	Number of Valid Samples	15					Number of Unique Samples	15			
	Raw Statistics					**Log-transformed Statistics**					
	Minimum	489.1				Minimum of Log Data	6.193				
	Maximum	957.4				Maximum of Log Data	6.864				
	Mean	711.7				Mean of log Data	6.55				
	Median	709.7				SD of log Data	0.198				
	SD	138.1									
	Coefficient of Variation	0.194									
	Skewness	0.151									
			Relevant UCL Statistics								
	Normal Distribution Test					**Lognormal Distribution Test**					
	Shapiro Wilk Test Statistic	0.966				Shapiro Wilk Test Statistic	0.963				
	Shapiro Wilk Critical Value	0.881				Shapiro Wilk Critical Value	0.881				
	Data appear Normal at 5% Significance Level					**Data appear Lognormal at 5% Significance Level**					
	Assuming Normal Distribution					**Assuming Lognormal Distribution**					
	95% Student's-t UCL	774.5				95% H-UCL	784.4				
	95% UCLs (Adjusted for Skewness)					95% Chebyshev (MVUE) UCL	871.4				
	95% Adjusted-CLT UCL	771.8				97.5% Chebyshev (MVUE) UCL	940.5				
	95% Modified-t UCL	774.7				99% Chebyshev (MVUE) UCL	1076				
	Gamma Distribution Test					**Data Distribution**					
	k star (bias corrected)	22.39				**Data appear Normal at 5% Significance Level**					
	Theta Star	31.79									
	nu star	671.6									
	Approximate Chi Square Value (.05)	612.5				**Nonparametric Statistics**					
	Adjusted Level of Significance	0.0324				95% CLT UCL	770.3				
	Adjusted Chi Square Value	605.5				95% Jackknife UCL	774.5				
						95% Standard Bootstrap UCL	769.3				
	Anderson-Darling Test Statistic	0.222				95% Bootstrap-t UCL	779.4				
	Anderson-Darling 5% Critical Value	0.735				95% Hall's Bootstrap UCL	776				
	Kolmogorov-Smirnov Test Statistic	0.112				95% Percentile Bootstrap UCL	767				
	Kolmogorov-Smirnov 5% Critical Value	0.221				95% BCA Bootstrap UCL	768.6				
	Data appear Gamma Distributed at 5% Significance Level					95% Chebyshev(Mean, Sd) UCL	867.1				
						97.5% Chebyshev(Mean, Sd) UCL	934.4				
	Assuming Gamma Distribution					99% Chebyshev(Mean, Sd) UCL	1066				
	95% Approximate Gamma UCL	780.4									
	95% Adjusted Gamma UCL	789.3									
	Potential UCL to Use					Use 95% Student's-t UCL	774.5				

	Table 8	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-5 Thallium

Table 8 General UCL Statistics for Data Sets with Non-Detects, Spoils EA-5 Thallium

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\Spoils
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Thallium

General Statistics

Number of Valid Samples	16	Number of Detected Data	13
Number of Unique Samples	13	Number of Non-Detect Data	3
		Percent Non-Detects	18.75%

Raw Statistics		Log-transformed Statistics	
Minimum Detected	111.7	Log Statistics Not Avaliable	
Maximum Detected	949.3		
Mean of Detected	342.8		
Mean of Detected	342.8		
Mean of Detected	342.8		
Maximum Non-Detect	0		

UCL Statistics

Normal Distribution Test with Detected Values Only		Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.852	Not Available	
5% Shapiro Wilk Critical Value	0.866		
Data not Normal at 5% Significance Level			

Assuming Normal Distribution		Assuming Lognormal Distribution	
DL/2 Substitution Method		DL/2 Substitution Method	N/A
Mean	278.5		
SD	255.3		
95% DL/2 (t) UCL	390.4		
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	N/A
Mean	247.9		
SD	292.7		
95% MLE (t) UCL	376.2		
95% MLE (Tiku) UCL	379.2		

Gamma Distribution Test with Detected Values Only		Data Distribution Test with Detected Values Only	
Gamma Statistics Not Available		Data appear Gamma Distributed at 5% Significance Level	

Potential UCLs to Use		Nonparametric Statistics	
95% KM (BCA) UCL	404	Kaplan-Meier (KM) Method	
		Mean	299.5
		SD	226.6
		SE of Mean	58.96
		95% KM (t) UCL	402.8
		95% KM (z) UCL	396.4
		95% KM (jackknife) UCL	401.8
		95% KM (bootstrap t) UCL	453.6
		95% KM (BCA) UCL	404
		95% KM (Percentile Bootstrap) UCL	402.8
		95% KM (Chebyshev) UCL	556.5
		97.5% KM (Chebyshev) UCL	667.7
		99% KM (Chebyshev) UCL	886.1

Note: DL/2 is not a recommended method.

Appendix B-6
Exposure Point Concentrations and ProUCL Results
Exposure Area 6, West Avoca

	Table 1	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-6 Antimony

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Sb

General Statistics

Number of Valid Samples	36	Number of Detected Data	27
Number of Unique Samples	27	Number of Non-Detect Data	9
		Percent Non-Detects	25.00%

Raw Statistics		Log-transformed Statistics	
Minimum Detected	0.227	Minimum Detected	-1.484
Maximum Detected	19.93	Maximum Detected	2.992
Mean of Detected	3.982	Mean of Detected	0.784
SD of Detected	5.009	SD of Detected	1.154
Minimum Non-Detect	0.2	Minimum Non-Detect	-1.609
Maximum Non-Detect	0.2	Maximum Non-Detect	-1.609

UCL Statistics

Normal Distribution Test with Detected Values Only		Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.661	Shapiro Wilk Test Statistic	0.974
5% Shapiro Wilk Critical Value	0.923	5% Shapiro Wilk Critical Value	0.923
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	

Assuming Normal Distribution		Assuming Lognormal Distribution	
DL/2 Substitution Method		DL/2 Substitution Method	
Mean	3.012	Mean	0.0123
SD	4.642	SD	1.681
95% DL/2 (t) UCL	4.319	95% H-Stat (DL/2) UCL	4.834
Maximum Likelihood Estimate(MLE) Method		Log ROS Method	
Mean	2.073	Mean in Log Scale	0.109
SD	5.602	SD in Log Scale	1.579
95% MLE (t) UCL	3.651	Mean in Original Scale	3.03
95% MLE (Tiku) UCL	3.673	SD in Original Scale	4.63
		95% Percentile Bootstrap UCL	4.391
		95% BCA Bootstrap UCL	4.757

Gamma Distribution Test with Detected Values Only		Data Distribution Test with Detected Values Only	
k star (bias corrected)	0.886	Data appear Gamma Distributed at 5% Significance Level	
Theta Star	4.494		
nu star	47.85		
A-D Test Statistic	0.487	Nonparametric Statistics	
5% A-D Critical Value	0.775	Kaplan-Meier (KM) Method	
K-S Test Statistic	0.775	Mean	3.043
5% K-S Critical Value	0.173	SD	4.557
Data appear Gamma Distributed at 5% Significance Level		SE of Mean	0.774
		95% KM (t) UCL	4.351
Assuming Gamma Distribution		95% KM (z) UCL	4.316
Gamma ROS Statistics using Extrapolated Data		95% KM (jackknife) UCL	4.327
Minimum	0	95% KM (bootstrap t) UCL	5.607
Maximum	19.93	95% KM (BCA) UCL	4.425
Mean	3.048	95% KM (Percentile Bootstrap) UCL	4.404
Median	1.261	95% KM (Chebyshev) UCL	6.417
SD	4.623	97.5% KM (Chebyshev) UCL	7.877
k star	0.188	99% KM (Chebyshev) UCL	10.74
Theta star	16.17		
Nu star	13.57	Potential UCLs to Use	
AppChi2	6.279	95% KM (Chebyshev) UCL	6.417
95% Gamma Approximate UCL	6.589		
95% Adjusted Gamma UCL	6.834		

Note: DL/2 is not a recommended method.

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 2	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-6 Arsenic							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4		Full Precision		OFF								
5		Confidence Coefficient		95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	As											
10												
11					General Statistics							
12				Number of Valid Samples	36				Number of Unique Samples	36		
13												
14			Raw Statistics					Log-transformed Statistics				
15				Minimum	12.69				Minimum of Log Data	2.541		
16				Maximum	1798				Maximum of Log Data	7.494		
17				Mean	551.9				Mean of log Data	5.084		
18				Median	167.5				SD of log Data	1.857		
19				SD	645.6							
20			Coefficient of Variation		1.17							
21				Skewness	0.75							
22												
23					Relevant UCL Statistics							
24			Normal Distribution Test					Lognormal Distribution Test				
25			Shapiro Wilk Test Statistic		0.757				Shapiro Wilk Test Statistic	0.855		
26			Shapiro Wilk Critical Value		0.935				Shapiro Wilk Critical Value	0.935		
27		Data not Normal at 5% Significance Level						Data not Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution					Assuming Lognormal Distribution				
30			95% Student's-t UCL		733.7				95% H-UCL	2744		
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL		2289		
32			95% Adjusted-CLT UCL		743.2				97.5% Chebyshev (MVUE) UCL	2930		
33			95% Modified-t UCL		735.9				99% Chebyshev (MVUE) UCL	4191		
34												
35			Gamma Distribution Test					Data Distribution				
36			k star (bias corrected)		0.49			Data do not follow a Discernable Distribution (0.05)				
37				Theta Star	1126							
38				nu star	35.28							
39		Approximate Chi Square Value (.05)			22.69			Nonparametric Statistics				
40			Adjusted Level of Significance		0.0428				95% CLT UCL	728.8		
41			Adjusted Chi Square Value		22.23				95% Jackknife UCL	733.7		
42									95% Standard Bootstrap UCL	724.4		
43			Anderson-Darling Test Statistic		1.916				95% Bootstrap-t UCL	741		
44			Anderson-Darling 5% Critical Value		0.811				95% Hall's Bootstrap UCL	726.4		
45			Kolmogorov-Smirnov Test Statistic		0.179				95% Percentile Bootstrap UCL	723.1		
46			Kolmogorov-Smirnov 5% Critical Value		0.155				95% BCA Bootstrap UCL	758.6		
47		Data not Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL	1021		
48									97.5% Chebyshev(Mean, Sd) UCL	1224		
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL	1622		
50			95% Approximate Gamma UCL		858.1							
51			95% Adjusted Gamma UCL		875.9							
52												
53		Potential UCL to Use							Use 99% Chebyshev (Mean, Sd) UCL	1622		
54												

	Table 3	General UCL Statistics for Data Sets with Non-Detects, Spoils, Cobalt, EA-6							

User Selected Options

From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProUC
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Co

General Statistics

Number of Valid Samples	36		Number of Detected Data	35
Number of Unique Samples	35		Number of Non-Detect Data	1
			Percent Non-Detects	2.78%

Raw Statistics			Log-transformed Statistics	
Minimum Detected	0.566		Minimum Detected	-0.57
Maximum Detected	17.64		Maximum Detected	2.87
Mean of Detected	6.233		Mean of Detected	1.339
SD of Detected	5.549		SD of Detected	1.07
Minimum Non-Detect	0.4		Minimum Non-Detect	-0.916
Maximum Non-Detect	0.4		Maximum Non-Detect	-0.916

UCL Statistics

Normal Distribution Test with Detected Values Only			Lognormal Distribution Test with Detected Values Only	
Shapiro Wilk Test Statistic	0.83		Shapiro Wilk Test Statistic	0.899
5% Shapiro Wilk Critical Value	0.934		5% Shapiro Wilk Critical Value	0.934
Data not Normal at 5% Significance Level			Data not Lognormal at 5% Significance Level	

Assuming Normal Distribution			Assuming Lognormal Distribution	
DL/2 Substitution Method			DL/2 Substitution Method	
Mean	6.065		Mean	1.257
SD	5.561		SD	1.164
95% DL/2 (t) UCL	7.631		95% H-Stat (DL/2) UCL	10.25
Maximum Likelihood Estimate(MLE) Method			Log ROS Method	
Mean	5.989		Mean in Log Scale	1.265
SD	5.597		SD in Log Scale	1.144
95% MLE (t) UCL	7.566		Mean in Original Scale	6.067
95% MLE (Tiku) UCL	7.486		SD in Original Scale	5.559
			95% Percentile Bootstrap UCL	7.684
			95% BCA Bootstrap UCL	7.731

Gamma Distribution Test with Detected Values Only			Data Distribution Test with Detected Values Only	
k star (bias corrected)	1.076		Data do not follow a Discernable Distribution (0.05)	
Theta Star	5.793			
nu star	75.32			
A-D Test Statistic	1.616		Nonparametric Statistics	
5% A-D Critical Value	0.773		Kaplan-Meier (KM) Method	
K-S Test Statistic	0.773		Mean	6.076
5% K-S Critical Value	0.153		SD	5.472
Data not Gamma Distributed at 5% Significance Level			SE of Mean	0.925
			95% KM (t) UCL	7.639
Assuming Gamma Distribution			95% KM (z) UCL	7.598
Gamma ROS Statistics using Extrapolated Data			95% KM (jackknife) UCL	7.636
Minimum	0		95% KM (bootstrap t) UCL	7.704
Maximum	17.64		95% KM (BCA) UCL	7.67
Mean	6.06		95% KM (Percentile Bootstrap) UCL	7.559
Median	2.578		95% KM (Chebyshev) UCL	10.11
SD	5.567		97.5% KM (Chebyshev) UCL	11.85
k star	0.548		99% KM (Chebyshev) UCL	15.28
Theta star	11.06			
Nu star	39.45		Potential UCLs to Use	
AppChi2	26.06		97.5% KM (Chebyshev) UCL	11.85
95% Gamma Approximate UCL	9.173			
95% Adjusted Gamma UCL	9.351			

Note: DL/2 is not a recommended method.

	A	B	C	D	E	F	G	H	I	J	K	L

Table 4 General UCL Statistics for Data Sets with Non-Detects, Spoils,Copper, EA-6

User Selected Options		
From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU	
Full Precision	OFF	
Confidence Coefficient	95%	
Number of Bootstrap Operations	2000	

Cu

<p align="center">General Statistics</p>

Number of Valid Samples	36	Number of Unique Samples	36

Raw Statistics		Log-transformed Statistics	
Minimum	2.493	Minimum of Log Data	0.913
Maximum	2822	Maximum of Log Data	7.945
Mean	399.8	Mean of log Data	4.8
Median	73.9	SD of log Data	1.67
SD	668.8		
Coefficient of Variation	1.673		
Skewness	2.647		

<p align="center">Relevant UCL Statistics</p>

Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.61	Shapiro Wilk Test Statistic	0.949
Shapiro Wilk Critical Value	0.935	Shapiro Wilk Critical Value	0.935
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	

Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	588.2	95% H-UCL	1230
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1174
95% Adjusted-CLT UCL	635.7	97.5% Chebyshev (MVUE) UCL	1488
95% Modified-t UCL	596.3	99% Chebyshev (MVUE) UCL	2103

Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.503	**Data appear Lognormal at 5% Significance Level**	
Theta Star	794.7		
nu star	36.22		
Approximate Chi Square Value (.05)	23.45	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0428	95% CLT UCL	583.2
Adjusted Chi Square Value	22.98	95% Jackknife UCL	588.2
		95% Standard Bootstrap UCL	578.8
Anderson-Darling Test Statistic	1.498	95% Bootstrap-t UCL	724.4
Anderson-Darling 5% Critical Value	0.81	95% Hall's Bootstrap UCL	736.6
Kolmogorov-Smirnov Test Statistic	0.217	95% Percentile Bootstrap UCL	595.3
Kolmogorov-Smirnov 5% Critical Value	0.155	95% BCA Bootstrap UCL	645.2
Data not Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	885.7
		97.5% Chebyshev(Mean, Sd) UCL	1096
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1509
95% Approximate Gamma UCL	617.7		
95% Adjusted Gamma UCL	630.2		
Potential UCL to Use		Use 95% Chebyshev (MVUE) UCL	1174

	A	B	C	D	E	F	G	H	I	J	K	L
1	Table 5			General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-6 Iron								
2	User Selected Options											
3	From File			C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU								
4	Full Precision			OFF								
5	Confidence Coefficient			95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	Fe											
10												
11					General Statistics							
12		Number of Valid Samples			36				Number of Unique Samples			36
13												
14		Raw Statistics						Log-transformed Statistics				
15			Minimum		2.214				Minimum of Log Data			0.795
16			Maximum		29.92				Maximum of Log Data			3.398
17			Mean		12.01				Mean of log Data			2.127
18			Median		9.396				SD of log Data			0.919
19			SD		9.15							
20		Coefficient of Variation			0.762							
21			Skewness		0.55							
22												
23					Relevant UCL Statistics							
24		Normal Distribution Test						Lognormal Distribution Test				
25		Shapiro Wilk Test Statistic			0.871				Shapiro Wilk Test Statistic			0.883
26		Shapiro Wilk Critical Value			0.935				Shapiro Wilk Critical Value			0.935
27		Data not Normal at 5% Significance Level						Data not Lognormal at 5% Significance Level				
28												
29		Assuming Normal Distribution						Assuming Lognormal Distribution				
30		95% Student's-t UCL			14.59				95% H-UCL			18.31
31		95% UCLs (Adjusted for Skewness)						95% Chebyshev (MVUE) UCL				22.17
32		95% Adjusted-CLT UCL			14.67			97.5% Chebyshev (MVUE) UCL				26.32
33		95% Modified-t UCL			14.61			99% Chebyshev (MVUE) UCL				34.46
34												
35		Gamma Distribution Test						Data Distribution				
36		k star (bias corrected)			1.429			Data do not follow a Discernable Distribution (0.05)				
37			Theta Star		8.406							
38			nu star		102.9							
39		Approximate Chi Square Value (.05)			80.45			Nonparametric Statistics				
40		Adjusted Level of Significance			0.0428				95% CLT UCL			14.52
41		Adjusted Chi Square Value			79.56				95% Jackknife UCL			14.59
42									95% Standard Bootstrap UCL			14.45
43		Anderson-Darling Test Statistic			1.123				95% Bootstrap-t UCL			14.91
44		Anderson-Darling 5% Critical Value			0.766				95% Hall's Bootstrap UCL			14.75
45		Kolmogorov-Smirnov Test Statistic			0.165				95% Percentile Bootstrap UCL			14.43
46		Kolmogorov-Smirnov 5% Critical Value			0.15				95% BCA Bootstrap UCL			14.62
47		Data not Gamma Distributed at 5% Significance Level						95% Chebyshev(Mean, Sd) UCL				18.66
48								97.5% Chebyshev(Mean, Sd) UCL				21.53
49		Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL				27.18
50		95% Approximate Gamma UCL			15.35							
51		95% Adjusted Gamma UCL			15.53							
52												
53		Potential UCL to Use						Use 95% Chebyshev (Mean, Sd) UCL				18.66
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 6	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-6, Lead							
2		User Selected Options										
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Da								
4			Full Precision	OFF								
5			Confidence Coefficient	95%								
6		Number of Bootstrap Operations		2000								
7												
8												
9	Pb											
10												
11						General Statistics						
12				Number of Valid Samples		36				Number of Unique Samples		36
13												
14			Raw Statistics						Log-transformed Statistics			
15					Minimum	5.354				Minimum of Log Data		1.678
16					Maximum	28363				Maximum of Log Data		10.25
17					Mean	2165				Mean of log Data		5.792
18					Median	336.2				SD of log Data		2.052
19					SD	5890						
20				Coefficient of Variation		2.721						
21					Skewness	3.945						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test						Lognormal Distribution Test			
25				Shapiro Wilk Test Statistic		0.384				Shapiro Wilk Test Statistic		0.977
26				Shapiro Wilk Critical Value		0.935				Shapiro Wilk Critical Value		0.935
27		Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level				
28												
29			Assuming Normal Distribution						Assuming Lognormal Distribution			
30				95% Student's-t UCL		3823				95% H-UCL		10122
31		95% UCLs (Adjusted for Skewness)							95% Chebyshev (MVUE) UCL			7077
32				95% Adjusted-CLT UCL		4469				97.5% Chebyshev (MVUE) UCL		9146
33				95% Modified-t UCL		3931				99% Chebyshev (MVUE) UCL		13209
34												
35			Gamma Distribution Test						Data Distribution			
36				k star (bias corrected)		0.344		Data Follow Appr. Gamma Distribution at 5% Significance Level				
37					Theta Star	6288						
38					nu star	24.79						
39			Approximate Chi Square Value (.05)			14.45			Nonparametric Statistics			
40				Adjusted Level of Significance		0.0428				95% CLT UCL		3779
41				Adjusted Chi Square Value		14.09				95% Jackknife UCL		3823
42										95% Standard Bootstrap UCL		3770
43				Anderson-Darling Test Statistic		1.752				95% Bootstrap-t UCL		11188
44				Anderson-Darling 5% Critical Value		0.844				95% Hall's Bootstrap UCL		11724
45				Kolmogorov-Smirnov Test Statistic		0.154				95% Percentile Bootstrap UCL		3886
46				Kolmogorov-Smirnov 5% Critical Value		0.158				95% BCA Bootstrap UCL		4625
47		Data follow Appr. Gamma Distribution at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL			6444
48										97.5% Chebyshev(Mean, Sd) UCL		8295
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL			11932
50				95% Approximate Gamma UCL		3713						
51				95% Adjusted Gamma UCL		3808						
52												
53			Potential UCL to Use						Use 95% Adjusted Gamma UCL			3808
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 7	General UCL Statistics for Data Sets with Non-Detects, Spoils, EA-6 Manganese							
2	User Selected Options											
3			From File	C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\Spoils\ProU								
4		Full Precision		OFF								
5		Confidence Coefficient		95%								
6	Number of Bootstrap Operations			2000								
7												
8												
9	Mn											
10												
11						General Statistics						
12			Number of Valid Samples			36				Number of Unique Samples		36
13												
14			Raw Statistics						Log-transformed Statistics			
15				Minimum		11.35				Minimum of Log Data		2.429
16				Maximum		1876				Maximum of Log Data		7.537
17				Mean		617.6				Mean of log Data		5.858
18				Median		467.5				SD of log Data		1.261
19				SD		559.4						
20			Coefficient of Variation			0.906						
21				Skewness		0.876						
22												
23						Relevant UCL Statistics						
24			Normal Distribution Test						Lognormal Distribution Test			
25			Shapiro Wilk Test Statistic			0.86				Shapiro Wilk Test Statistic		0.936
26			Shapiro Wilk Critical Value			0.935				Shapiro Wilk Critical Value		0.935
27		Data not Normal at 5% Significance Level							Data appear Lognormal at 5% Significance Level			
28												
29			Assuming Normal Distribution						Assuming Lognormal Distribution			
30			95% Student's-t UCL			775.1				95% H-UCL		1383
31		95% UCLs (Adjusted for Skewness)							95% Chebyshev (MVUE) UCL			1588
32			95% Adjusted-CLT UCL			785.5				97.5% Chebyshev (MVUE) UCL		1952
33			95% Modified-t UCL			777.4				99% Chebyshev (MVUE) UCL		2667
34												
35			Gamma Distribution Test						Data Distribution			
36			k star (bias corrected)			0.949			Data appear Gamma Distributed at 5% Significance Level			
37				Theta Star		650.7						
38				nu star		68.34						
39			Approximate Chi Square Value (.05)			50.31				Nonparametric Statistics		
40			Adjusted Level of Significance			0.0428				95% CLT UCL		771
41			Adjusted Chi Square Value			49.61				95% Jackknife UCL		775.1
42										95% Standard Bootstrap UCL		767.1
43			Anderson-Darling Test Statistic			0.403				95% Bootstrap-t UCL		801.4
44			Anderson-Darling 5% Critical Value			0.776				95% Hall's Bootstrap UCL		785.1
45			Kolmogorov-Smirnov Test Statistic			0.122				95% Percentile Bootstrap UCL		772.8
46			Kolmogorov-Smirnov 5% Critical Value			0.151				95% BCA Bootstrap UCL		787.3
47		Data appear Gamma Distributed at 5% Significance Level							95% Chebyshev(Mean, Sd) UCL			1024
48										97.5% Chebyshev(Mean, Sd) UCL		1200
49			Assuming Gamma Distribution						99% Chebyshev(Mean, Sd) UCL			1545
50			95% Approximate Gamma UCL			838.9						
51			95% Adjusted Gamma UCL			850.8						
52												
53		Potential UCL to Use							Use 95% Approximate Gamma UCL			838.9
54												

	A	B	C	D	E	F	G	H	I	J	K	L
1				Table 8	General UCL Statistics for Data Sets with Non-Detects, Spoils EA-6 Vanadium							
2			User Selected Options									
3				From File		C:\Documents and Settings\marcumtr\My Documents\1_PROJECTS_WORKING\Ireland\2008\Data\ProUCL_Dat						
4			Full Precision			OFF						
5			Confidence Coefficient			95%						
6		Number of Bootstrap Operations				2000						
7												
8												
9	V											
10												
11						General Statistics						
12				Number of Valid Samples		36			Number of Detected Data			33
13				Number of Unique Samples		32			Number of Non-Detect Data			3
14									Percent Non-Detects			8.33%
15												
16			Raw Statistics						Log-transformed Statistics			
17				Minimum Detected		2.65			Minimum Detected			0.974
18				Maximum Detected		179.9			Maximum Detected			5.192
19				Mean of Detected		27.78			Mean of Detected			2.991
20				SD of Detected		31.51			SD of Detected			0.797
21				Minimum Non-Detect		8			Minimum Non-Detect			2.079
22				Maximum Non-Detect		8			Maximum Non-Detect			2.079
23												
24												
25						UCL Statistics						
26			Normal Distribution Test with Detected Values Only						Lognormal Distribution Test with Detected Values Only			
27				Shapiro Wilk Test Statistic		0.572			Shapiro Wilk Test Statistic			0.944
28			5% Shapiro Wilk Critical Value			0.931			5% Shapiro Wilk Critical Value			0.931
29			Data not Normal at 5% Significance Level						Data appear Lognormal at 5% Significance Level			
30												
31			Assuming Normal Distribution						Assuming Lognormal Distribution			
32				DL/2 Substitution Method					DL/2 Substitution Method			
33					Mean	25.8			Mean			2.857
34					SD	30.86			SD			0.885
35				95% DL/2 (t) UCL		34.49			95% H-Stat (DL/2) UCL			33.2
36												
37			Maximum Likelihood Estimate(MLE) Method						Log ROS Method			
38					Mean	23.4			Mean in Log Scale			2.866
39					SD	33.32			SD in Log Scale			0.873
40				95% MLE (t) UCL		32.78			Mean in Original Scale			25.85
41				95% MLE (Tiku) UCL		32.37			SD in Original Scale			30.82
42									95% Percentile Bootstrap UCL			35.35
43									95% BCA Bootstrap UCL			39.92
44												
45			Gamma Distribution Test with Detected Values Only						Data Distribution Test with Detected Values Only			
46				k star (bias corrected)		1.516			Data appear Lognormal at 5% Significance Level			
47					Theta Star	18.33						
48					nu star	100.1						
49												
50				A-D Test Statistic		1.274			Nonparametric Statistics			
51				5% A-D Critical Value		0.763			Kaplan-Meier (KM) Method			
52				K-S Test Statistic		0.763			Mean			25.72
53				5% K-S Critical Value		0.156			SD			30.49
54			Data not Gamma Distributed at 5% Significance Level						SE of Mean			5.16
55									95% KM (t) UCL			34.43
56			Assuming Gamma Distribution						95% KM (z) UCL			34.2
57			Gamma ROS Statistics using Extrapolated Data						95% KM (jackknife) UCL			34.42
58					Minimum	0			95% KM (bootstrap t) UCL			43.22
59					Maximum	179.9			95% KM (BCA) UCL			36.83
60					Mean	25.47			95% KM (Percentile Bootstrap) UCL			34.91
61					Median	16.78			95% KM (Chebyshev) UCL			48.21
62					SD	31.12			97.5% KM (Chebyshev) UCL			57.94
63					k star	0.361			99% KM (Chebyshev) UCL			77.06
64					Theta star	70.54						
65					Nu star	25.99			Potential UCLs to Use			
66					AppChi2	15.37			95% KM (Chebyshev) UCL			48.21
67				95% Gamma Approximate UCL		43.06						
68				95% Adjusted Gamma UCL		44.12						
69		Note: DL/2 is not a recommended method.										
70												

Appendix C
Risk Calculations

Table 1 Summary of Risks and Hazards for Avoca Spoil Exposure Areas
Avoca Mining Site

COPC	Recreational Scenario				Commercial/Industrial Worker		Construction Worker	
	Cancer Risk		Hazard Index		Cancer Risk	Index	Cancer Risk	Index
	Adult	Teen	Adult	Teen	Adult	Adult	Adult	Adult
EA-1	Connary							
Antimony	NC	NC	2.0E-02	2.6E-02	NC	4.9E-02	NC	8.5E-02
Arsenic	1.11E-06	3.88E-07	6.0E-03	7.8E-03	2.88E-06	2.6E-02	1.61E-07	2.9E-02
Cobalt	NC	NC	1.7E-05	2.2E-05	NC	6.1E-05	NC	8.1E-05
Copper	NC	NC	2.7E-02	3.5E-02	NC	6.5E-02	NC	1.1E-01
Iron	NC	NC	4.6E-06	5.9E-06	NC	1.1E-05	NC	1.9E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	5.1E-03	6.4E-03	NC	1.2E-02	NC	2.1E-02
Thallium	NC	NC	0.0E+00	NC	NC	0.0E+00	NC	NC
Vanadium	NC	NC	4.3E-03	5.4E-03	NC	1.0E-02	NC	1.8E-02
Total	1.E-06	4.E-07	0.06	0.08	3.E-06	0.16	2.E-07	0.27
EA-2	Mount Platt/ Cronebane							
Antimony	NC	NC	4.1E-03	5.3E-03	NC	1.0E-02	NC	1.7E-02
Arsenic	4.41E-07	1.53E-07	2.5E-03	3.2E-03	1.32E-06	1.4E-02	6.71E-08	1.4E-02
Cobalt	NC	NC	3.9E-05	4.9E-05	NC	1.4E-04	NC	1.8E-04
Copper	NC	NC	6.9E-03	8.8E-03	NC	1.7E-02	NC	2.9E-02
Iron	NC	NC	4.1E-06	5.2E-06	NC	9.8E-06	NC	1.7E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	3.4E-03	4.3E-03	NC	8.1E-03	NC	1.4E-02
Thallium	NC	NC	0.0E+00	0.0E+00	NC	0.0E+00	NC	NC
Vanadium	NC	NC	2.2E-03	2.8E-03	NC	5.4E-03	NC	9.4E-03
Total	4.E-07	2.E-07	0.02	0.02	1.E-06	0.05	7.E-08	0.08
EA-3	East Avoca/Tigroney West							
Antimony	NC	NC	2.5E-03	3.1E-03	NC	5.9E-03	NC	1.0E-02
Arsenic	4.64E-07	1.61E-07	2.6E-03	3.4E-03	1.40E-06	1.5E-02	7.07E-08	1.4E-02
Cobalt	NC	NC	7.3E-05	9.1E-05	NC	2.6E-04	NC	3.4E-04
Copper	NC	NC	2.3E-02	2.9E-02	NC	5.4E-02	NC	9.5E-02
Iron	NC	NC	8.3E-06	1.1E-05	NC	2.0E-05	NC	3.5E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	1.2E-02	1.6E-02	NC	2.9E-02	NC	5.1E-02
Thallium	NC	NC	0.0E+00	0.0E+00	NC	0.0E+00	NC	NC
Vanadium	NC	NC	8.0E-03	1.0E-02	NC	1.9E-02	NC	3.4E-02
Total	5.E-07	2.E-07	0.05	0.06	1.E-06	0.12	7.E-08	0.20
EA-4	Ore Bins	Tigroney West						
Antimony	NC	NC	2.1E-02	2.7E-02	NC	5.0E-02	NC	8.8E-02
Arsenic	7.47E-06	2.62E-06	3.9E-02	5.2E-02	1.74E-05	1.3E-01	1.05E-06	1.7E-01
Cobalt	NC	NC	1.0E-04	1.3E-04	NC	3.6E-04	NC	4.8E-04
Copper	NC	NC	4.9E-02	6.2E-02	NC	1.2E-01	NC	2.0E-01
Iron	NC	NC	8.1E-06	1.0E-05	NC	1.9E-05	NC	3.4E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	8.6E-03	1.1E-02	NC	2.1E-02	NC	3.6E-02
Thallium	NC	NC	0.0E+00	0.0E+00	NC	0.0E+00	NC	NC
Vanadium	NC	NC	6.3E-03	8.0E-03	NC	1.5E-02	NC	2.6E-02
Total	7.E-06	3.E-06	0.12	0.16	2.E-05	0.33	1.E-06	0.53
EA-5	Deep Adit Area							
Antimony	NC	NC	2.1E-01	2.6E-01	NC	5.0E-01	NC	8.6E-01
Arsenic	5.98E-06	2.10E-06	3.2E-02	4.1E-02	1.40E-05	1.0E-01	8.43E-07	1.4E-01
Cobalt	NC	NC	2.6E-02	3.3E-02	NC	9.1E-02	NC	1.2E-01
Copper	NC	NC	1.7E-02	2.1E-02	NC	4.0E-02	NC	7.0E-02
Iron	NC	NC	1.3E-01	1.7E-01	NC	3.1E-01	NC	**5.5E-01**
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	1.6E-02	2.0E-02	NC	3.8E-02	NC	6.6E-02
Thallium	NC	NC	2.2E+00	4.6E-02	NC	5.2E+00	NC	9.1E+00
Vanadium	NC	NC	0.0E+00	0.0E+00	NC	NC	NC	NC
Total	6.E-06	2.E-06	2.59	0.59	1.E-05	6.28	8.E-07	**10.87**
EA-6	West Avoca							
Antimony	NC	NC	6.5E-03	8.3E-03	NC	1.6E-02	NC	2.7E-02
Arsenic	3.54E-05	1.24E-05	1.8E-01	2.4E-01	7.85E-05	5.1E-01	4.92E-06	7.8E-01
Cobalt	NC	NC	2.5E-04	3.2E-04	NC	8.9E-04	NC	1.2E-03
Copper	NC	NC	1.2E-02	1.5E-02	NC	2.9E-02	NC	5.0E-02
Iron	NC	NC	1.1E-05	1.4E-05	NC	2.6E-05	NC	4.5E-05
Lead	NC	NC	NC	NC	NC	NC	NC	NC
Manganese	NC	NC	1.7E-02	2.2E-02	NC	4.1E-02	NC	7.2E-02
Thallium	NC	NC	NC	NC	NC	0.0E+00	NC	NC
Vanadium	NC	NC	2.0E-02	2.5E-02	NC	4.7E-02	NC	8.2E-02
Total	4.E-05	1.E-05	0.24	0.31	8.E-05	0.64	5.E-06	1.01
EA-7	Shelton Abbey no surface data							

Table 2
Exposure Point Concentration Summary for Surface Spoils
Avoca Mining Site

COPC	Number of Detects	Number of Samples	FOD %	Minimum Detected Concentration	Arithmetic Average	Maximum Detected Concentration	95% UCL	Rationale
EA-1	Connnary							
Antimony	18	18	100	0.7	12.8	39.4	19.9	95% Approximate Gamma UCL
Arsenic	18	18	100	64.7	422	962	631	95% Approximate Gamma UCL
Cobalt	13	18	72	0.4	0.8	1.4	0.815	95% KM (Percentile Bootstrap) UCL
Copper	18	18	100	12.6	1,485	6,426	2,673	95% Approximate Gamma UCL
Iron	18	18	100	0.979	6.826	11.15	8	95% Student's-t UCL
Lead	18	18	100	24.9	17,430	78,441	34,525	95% Approximate Gamma UCL
Manganese	18	18	100	13.7	192.1	443.4	248	95% Student's-t UCL
Thallium	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	7	18	39	8.4	14.9	10.9	10.5	95% KM (Percentile Bootstrap) UCL
EA-2	Mount Platt/ Cronbane							
Antimony	24	24	100	1.3	3.6	7.4	4.1	95% Student's-t UCL
Arsenic	24	24	100	5.6	412	747	493	95% Student's-t UCL
Cobalt	22	24	92	0.4	1.6	3.7	1.84	95% KM (BCA) UCL
Copper	24	24	100	149.7	574	1,337	678	95% Student's-t UCL
Iron	24	24	100	1.692	6	15	7	95% Approximate Gamma UCL
Lead	24	24	100	156.2	4,274	24,266	13,768	99% Chebyshev (Mean, Sd) UCL
Manganese	24	24	100	2	115.3	416.9	165	95% Approximate Gamma UCL
Thallium	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	7	24	29	1.2	8.2	15.7	5.5	95% KM (Percentile Bootstrap) UCL
EA-3	East Avoca	Tigroney West						
Antimony	10	10	100	0.9	1.9	3.2	2.4	95% Student's-t UCL
Arsenic	10	10	100	8.1	364	886	535	95% Student's-t UCL
Cobalt	10	10	100	0.6	2	6	3.4	95% Student's-t UCL
Copper	10	10	100	74.0	991	2,912	2,227	95% Approximate Gamma UCL
Iron	10	10	100	0.377	10.74	16.97	14	95% Student's-t UCL
Lead	10	10	100	58.3	3,385	7,974	5,221	95% Student's-t UCL
Manganese	10	10	100	34.53	410.8	968.5	601	95% Student's-t UCL
Thallium	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	4	10	40	1.9	13.1	23.0	19.7	95% KM (Percentile Bootstrap) UCL
EA-4	Ore Bins at	Tigroney West						
Antimony	10	10	100	0.9	9.7	44.1	20.6	95% Approximate Gamma UCL
Arsenic	10	10	100	118.7	814	2,893	1,545	95% Approximate Gamma UCL
Cobalt	10	10	100	0.5	3	9	5	95% Approximate Gamma UCL
Copper	10	10	100	213.6	2,196	11,116	4,803	95% Approximate Gamma UCL
Iron	10	10	100	2.116	11.08	17.52	14	95% Student's-t UCL
Lead	10	10	100	19.8	19,675	74,877	70,792	95% Adjusted Gamma UCL
Manganese	10	10	100	97.65	359.6	471.3	423	95% Student's-t UCL
Thallium	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	7	10	70	2.7	13.3	26.3	15.5	95% KM (Percentile Bootstrap) UCL
EA-5	Deep Adit Area		XRF Data					
Antimony	6	16	38	0.0	67.2	229	203	95% KM (Percentile Bootstrap) UCL
Arsenic	16	16	100	371.91	981.7	2,940	1,237	Use 95% Approximate Gamma UCL
Cobalt	5	16	31	0.0	389.9	1,774	1,217	95% KM (Percentile Bootstrap) UCL
Copper	16	16	100	410.12	1,209.9	3,404	1,637	95% Approximate Gamma UCL
Iron	16	16	100	93,685	191,976	363,041	224,969	95% Approximate Gamma UCL
Lead	16	16	100	1128.21	7,845.6	22,877	10,834	95% Approximate Gamma UCL
Manganese	15	16	94	489.1	711.7	957.4	775	95% Student's-t UCL
Thallium	13	16	81	0.0	278.5	949	404	95% KM (BCA) UCL
Vanadium	NA	NA	NA	NA	NA	NA	NA	NA
EA-6	West Avoca							
Antimony	10	10	100	0.2	4.0	19.9	6.4	95% KM (Chebyshev) UCL
Arsenic	36	36	100	12.7	552	1,798	1,622	99% Chebyshev (Mean, Sd) UCL
Cobalt	35	36	97	0.566	6.233	17.64	12	97.5% KM (Chebyshev) UCL
Copper	36	36	100	2.493	399.8	2822	1,174	Use 95% Chebyshev (MVUE) UCL
Iron	36	36	100	2.214	12.01	29.92	19	95% Chebyshev (Mean, Sd) UCL
Lead	36	36	100	5.4	2,165	28,363	3,808	95% Adjusted Gamma UCL
Manganese	36	36	100	11.35	617.6	1876	839	95% Approximate Gamma UCL
Thallium	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	7	10	70	2.7	27.8	179.9	48.2	95% KM (Chebyshev) UCL
EA-7	Shelton Abbey							
	no data		only samples at depth					

CDM

Table 3
Adult Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)⁻¹	SF_inhl (mg/kg-day)⁻¹	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation	$(mg/kg\text{-}day)^{-1}$	$(mg/kg\text{-}day)^{-1}$	Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	631	0.030	6.60E-07	6.54E-08	1.39E-09	1.50E+00	1.50E+01	9.91E-07	9.81E-08	2.08E-08	1.11E-06
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**1.11E-06**

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	19.89	NA	8.10E-06	NC	1.02E-10	4.00E-04	NA	2.02E-02	NC	NC	2.02E-02
Arsenic (1)	631	0.030	1.54E-06	1.53E-07	3.24E-09	3.00E-04	8.57E-06	5.14E-03	5.09E-04	3.78E-04	6.02E-03
Cobalt	0.815	NA	3.32E-07	NC	4.19E-12	2.00E-02	5.70E-06	1.66E-05	NC	7.35E-07	1.73E-05
Copper	2,673	NA	1.09E-03	NC	1.37E-08	4.00E-02	NA	2.72E-02	NC	NC	2.72E-02
Iron	8	NA	3.25E-06	NC	4.11E-11	7.00E-01	NA	4.65E-06	NC	NC	4.65E-06
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	248	NA	1.01E-04	NC	1.28E-09	2.00E-02	5.71E-03	5.06E-03	NC	2.23E-07	5.06E-03
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	10.5	NA	4.27E-06	NC	5.40E-11	1.00E-03	NA	4.27E-03	NC	NC	4.27E-03
										TOTAL	**0.06**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.006
Inhalation Rate	IRi	m^3/hr	0.83
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	$cm^2/event$	3300
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.006 on the high end for EA-1.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 4
Teen Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	631	0.030	2.24E-07	3.07E-08	3.58E-10	1.50E+00	1.50E+01	3.36E-07	4.61E-08	5.38E-09	3.88E-07
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	3.88E-07

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	19.89	NA	1.03E-05	NC	9.89E-11	4.00E-04	NA	2.58E-02	NC	NC	2.58E-02
Arsenic (1)	631	0.030	1.96E-06	2.69E-07	3.14E-09	3.00E-04	8.57E-06	6.54E-03	8.96E-04	3.66E-04	7.80E-03
Cobalt	0.815	NA	4.22E-07	NC	4.05E-12	2.00E-02	5.70E-06	2.11E-05	NC	7.11E-07	2.18E-05
Copper	2,673	NA	1.38E-03	NC	1.33E-08	4.00E-02	NA	3.46E-02	NC	NC	3.46E-02
Iron	8	NA	4.14E-06	NC	3.97E-11	7.00E-01	NA	5.91E-06	NC	NC	5.91E-06
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	248	NA	1.29E-04	NC	1.23E-09	2.00E-02	5.71E-03	6.43E-03	NC	2.16E-07	6.43E-03
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	10.5	NA	5.44E-06	NC	5.22E-11	1.00E-03	NA	5.44E-03	NC	NC	5.44E-03
										TOTAL	0.08

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2920
Body Weight	BW	kg	55
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	8
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.006
Inhalation Rate	IRi	m^3/hr	0.63
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	4570
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.006 on the high end for EA-1.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 5
Adult Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)-1	SF_inhl (mg/kg-day)-1	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	492.7	0.030	2.58E-07	2.55E-08	1.09E-09	1.50E+00	1.50E+01	3.87E-07	3.83E-08	1.63E-08	4.41E-07
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	4.41E-07

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	4.1	NA	1.66E-06	NC	2.09E-11	4.00E-04	NA	4.15E-03	NC	NC	4.15E-03
Arsenic (1)	492.7	0.030	6.02E-07	5.96E-08	2.53E-09	3.00E-04	8.57E-06	2.01E-03	1.99E-04	2.95E-04	2.50E-03
Cobalt	1.8	NA	7.48E-07	NC	9.45E-12	2.00E-02	5.70E-06	3.74E-05	NC	1.66E-06	3.91E-05
Copper	678.4	NA	2.76E-04	NC	3.49E-09	4.00E-02	NA	6.90E-03	NC	NC	6.90E-03
Iron	7.0	NA	2.85E-06	NC	3.60E-11	7.00E-01	NA	4.08E-06	NC	NC	4.08E-06
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	165	NA	6.73E-05	NC	8.50E-10	2.00E-02	5.71E-03	3.37E-03	NC	1.49E-07	3.37E-03
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	5.5	NA	2.24E-06	NC	2.82E-11	1.00E-03	NA	2.24E-03	NC	NC	2.24E-03
										TOTAL	0.02

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.003
Inhalation Rate	IRi	m^3/hr	0.83
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.003 on the high end for EA-2.

Intake Equations:
Oral Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 6
Teen Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	492.7	0.030	8.75E-08	1.20E-08	2.80E-10	1.50E+00	1.50E+01	1.31E-07	1.80E-08	4.20E-09	1.53E-07
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**1.53E-07**

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	4.1	NA	2.11E-06	NC	2.03E-11	4.00E-04	NA	5.28E-03	NC	NC	5.28E-03
Arsenic (1)	492.7	0.030	7.66E-07	1.05E-07	2.45E-09	3.00E-04	8.57E-06	2.55E-03	3.50E-04	2.86E-04	3.19E-03
Cobalt	1.8	NA	9.52E-07	NC	9.14E-12	2.00E-02	5.70E-06	4.76E-05	NC	1.60E-06	4.92E-05
Copper	678.4	NA	3.51E-04	NC	3.37E-09	4.00E-02	NA	8.79E-03	NC	NC	8.79E-03
Iron	7.0	NA	3.63E-06	NC	3.48E-11	7.00E-01	NA	5.19E-06	NC	NC	5.19E-06
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	165	NA	8.57E-05	NC	8.22E-10	2.00E-02	5.71E-03	4.28E-03	NC	1.44E-07	4.28E-03
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	5.5	NA	2.85E-06	NC	2.73E-11	1.00E-03	NA	2.85E-03	NC	NC	2.85E-03
										TOTAL	**0.02**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2920
Body Weight	BW	kg	55
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	8
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.003
Inhalation Rate	IRi	m^3/hr	0.63
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	4570
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.003 on the high end for EA-2.

Intake Equations:
Oral — Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal — Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation — Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))

Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 7
Adult Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	534.9	0.030	2.71E-07	2.68E-08	1.18E-09	1.50E+00	1.50E+01	4.06E-07	4.02E-08	1.77E-08	4.64E-07
Lead	5,221	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**4.64E-07**

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	2.4	NA	9.85E-07	NC	1.24E-11	4.00E-04	NA	2.46E-03	NC	NC	2.46E-03
Arsenic (1)	534.9	0.030	6.31E-07	6.25E-08	2.75E-09	3.00E-04	8.57E-06	2.10E-03	2.08E-04	3.21E-04	2.63E-03
Cobalt	3.4	NA	1.39E-06	NC	1.75E-11	2.00E-02	5.70E-06	6.94E-05	NC	3.08E-06	7.25E-05
Copper	2,227	NA	9.06E-04	NC	1.14E-08	4.00E-02	NA	2.27E-02	NC	NC	2.27E-02
Iron	14	NA	5.78E-06	NC	7.29E-11	7.00E-01	NA	8.25E-06	NC	NC	8.25E-06
Lead	5,221	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	601	NA	2.44E-04	NC	3.09E-09	2.00E-02	5.71E-03	1.22E-02	NC	5.40E-07	1.22E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	19.7	NA	8.04E-06	NC	1.01E-10	1.00E-03	NA	8.04E-03	NC	NC	8.04E-03
										TOTAL	**0.05**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0029
Inhalation Rate	IRi	m^3/hr	0.83
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0029 on the high end for EA-3.

Intake Equations:
- Oral: Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
- Dermal: Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
- Inhalation: Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))

Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 8
Teen Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)^-1	SF_inhl (mg/kg-day)^-1	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	534.9	0.030	9.18E-08	1.26E-08	3.04E-10	1.50E+00	1.50E+01	1.38E-07	1.89E-08	4.56E-09	1.61E-07
Lead	5,221.0	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**1.61E-07**

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	2.4	NA	1.25E-06	NC	1.20E-11	4.00E-04	NA	3.13E-03	NC	NC	3.13E-03
Arsenic (1)	534.9	0.030	8.04E-07	1.10E-07	2.66E-09	3.00E-04	8.57E-06	2.68E-03	3.67E-04	3.10E-04	3.36E-03
Cobalt	3.4	NA	1.77E-06	NC	1.70E-11	2.00E-02	5.70E-06	8.84E-05	NC	2.98E-06	9.14E-05
Copper	2,227.0	NA	1.15E-03	NC	1.11E-08	4.00E-02	NA	2.88E-02	NC	NC	2.88E-02
Iron	14.2	NA	7.35E-06	NC	7.05E-11	7.00E-01	NA	1.05E-05	NC	NC	1.05E-05
Lead	5,221.0	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	600.5	NA	3.11E-04	NC	2.99E-09	2.00E-02	5.71E-03	1.56E-02	NC	5.22E-07	1.56E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	19.7	NA	1.02E-05	NC	9.81E-11	1.00E-03	NA	1.02E-02	NC	NC	1.02E-02
										TOTAL	**0.06**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2920
Body Weight	BW	kg	55
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	8
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0029
Inhalation Rate	IRi	m^3/hr	0.63
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	4570
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0029 on the high end for EA-3.

Intake Equations:	Oral	Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
	Dermal	Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
	Inhalation	Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT
Cancer Risk:		=(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient:		=(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 9
Adult Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,545	0.030	4.50E-06	4.46E-07	3.40E-09	1.50E+00	1.50E+01	6.75E-06	6.68E-07	5.10E-08	7.47E-06
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	7.47E-06

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	20.6	NA	8.39E-06	NC	1.06E-10	4.00E-04	NA	2.10E-02	NC	NC	2.10E-02
Arsenic (1)	1,545	0.030	1.05E-05	1.04E-06	7.94E-09	3.00E-04	8.57E-06	3.50E-02	3.47E-03	9.26E-04	3.94E-02
Cobalt	4.8	NA	1.96E-06	NC	2.47E-11	2.00E-02	5.70E-06	9.79E-05	NC	4.34E-06	1.02E-04
Copper	4,803	NA	1.96E-03	NC	2.47E-08	4.00E-02	NA	4.89E-02	NC	NC	4.89E-02
Iron	14	NA	5.65E-06	NC	7.14E-11	7.00E-01	NA	8.08E-06	NC	NC	8.08E-06
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	423	NA	1.72E-04	NC	2.17E-09	2.00E-02	5.71E-03	8.60E-03	NC	3.80E-07	8.61E-03
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	15.5	NA	6.32E-06	NC	7.98E-11	1.00E-03	NA	6.32E-03	NC	NC	6.32E-03
										TOTAL	0.12

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	0.83
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0167 on the high end for EA-4.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))

Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 10
Teen Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,545	0.030	1.53E-06	2.09E-07	8.78E-10	1.50E+00	1.50E+01	2.29E-06	3.14E-07	1.32E-08	2.62E-06
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**2.62E-06**

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	21	NA	1.07E-05	NC	1.02E-10	4.00E-04	NA	2.67E-02	NC	NC	2.67E-02
Arsenic (1)	1,545	0.030	1.34E-05	1.83E-06	7.68E-09	3.00E-04	8.57E-06	4.46E-02	6.11E-03	8.96E-04	5.16E-02
Cobalt	5	NA	2.49E-06	NC	2.39E-11	2.00E-02	5.70E-06	1.25E-04	NC	4.20E-06	1.29E-04
Copper	4,803	NA	2.49E-03	NC	2.39E-08	4.00E-02	NA	6.22E-02	NC	NC	6.22E-02
Iron	14	NA	7.20E-06	NC	6.91E-11	7.00E-01	NA	1.03E-05	NC	NC	1.03E-05
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	423	NA	2.19E-04	NC	2.10E-09	2.00E-02	5.71E-03	1.10E-02	NC	3.68E-07	1.10E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	16	NA	8.04E-06	NC	7.72E-11	1.00E-03	NA	8.04E-03	NC	NC	8.04E-03
										TOTAL	**0.16**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	2920
Body Weight	BW	kg	55
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	8
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	0.63
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	4570
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0167 on the high end for EA-4.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 11
Adult Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)[-1]	SF_inhl (mg/kg-day)[-1]	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure **METALS**											
Arsenic (1)	1,237	0.030	3.60E-06	3.57E-07	2.72E-09	1.50E+00	1.50E+01	5.41E-06	5.35E-07	4.09E-08	5.98E-06
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	5.98E-06

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure **METALS**											
Antimony	203	NA	8.25E-05	NC	1.04E-09	4.00E-04	NA	2.06E-01	NC	NC	2.06E-01
Arsenic (1)	1,237	0.030	8.41E-06	8.32E-07	6.36E-09	3.00E-04	8.57E-06	2.80E-02	2.77E-03	7.42E-04	3.15E-02
Cobalt	1,217	NA	4.95E-04	NC	6.25E-09	2.00E-02	5.70E-06	2.48E-02	NC	1.10E-03	2.59E-02
Copper	1,637	NA	6.66E-04	NC	8.41E-09	4.00E-02	NA	1.67E-02	NC	NC	1.67E-02
Iron	224,969	NA	9.16E-02	NC	1.16E-06	7.00E-01	NA	1.31E-01	NC	NC	1.31E-01
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	775	NA	3.15E-04	NC	3.98E-09	2.00E-02	5.71E-03	1.58E-02	NC	6.97E-07	1.58E-02
Thallium	404	NA	1.64E-04	NC	2.08E-09	7.60E-05	NA	2.16E+00	NC	NC	2.16E+00
Vanadium	NA	NA	NC	NC	NC	1.00E-03	NA	NC	NC	NC	0.00E+00
										TOTAL	2.59

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	0.83
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	$(m^3$/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0167 on the high end for EA-4 used for EA-5.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))

Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 12
Teen Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,237	0.030	1.22E-06	1.68E-07	7.03E-10	1.50E+00	1.50E+01	1.83E-06	2.52E-07	1.05E-08	2.10E-06
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	2.10E-06

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	203	NA	1.05E-04	NC	1.01E-09	4.00E-04	NA	2.63E-01	NC	NC	2.63E-01
Arsenic (1)	1,237	0.030	1.07E-05	1.47E-06	6.15E-09	3.00E-04	8.57E-06	3.57E-02	4.89E-03	7.17E-04	4.13E-02
Cobalt	1,217	NA	6.30E-04	NC	6.05E-09	2.00E-02	5.70E-06	3.15E-02	NC	1.06E-03	3.26E-02
Copper	1,637	NA	8.48E-04	NC	8.14E-09	4.00E-02	NA	2.12E-02	NC	NC	2.12E-02
Iron	224,969	NA	1.17E-01	NC	1.12E-06	7.00E-01	NA	1.66E-01	NC	NC	1.66E-01
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	775	NA	4.01E-04	NC	3.85E-09	2.00E-02	5.71E-03	2.01E-02	NC	6.74E-07	2.01E-02
Thallium	404	NA	3.50E-06	NC	2.01E-09	7.60E-05	NA	4.60E-02	NC	NC	4.60E-02
Vanadium	NA	NA	NC	NC	NC	1.00E-03	NA	NC	NC	NC	0.00E+00
										TOTAL	0.59

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2920
Body Weight	BW	kg	55
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	8
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	0.63
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	4570
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0167 on the high end for EA-4 used for EA-5.

Intake Equations:
Oral — Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal — Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation — Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 13
Adult Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure **METALS**											
Arsenic (1)	1,622	0.030	2.14E-05	2.12E-06	3.57E-09	1.50E+00	1.50E+01	3.22E-05	3.19E-06	5.36E-08	3.54E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**3.54E-05**

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure **METALS**											
Antimony	6	NA	2.61E-06	NC	3.30E-11	4.00E-04	NA	6.53E-03	NC	NC	6.53E-03
Arsenic (1)	1,622	0.030	5.00E-05	4.95E-06	8.34E-09	3.00E-04	8.57E-06	1.67E-01	1.65E-02	9.73E-04	1.84E-01
Cobalt	12	NA	4.82E-06	NC	6.09E-11	2.00E-02	5.70E-06	2.41E-04	NC	1.07E-05	2.52E-04
Copper	1,174	NA	4.78E-04	NC	6.03E-09	4.00E-02	NA	1.19E-02	NC	NC	1.19E-02
Iron	19	NA	7.60E-06	NC	9.59E-11	7.00E-01	NA	1.09E-05	NC	NC	1.09E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	839	NA	3.41E-04	NC	4.31E-09	2.00E-02	5.71E-03	1.71E-02	NC	7.55E-07	1.71E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	48	NA	1.96E-05	NC	2.48E-10	1.00E-03	NA	1.96E-02	NC	NC	1.96E-02
										TOTAL	**0.24**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0758
Inhalation Rate	IRi	m^3/hr	0.83
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0758 on the high end for EA-6.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))

Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 14
Teen Recreational Visitor Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,622	0.030	7.28E-06	9.98E-07	9.22E-10	1.50E+00	1.50E+01	1.09E-05	1.50E-06	1.38E-08	1.24E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**1.24E-05**

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	6	NA	3.32E-06	NC	3.19E-11	4.00E-04	NA	8.31E-03	NC	NC	8.31E-03
Arsenic (1)	1,622	0.030	6.37E-05	8.73E-06	8.06E-09	3.00E-04	8.57E-06	2.12E-01	2.91E-02	9.41E-04	2.42E-01
Cobalt	12	NA	6.14E-06	NC	5.89E-11	2.00E-02	5.70E-06	3.07E-04	NC	1.03E-05	3.17E-04
Copper	1,174	NA	6.08E-04	NC	5.84E-09	4.00E-02	NA	1.52E-02	NC	NC	1.52E-02
Iron	19	NA	9.67E-06	NC	9.28E-11	7.00E-01	NA	1.38E-05	NC	NC	1.38E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	839	NA	4.35E-04	NC	4.17E-09	2.00E-02	5.71E-03	2.17E-02	NC	7.30E-07	2.17E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	48	NA	2.50E-05	NC	2.40E-10	1.00E-03	NA	2.50E-02	NC	NC	2.50E-02
										TOTAL	**0.31**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2920
Body Weight	BW	kg	55
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	8
Exposure Frequency	EF	days/year	104
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0758
Inhalation Rate	IRi	m^3/hr	0.63
Exposure Time	ET	hr/day	2
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	4570
Contact Rate	CR	mg/cm^2	0.1

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.0758 on the high end for EA-6.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 15
Commercial/ Industrial Worker for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure											
METALS											
Arsenic (1)	631	0.030	1.32E-06	2.62E-07	3.34E-08	1.50E+00	1.50E+01	1.98E-06	3.93E-07	5.01E-07	2.88E-06
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**2.88E-06**

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure											
METALS											
Antimony	19.89	NA	1.95E-05	NC	2.95E-09	4.00E-04	NA	4.87E-02	NC	NC	4.87E-02
Arsenic (1)	631	0.030	3.70E-06	7.33E-07	9.35E-08	3.00E-04	8.57E-06	1.23E-02	2.44E-03	1.09E-02	2.57E-02
Cobalt	0.815	NA	7.97E-07	NC	1.21E-10	2.00E-02	5.70E-06	3.99E-05	NC	2.12E-05	6.11E-05
Copper	2,673	NA	2.62E-03	NC	3.96E-07	4.00E-02	NA	6.54E-02	NC	NC	6.54E-02
Iron	8	NA	7.82E-06	NC	1.18E-09	7.00E-01	NA	1.12E-05	NC	NC	1.12E-05
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	248	NA	2.43E-04	NC	3.68E-08	2.00E-02	5.71E-03	1.22E-02	NC	6.44E-06	1.22E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	10.5	NA	1.03E-05	NC	1.56E-09	1.00E-03	NA	1.03E-02	NC	NC	1.03E-02
										TOTAL	**0.16**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	9125
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	25
Exposure Frequency	EF	days/year	250
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.006
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	$(m^3$/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.2

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%.Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.006 on the high end for EA-1

Intake Equations: Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT

      Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT

      Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))

Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 16
Commercial/ Industrial Worker for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure											
METALS											
Arsenic (1)	493	0.030	5.17E-07	1.02E-07	2.61E-08	1.50E+00	1.50E+01	7.75E-07	1.53E-07	3.91E-07	1.32E-06
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	1.32E-06

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure											
METALS											
Antimony	4.1	NA	3.99E-06	NC	6.04E-10	4.00E-04	NA	9.97E-03	NC	NC	9.97E-03
Arsenic (1)	492.7	0.030	1.45E-06	2.86E-07	7.30E-08	3.00E-04	8.57E-06	4.82E-03	9.55E-04	8.52E-03	1.43E-02
Cobalt	1.8	NA	1.80E-06	NC	2.72E-10	2.00E-02	5.70E-06	8.99E-05	NC	4.78E-05	1.38E-04
Copper	678.4	NA	6.64E-04	NC	1.01E-07	4.00E-02	NA	1.66E-02	NC	NC	1.66E-02
Iron	7.0	NA	6.86E-06	NC	1.04E-09	7.00E-01	NA	9.80E-06	NC	NC	9.80E-06
Lead	13,768.0	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	165.4	NA	1.62E-04	NC	2.45E-08	2.00E-02	5.71E-03	8.09E-03	NC	4.29E-06	8.10E-03
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	5.5	NA	5.37E-06	NC	8.14E-10	1.00E-03	NA	5.37E-03	NC	NC	5.37E-03
										TOTAL	0.05

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	9125
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	25
Exposure Frequency	EF	days/year	250
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.003
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.2

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.003 on the high end for EA-2

Intake Equations:
Oral Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 17
Commercial/ Industrial Worker for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)⁻¹	SF_inhl (mg/kg-day)⁻¹	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	535	0.030	5.42E-07	1.07E-07	2.83E-08	1.50E+00	1.50E+01	8.13E-07	1.61E-07	4.25E-07	1.40E-06
Lead	5,221	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	1.40E-06

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	2.4	NA	2.37E-06	NC	3.59E-10	4.00E-04	NA	5.92E-03	NC	NC	5.92E-03
Arsenic (1)	535	0.030	1.52E-06	3.01E-07	7.93E-08	3.00E-04	8.57E-06	5.06E-03	1.00E-03	9.25E-03	1.53E-02
Cobalt	3.4	NA	3.34E-06	NC	5.06E-10	2.00E-02	5.70E-06	1.67E-04	NC	8.87E-05	2.56E-04
Copper	2,227	NA	2.18E-03	NC	3.30E-07	4.00E-02	NA	5.45E-02	NC	NC	5.45E-02
Iron	14.2	NA	1.39E-05	NC	2.10E-09	7.00E-01	NA	1.98E-05	NC	NC	1.98E-05
Lead	5,221	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	601	NA	5.88E-04	NC	8.90E-08	2.00E-02	5.71E-03	2.94E-02	NC	1.56E-05	2.94E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	19.7	NA	1.93E-05	NC	2.93E-09	1.00E-03	NA	1.93E-02	NC	NC	1.93E-02
										TOTAL	0.12

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	9125
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	25
Exposure Frequency	EF	days/year	250
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0029
Inhalation Rate	IRi	m³/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m³/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm²/event	3300
Contact Rate	CR	mg/cm²	0.2

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0029 on the high end for EA-3

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 18
Commercial/ Industrial Worker for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure											
METALS											
Arsenic (1)	1,545	0.030	9.02E-06	1.79E-06	8.18E-08	1.50E+00	1.50E+01	1.35E-05	2.68E-06	1.23E-06	1.74E-05
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	1.74E-05

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure											
METALS											
Antimony	20.6	NA	2.02E-05	NC	3.05E-09	4.00E-04	NA	5.04E-02	NC	NC	5.04E-02
Arsenic (1)	1,545	0.030	2.52E-05	5.00E-06	2.29E-07	3.00E-04	8.57E-06	8.42E-02	1.67E-02	2.67E-02	1.28E-01
Cobalt	4.8	NA	4.71E-06	NC	7.13E-10	2.00E-02	5.70E-06	2.35E-04	NC	1.25E-04	3.60E-04
Copper	4,803	NA	4.70E-03	NC	7.12E-07	4.00E-02	NA	1.17E-01	NC	NC	1.17E-01
Iron	13.9	NA	1.36E-05	NC	2.06E-09	7.00E-01	NA	1.94E-05	NC	NC	1.94E-05
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	423	NA	4.14E-04	NC	6.27E-08	2.00E-02	5.71E-03	2.07E-02	NC	1.10E-05	2.07E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	15.5	NA	1.52E-05	NC	2.30E-09	1.00E-03	NA	1.52E-02	NC	NC	1.52E-02
										TOTAL	0.33

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	9125
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	25
Exposure Frequency	EF	days/year	250
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.2

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%.Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0167 on the high end for EA-4

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 19
Commercial/ Industrial Worker for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure **METALS**											
Arsenic (1)	1,237	0.030	7.22E-06	1.43E-06	6.55E-08	1.50E+00	1.50E+01	1.08E-05	2.14E-06	9.82E-07	1.40E-05
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**1.40E-05**

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure **METALS**											
Antimony	203	NA	1.98E-04	NC	3.01E-08	4.00E-04	NA	4.96E-01	NC	NC	4.96E-01
Arsenic (1)	1,237	0.030	2.02E-05	4.00E-06	1.83E-07	3.00E-04	8.57E-06	6.74E-02	1.33E-02	2.14E-02	1.02E-01
Cobalt	1,217	NA	1.19E-03	NC	1.80E-07	2.00E-02	5.70E-06	5.95E-02	NC	3.17E-02	9.12E-02
Copper	1,637	NA	1.60E-03	NC	2.43E-07	4.00E-02	NA	4.00E-02	NC	NC	4.00E-02
Iron	224,969	NA	2.20E-01	NC	3.34E-05	7.00E-01	NA	3.14E-01	NC	NC	3.14E-01
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	775	NA	7.58E-04	NC	1.15E-07	2.00E-02	5.71E-03	3.79E-02	NC	2.01E-05	3.79E-02
Thallium	404	NA	3.95E-04	NC	5.99E-08	7.60E-05	NA	5.20E+00	NC	NC	5.20E+00
Vanadium	NA	NA	NC	NC	NC	1.00E-03	NA	NC	NC	NC	NC
										TOTAL	**6.28**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	9125
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	25
Exposure Frequency	EF	days/year	250
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.2

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0167 on the high end for EA-4 is used for EA-5.

Intake Equations:
Oral — Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal — Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation — Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 20
Commercial/ Industrial Worker for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day) Ingestion	Dermal	Inhalation	SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway Ingestion	Dermal	Inhalation	CANCER RISK
Carcinogenic Exposure METALS											
Arsenic (1)	1,622	0.030	4.30E-05	8.51E-06	8.59E-08	1.50E+00	1.50E+01	6.44E-05	1.28E-05	1.29E-06	7.85E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**7.85E-05**

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day) Ingestion	Dermal	Inhalation	RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient Ingestion	Dermal	Inhalation	Hazard Index
Noncarcinogenic Exposure METALS											
Antimony	6.4	NA	6.28E-06	NC	9.51E-10	4.00E-04	NA	1.57E-02	NC	NC	1.57E-02
Arsenic (1)	1,622	0.030	1.20E-04	2.38E-05	2.40E-07	3.00E-04	8.57E-06	4.01E-01	7.94E-02	2.81E-02	5.08E-01
Cobalt	11.9	NA	1.16E-05	NC	1.76E-09	2.00E-02	5.70E-06	5.80E-04	NC	3.08E-04	8.88E-04
Copper	1,174	NA	1.15E-03	NC	1.74E-07	4.00E-02	NA	2.87E-02	NC	NC	2.87E-02
Iron	18.7	NA	1.83E-05	NC	2.77E-09	7.00E-01	NA	2.61E-05	NC	NC	2.61E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	839	NA	8.21E-04	NC	1.24E-07	2.00E-02	5.71E-03	4.10E-02	NC	2.18E-05	4.11E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	48.2	NA	4.72E-05	NC	7.15E-09	1.00E-03	NA	4.72E-02	NC	NC	4.72E-02
										TOTAL	**0.64**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	9125
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	25
Exposure Frequency	EF	days/year	250
Ingestion Rate	InR	mg soil/day	100
Arsenic BAF (1)	BAF	percentage	0.0758
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.2

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%.Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0758 on the high end for EA-6

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 21
Construction Worker Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	631	0.030	9.22E-08	8.30E-09	7.06E-10	1.50E+00	1.50E+01	1.38E-07	1.24E-08	1.06E-08	1.61E-07
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
									TOTAL		1.61E-07

COPCs	EPC Concentration EA-1 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	19.89	NA	3.39E-05	NC	1.56E-09	4.00E-04	NA	8.48E-02	NC	NC	8.48E-02
Arsenic (1)	631	0.030	6.45E-06	5.81E-07	4.94E-08	3.00E-04	8.57E-06	2.15E-02	1.94E-03	5.76E-03	2.92E-02
Cobalt	0.815	NA	1.39E-06	NC	6.38E-11	2.00E-02	5.70E-06	6.95E-05	NC	1.12E-05	8.07E-05
Copper	2,673	NA	4.56E-03	NC	2.09E-07	4.00E-02	NA	1.14E-01	NC	NC	1.14E-01
Iron	8	NA	1.36E-05	NC	6.25E-10	7.00E-01	NA	1.95E-05	NC	NC	1.95E-05
Lead	34,525	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	248	NA	4.23E-04	NC	1.94E-08	2.00E-02	5.71E-03	2.12E-02	NC	3.40E-06	2.12E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	10.5	NA	1.79E-05	NC	8.22E-10	1.00E-03	NA	1.79E-02	NC	NC	1.79E-02
									TOTAL		0.27

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	365
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	1
Exposure Frequency	EF	days/year	132
Ingestion Rate	InR	mg soil/day	330
Arsenic BAF (1)	BAF	percentage	0.006
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.3

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.006 on the high end for EA-1

Intake Equations:
Oral: Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal: Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation: Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 22
Construction Worker Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure											
METALS											
Arsenic (1)	493	0.030	3.60E-08	3.24E-09	5.51E-10	1.50E+00	1.50E+01	5.40E-08	4.86E-09	8.26E-09	6.71E-08
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	6.71E-08

COPCs	EPC Concentration EA-2 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure											
METALS											
Antimony	4.1	NA	6.95E-06	NC	3.19E-10	4.00E-04	NA	1.74E-02	NC	NC	1.74E-02
Arsenic (1)	492.7	0.030	2.52E-06	2.27E-07	3.86E-08	3.00E-04	8.57E-06	8.40E-03	7.56E-04	4.50E-03	1.37E-02
Cobalt	1.8	NA	3.13E-06	NC	1.44E-10	2.00E-02	5.70E-06	1.57E-04	NC	2.52E-05	1.82E-04
Copper	678.4	NA	1.16E-03	NC	5.31E-08	4.00E-02	NA	2.89E-02	NC	NC	2.89E-02
Iron	7.0	NA	1.20E-05	NC	5.49E-10	7.00E-01	NA	1.71E-05	NC	NC	1.71E-05
Lead	13,768	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	165.4	NA	2.82E-04	NC	1.29E-08	2.00E-02	5.71E-03	1.41E-02	NC	2.27E-06	1.41E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	5.5	NA	9.36E-06	NC	4.30E-10	1.00E-03	NA	9.36E-03	NC	NC	9.36E-03
										TOTAL	0.08

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	365
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	1
Exposure Frequency	EF	days/year	132
Ingestion Rate	InR	mg soil/day	330
Arsenic BAF (1)	BAF	percentage	0.003
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.3

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.003 on the high end for EA-2

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 23
Construction Worker Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)⁻¹	SF_inhl (mg/kg-day)⁻¹	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure											
METALS											
Arsenic (1)	535	0.030	3.78E-08	3.40E-09	5.98E-10	1.50E+00	1.50E+01	5.67E-08	5.10E-09	8.97E-09	7.07E-08
Lead	5,221	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	7.07E-08

COPCs	EPC Concentration EA-3 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure											
METALS											
Antimony	2.4	NA	4.13E-06	NC	1.89E-10	4.00E-04	NA	1.03E-02	NC	NC	1.03E-02
Arsenic (1)	534.9	0.030	2.64E-06	2.38E-07	4.19E-08	3.00E-04	8.57E-06	8.82E-03	7.93E-04	4.88E-03	1.45E-02
Cobalt	3.4	NA	5.82E-06	NC	2.67E-10	2.00E-02	5.70E-06	2.91E-04	NC	4.69E-05	3.38E-04
Copper	2,227	NA	3.80E-03	NC	1.74E-07	4.00E-02	NA	9.49E-02	NC	NC	9.49E-02
Iron	14.2	NA	2.42E-05	NC	1.11E-09	7.00E-01	NA	3.46E-05	NC	NC	3.46E-05
Lead	5,221	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	600.5	NA	1.02E-03	NC	4.70E-08	2.00E-02	5.71E-03	5.12E-02	NC	8.23E-06	5.12E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	19.7	NA	3.37E-05	NC	1.55E-09	1.00E-03	NA	3.37E-02	NC	NC	3.37E-02
										TOTAL	0.20

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	365
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	1
Exposure Frequency	EF	days/year	132
Ingestion Rate	InR	mg soil/day	330
Arsenic BAF (1)	BAF	percentage	0.0029
Inhalation Rate	IRi	m³/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m³/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm²/event	3300
Contact Rate	CR	mg/cm²	0.3

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%.Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0029 on the high end for EA-3

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 24
Construction Worker Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,545	0.030	6.28E-07	5.66E-08	1.73E-09	1.50E+00	1.50E+01	9.43E-07	8.48E-08	2.59E-08	1.05E-06
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**1.05E-06**

COPCs	EPC Concentration EA-4 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	20.6	NA	3.51E-05	NC	1.61E-09	4.00E-04	NA	8.78E-02	NC	NC	8.78E-02
Arsenic (1)	1,545	0.030	4.40E-05	3.96E-06	1.21E-07	3.00E-04	8.57E-06	1.47E-01	1.32E-02	1.41E-02	1.74E-01
Cobalt	4.8	NA	8.20E-06	NC	3.77E-10	2.00E-02	5.70E-06	4.10E-04	NC	6.61E-05	4.76E-04
Copper	4,803	NA	8.19E-03	NC	3.76E-07	4.00E-02	NA	2.05E-01	NC	NC	2.05E-01
Iron	13.9	NA	2.37E-05	NC	1.09E-09	7.00E-01	NA	3.38E-05	NC	NC	3.38E-05
Lead	70,792	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	422.8	NA	7.21E-04	NC	3.31E-08	2.00E-02	5.71E-03	3.60E-02	NC	5.79E-06	3.60E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	15.5	NA	2.65E-05	NC	1.21E-09	1.00E-03	NA	2.65E-02	NC	NC	2.65E-02
										TOTAL	**0.53**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	365
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	1
Exposure Frequency	EF	days/year	132
Ingestion Rate	InR	mg soil/day	330
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.3

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0167 on the high end for EA-4

Intake Equations:
Oral — Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal — Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation — Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 25
Construction Worker Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,237	0.030	5.03E-07	4.53E-08	1.38E-09	1.50E+00	1.50E+01	7.55E-07	6.79E-08	2.07E-08	8.43E-07
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	**8.43E-07**

COPCs	EPC Concentration EA-5 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	202.8	NA	3.46E-04	NC	1.59E-08	4.00E-04	NA	8.64E-01	NC	NC	8.64E-01
Arsenic (1)	1,237	0.030	3.52E-05	3.17E-06	9.68E-08	3.00E-04	8.57E-06	1.17E-01	1.06E-02	1.13E-02	1.39E-01
Cobalt	1,217	NA	2.07E-03	NC	9.53E-08	2.00E-02	5.70E-06	1.04E-01	NC	1.67E-02	1.20E-01
Copper	1,637	NA	2.79E-03	NC	1.28E-07	4.00E-02	NA	6.98E-02	NC	NC	6.98E-02
Iron	224,969	NA	3.84E-01	NC	1.76E-05	7.00E-01	NA	5.48E-01	NC	NC	5.48E-01
Lead	10,834	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	774.5	NA	1.32E-03	NC	6.06E-08	2.00E-02	5.71E-03	6.60E-02	NC	1.06E-05	6.60E-02
Thallium	404.0	NA	6.89E-04	NC	3.16E-08	7.60E-05	NA	9.06E+00	NC	NC	9.06E+00
Vanadium	NA	NA	NC	NC	NC	1.00E-03	NA	NC	NC	NC	NC
										TOTAL	**10.87**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	365
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	1
Exposure Frequency	EF	days/year	132
Ingestion Rate	InR	mg soil/day	330
Arsenic BAF (1)	BAF	percentage	0.0167
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	$(m^3$/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.3

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%.Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0167 on the high end for EA-4 is used for EA-5

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 26
Construction Worker Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure METALS											
Arsenic (1)	1,622	0.030	2.99E-06	2.70E-07	1.81E-09	1.50E+00	1.50E+01	4.49E-06	4.04E-07	2.72E-08	4.92E-06
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	4.92E-06

COPCs	EPC Concentration EA-6 (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure METALS											
Antimony	6.4	NA	1.09E-05	NC	5.02E-10	4.00E-04	NA	2.74E-02	NC	NC	2.74E-02
Arsenic (1)	1,622	0.030	2.10E-04	1.89E-05	1.27E-07	3.00E-04	8.57E-06	6.99E-01	6.29E-02	1.48E-02	7.76E-01
Cobalt	11.9	NA	2.02E-05	NC	9.28E-10	2.00E-02	5.70E-06	1.01E-03	NC	1.63E-04	1.17E-03
Copper	1,174	NA	2.00E-03	NC	9.19E-08	4.00E-02	NA	5.00E-02	NC	NC	5.00E-02
Iron	18.7	NA	3.18E-05	NC	1.46E-09	7.00E-01	NA	4.54E-05	NC	NC	4.54E-05
Lead	3,808	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
Manganese	838.9	NA	1.43E-03	NC	6.57E-08	2.00E-02	5.71E-03	7.15E-02	NC	1.15E-05	7.15E-02
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	48.2	NA	8.22E-05	NC	3.77E-09	1.00E-03	NA	8.22E-02	NC	NC	8.22E-02
										TOTAL	1.01

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	365
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	1
Exposure Frequency	EF	days/year	132
Ingestion Rate	InR	mg soil/day	330
Arsenic BAF (1)	BAF	percentage	0.0758
Inhalation Rate	IRi	m^3/hr	2.50
Exposure Time	ET	hr/day	8
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	3300
Contact Rate	CR	mg/cm^2	0.3

(1) BAFs for all COPCs except arsenic and lead are assumed to be 100%. Arsenic has been adjusted for bioavailability based on in-vitro bioassay analysis. Oral BAF is 0.0758 on the high end for EA-6

Intake Equations:
Oral   Cs x CF1 x BAF x InR x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x BAF x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT   Assumes BAF for inhalation pathway is 100%

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

Table 27
Summary of Risks and Hazards for Nearby Resident Exposed to Surface Soil
Avoca Mining Site

	Nearby Resident	
	Soil Pathways	
COPC	Cancer Risk	Hazard Index
	Adult/Child	Child
Antimony	NC	6.0E-02
Arsenic	4.37E-06	**9.2E-02**
Cobalt	NC	2.3E-02
Copper	NC	1.8E-01
Iron	NC	2.0E-04
Lead	NC	NC
Manganese	NC	**1.5E+00**
Thallium	NC	NC
Vanadium	NC	**1.6E+00**
Total	4.E-06	3

Summary of Risks and Hazards for Nearby Resident Exposed to Contaminants in Groundwater

Groundwater Pathways

	Homeowner Wells		Monitoring Wells (total concentrations)		Monitoring Wells (dissolved concentrations)	
COPC	Cancer Risk	Hazard Index	Adult	Child	Adult	Child
	Adult	Child				
Aluminum	NC	1.14E-01		5.99E+00		1.25E+02
Arsenic (1)	NC	NC	NC	NC	1.80E-03	4.66E+01
Cadmium	NC	NC		5.75E+00		5.64E+01
Chromium III	NC	2.56E-04		2.56E-04		2.37E-02
Chromium IV	NC	2.56E-04		2.56E-04		2.37E-02
Copper	NC	1.94E-01		1.92E+01		2.05E+02
Iron	NC	6.88E-02		1.45E-01		1.86E+01
Lead	NC	NC		NC		NC
Manganese	NC	1.20E-01		2.65E+01		2.46E+02
Nickel	NC	3.84E-02		2.78E-01		2.76E+00
Zinc	NC	7.48E-02		3.15E+00		4.40E+01
Total	NC	0.6	NC	61	1.8E-03	744

NC = Not calculated

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Table 28
Avoca Surface Soil, Fields and Pastures
Exposure Point Concentration Summary for Surface Spoils

COPC	Number of Detects	Number of Samples	FOD %	Maximum Detected Concentration	95% UCL	Rationale
Antimony	7	7	100	1.9	1.9	Maximum Concentration of Field Samples
Arsenic	7	7	100	276	275.5	
Cobalt	7	7	72	32.0	32.0	
Copper	7	7	100	575	574.7	
Iron	7	7	100	11.06	11.1	
Lead	7	7	100	818	818.0	
Manganese	7	7	100	2345	2,345.0	
Thallium	7	7	NA	NA	NA	
Vanadium	7	7	39	128.3	128.3	

Note: The "Maximum Concentration of Field Samples" rationale and the "Maximum" label appear at the top of the Rationale / COPC columns respectively.

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Table 29
Adult Resident Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration Maximum of Field Samples (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure for adult/child											
METALS											
Arsenic (1)	275.5	0.030	2.58E-06	1.62E-08	3.14E-08	1.50E+00	1.50E+01	3.87E-06	2.43E-08	4.72E-07	4.37E-06
Lead	818	NA	NC	NC	NC	NA	NA	NC	NC	NC	NC
										TOTAL	4.E-06

COPCs	EPC Concentration Maximum of Field Samples (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure for Adult											
METALS											
Antimony	1.87	NA	2.56E-06	NC	3.88E-10	4.00E-04	NA	6.40E-03	NC	NC	6.40E-03
Arsenic (1)	275.5	0.030	2.26E-06	4.52E-05	5.72E-08	3.00E-04	8.57E-06	7.55E-03	1.51E-01	6.67E-03	1.65E-01
Cobalt	32	NA	4.38E-05	NC	6.64E-09	2.00E-02	5.70E-06	2.19E-03	NC	1.17E-03	3.36E-03
Copper	574.7	NA	7.87E-04	NC	1.19E-07	4.00E-02	NA	1.97E-02	NC	NC	1.97E-02
Iron	11.06	NA	1.52E-05	NC	2.30E-09	7.00E-01	NA	2.16E-05	NC	NC	2.16E-05
Lead	818	NA	1.12E-03	NC	1.70E-07	NA	NA	NC	NC	NC	0.00E+00
Manganese	2345	NA	3.21E-03	NC	4.87E-07	2.00E-02	5.71E-03	1.61E-01	NC	8.52E-05	1.61E-01
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	0.00E+00
Vanadium	128.3	NA	1.76E-04	NC	2.66E-08	1.00E-03	NA	1.76E-01	NC	NC	1.76E-01
										TOTAL	0.53

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	mg soil/day	100
Age Adjusted Ingestion Rae	InRadj	mg-yr/kg-day	114
Arsenic BAF (1)	BAF	percentage	0.006
Inhalation Rate	IRi	m^3/hr	0.83
Inhalation Rate adjusted	InhFadj	m^3*yr/kg*day	11
Exposure Time	ET	hr/day	24
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	5700
Skin Surface Area Available for Contact Age Adjusted	SFSadj	mg*yr/kg*day	340
Contact Rate	CR	mg/cm^2	0.07

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.006 on the high end for EA-1.

Intake Equations:
Oral   Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
Inhalation   Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 30
Adult Resident Risks for Soil based on Ingestion and Dermal Contact with Soil and Inhalation of Particulates
Avoca Mining Site

COPCs	EPC Concentration Maximum of Field Samples (mg/kg)	ABS	Intake (mg/kg-day)			SF_oral (mg/kg-day)$^{-1}$	SF_inhl (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway			CANCER RISK
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Carcinogenic Exposure child											
METALS											
Arsenic (1)	275.5	0.030	1.81E-06	1.52E-07	1.14E-08	1.50E+00	1.50E+01	2.72E-06	2.28E-07	1.72E-07	3.12E-06
Lead	818	NA	8.96E-04	NC	3.40E-08	NA	NA	NC	NC	NC	NC
										TOTAL	**3.12E-06**

COPCs	EPC Concentration Maximum of Field Samples (mg/kg)	ABS	Intake (mg/kg-day)			RfD_oral (mg/kg-day)	RfD_inhl (mg/kg-day)	Hazard Quotient			Hazard Index
			Ingestion	Dermal	Inhalation			Ingestion	Dermal	Inhalation	
Noncarcinogenic Exposure child											
METALS											
Antimony	1.87	NA	2.39E-05	NC	9.06E-10	4.00E-04	NA	5.98E-02	NC	NC	5.98E-02
Arsenic (1)	275.5	0.030	2.11E-05	1.78E-06	1.33E-07	3.00E-04	8.57E-06	7.04E-02	5.92E-03	1.56E-02	9.19E-02
Cobalt	32	NA	4.09E-04	NC	1.55E-08	2.00E-02	5.70E-06	2.05E-02	NC	2.72E-03	2.32E-02
Copper	574.7	NA	7.35E-03	NC	2.78E-07	4.00E-02	NA	1.84E-01	NC	NC	1.84E-01
Iron	11.06	NA	1.41E-04	NC	5.36E-09	7.00E-01	NA	2.02E-04	NC	NC	2.02E-04
Lead	818	NA	1.05E-02	NC	3.96E-07	NA	NA	NC	NC	NC	NC
Manganese	2,345	NA	3.00E-02	NC	1.14E-06	2.00E-02	5.71E-03	1.50E+00	NC	1.99E-04	**1.50E+00**
Thallium	NA	NA	NC	NC	NC	7.60E-05	NA	NC	NC	NC	NC
Vanadium	128.3	NA	1.64E-03	NC	6.21E-08	1.00E-03	NA	1.64E+00	NC	NC	**1.64E+00**
										TOTAL	**3**

Parameter	Symbol	Unit	Value
Chemical Concentration in Soil	Cs	mg/kg	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2190
Body Weight	BW	kg	15
Conversion Factor 1	CF1	kg/mg	1E-06
Exposure Duration	ED	years	6
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	mg soil/day	200
Arsenic BAF (1)	BAF	percentage	0.006
Inhalation Rate	IRi	m^3/hr	0.42
Exposure Time	ET	hr/day	24
Particulate emissions factor	PEF	(m^3/kg)	1.32E+09
Skin Surface Area Available for Contact	SA	cm^2/event	2800
Contact Rate	CR	mg/cm^2	0.2

(1) Arsenic has been adjusted for bioavailability results from in vitro bioassay tests. Oral BAF is 0.006 on the high end for EA-1.

Intake Equations:	Oral	Cs x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
	Dermal	Cs x CF1 x SA x AF x ABS x EF x ED x 1/BW x 1/AT
	Inhalation	Cs x IRi x ET x EF x ED x 1/PEF x 1/BW x 1/AT
Cancer Risk:		=(Oral Intake+ Dermal Intake) x SF_oral + (Inhalation Intake *SF_inhl))
Hazard Quotient:		=(Oral Intake+ Dermal Intake) / RfD_oral + (Inhalation Intake / RFD_inhl))

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Table 31
Exposure Point Concentration Summary for Groundwater
Avoca Mining Site

Chemical	Ireland MCL	Residential PRG EPA Region 2, Tap Water	Maximum Concentration in Homeowner Well Total	Maximum Concentration in Monitoring Well Total	Maximum Concentration in Monitoring Well Dissolved	Is Chemical COPC Based on Homeowner Well?	Is Chemical COPC Based on Monitoring Well?	COPC Based on Homeowner Well	COPC Based on Monitoring Well
	ug/L	ug/L	ug/L	Only 3 results for total	12 results for dissolved				
Aluminium	200	36500	1,186	62,440	1,300,000	Yes	Yes	Aluminium	Aluminium
Antimony		15	1	ND	ND (<1)	No	No	Iron	Arsenic
Arsenic	10	0.04	ND	ND	27	No	Yes	Manganese	Cadmium
Barium		7300	46	47	41	No	No		Chromium III
Cadmium	5	18	ND	30	294	No	Yes		Chromium IV
Calcium			27,230	141,200	323,800	NA	NA		Cobalt
Chromium	50		4	4	370	No	Yes		Copper
Chromium III		54750	4	4	370	No	Yes		Iron
Chromium IV		110	4	4	370	No	Yes		Lead
Cobalt		730	ND	116	1,087	No	Yes		Manganese
Copper	2000	1460	81	8,028	85,460	No	Yes		Nickel
Iron	200	25550	502	1,058	136,000	Yes	Yes		Zinc
Lead		15	3	10	231	No	Yes		
Magnesium			9,883	97,580	1,216,000	NA	NA		
Manganese	50	730	25	5,537	51,310	No	Yes		
Mercury	1		0.0014	NA	NA	No	NA		
Nickel	20	730	8	58	575	No	Yes		
Phosphorous			527	404	NA				
Selenium		183	ND (<1)	ND (<1)	3	No	No		
Silver		183	ND (<2)	ND (<2)	ND (<2)	No	No		
Thallium		3	ND (<1)	ND (<1)	ND (<1)	No	No		
Tin		21900	2	4	ND (<1)	No	No		
Titanium		145979	5	21	9	No	No		
Uranium		110	4	7	93	No	No		
Vanadium		37	2	4	2	No	No		
Zinc	5000	10950	234	9,855	137,700	No	Yes		

Table 32
Adult Resident Risks for Groundwater Via Ingestion and Dermal Contact
Avoca Mining Site

COPCs	Maximum Concentration, Homeowner Well (ug/L)	Kp	Intake (mg/kg-day)		SF_oral (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway		CANCER RISK
			Ingestion	Dermal		Ingestion	Dermal	
Carcinogenic Exposure METALS								
Arsenic (1)	ND	0.001	NC	NC	1.50E+00	NC	NC	NC
Lead	3		NC	NC	NA	NC	NC	NC
							TOTAL	**0.00E+00**

COPCs	Maximum Concentration, Homeowner Well (ug/L)	Kp	Intake (mg/kg-day)		RfD_oral (mg/kg-day)	Hazard Quotient		Hazard Index
			Ingestion	Dermal		Ingestion	Dermal	
Noncarcinogenic Exposure METALS								
Aluminum	1,186		3.74E-02	NC	1.00E+00	3.74E-02	NC	3.74E-02
Arsenic (1)	ND	0.001	NC	NC	3.00E-04	NC	NC	NC
Cadmium	ND		NC	NC	5.00E-04	NC	NC	NC
Chromium III	4		1.26E-04	NC	1.50E+00	8.40E-05	NC	8.40E-05
Chromium IV	4		1.26E-04	NC	1.50E+00	8.40E-05	NC	8.40E-05
Copper	81		2.55E-03	NC	4.00E-02	6.38E-02	NC	6.38E-02
Iron	502		1.58E-02	NC	7.00E-01	2.26E-02	NC	2.26E-02
Lead	3		9.45E-05	NC	NA	NC	NC	NC
Manganese	25		7.88E-04	NC	2.00E-02	3.94E-02	NC	3.94E-02
Nickel	8		2.52E-04	NC	2.00E-02	1.26E-02	NC	1.26E-02
Zinc	234		7.37E-03	NC	3.00E-01	2.46E-02	NC	2.46E-02
							TOTAL	**0.20**

Parameter	Symbol	Unit	Value
Chemical Concentration in Groundv	Cgw	ug/L	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	mg/ug	1E-03
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	Ll/day	2.3
Exposure Time	ET	hr/day	0.58
Skin Surface Area Available for Contact	SA	cm^2/event	18,000
Dermal permeability coefficient of compound in water	Kp	cm/hr	Chemical specific

Intake Equations: Oral   Cgw x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
                   Dermal Cgw x CF1 x SA x ET x Kp x EF x ED x 1/BW x 1/AT
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral

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Table 33
Child Resident Risks for Groundwater Via Ingestion and Dermal Contact
Avoca Mining Site

COPCs	Maximum Concentration, Homeowner Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	SF_oral (mg/kg-day)[-1]	Cancer Risk By Exposure Pathway Ingestion	Cancer Risk By Exposure Pathway Dermal	CANCER RISK
Carcinogenic Exposure METALS								
Arsenic (1)	ND	0.001	NC	NC	1.50E+00	NC	NC	NC
Lead	3		2.47E-05	NC	NA	NC	NC	NC
							TOTAL	**0.00E+00**

COPCs	Maximum Concentration, Homeowner Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	RfD_oral (mg/kg-day)	Hazard Quotient Ingestion	Hazard Quotient Dermal	Hazard Index
Noncarcinogenic Exposure METALS								
Aluminum	1,186		1.14E-01	NC	1.00E+00	1.14E-01	NC	1.14E-01
Arsenic (1)	ND	0.001	NC	NC	3.00E-04	NC	NC	NC
Cadmium	ND		NC	NC	5.00E-04	NC	NC	NC
Chromium III	4		3.84E-04	NC	1.50E+00	2.56E-04	NC	2.56E-04
Chromium IV	4		3.84E-04	NC	1.50E+00	2.56E-04	NC	2.56E-04
Copper	81		7.77E-03	NC	4.00E-02	1.94E-01	NC	1.94E-01
Iron	502		4.81E-02	NC	7.00E-01	6.88E-02	NC	6.88E-02
Lead	3		2.88E-04	NC	NA	NC	NC	NC
Manganese	25		2.40E-03	NC	2.00E-02	1.20E-01	NC	1.20E-01
Nickel	8		7.67E-04	NC	2.00E-02	3.84E-02	NC	3.84E-02
Zinc	234		2.24E-02	NC	3.00E-01	7.48E-02	NC	7.48E-02
							TOTAL	**0.61**

Parameter	Symbol	Unit	Value
Chemical Concentration in Groundw	Cgw	ug/L	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2190
Body Weight	BW	kg	15
Conversion Factor 1	CF1	mg/ug	1E-03
Exposure Duration	ED	years	6
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	Ll/day	1.5
Exposure Time	ET	hr/day	1
Skin Surface Area Available for Contact	SA	cm^2/event	6,600
Dermal permeability coefficient of compound in water	Kp	cm/hr	Chemical specific

Intake Equations:
Oral Cgw x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal Cgw x CF1 x SA x ET x Kp x EF x ED x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral

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Table 34
Adult Resident Risks for Groundwater Via Ingestion and Dermal Contact - Monitoring Wells
Avoca Mining Site

COPCs	Maximum Total Concentration, Monitoring Well (1) (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	SF_oral (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway Ingestion	Cancer Risk By Exposure Pathway Dermal	CANCER RISK
Carcinogenic Exposure METALS								
Arsenic (1)	ND	0.001	NC	NC	1.50E+00	NC	NC	NC
Lead	10		NC	NC	NA	NC	NC	NC
							TOTAL	**0.00E+00**

COPCs	Maximum Concentration, Monitoring Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	RfD_oral (mg/kg-day)	Hazard Quotient Ingestion	Hazard Quotient Dermal	Hazard Index
Noncarcinogenic Exposure METALS								
Aluminum	62,440		1.97E+00	NC	1.00E+00	1.97E+00	NC	**1.97E+00**
Arsenic (1)	ND	0.001	NC	NC	3.00E-04	NC	NC	NC
Cadmium	30		9.45E-04	NC	5.00E-04	1.89E+00	NC	**1.89E+00**
Chromium III	4		1.26E-04	NC	1.50E+00	8.40E-05	NC	8.40E-05
Chromium IV	4		1.26E-04	NC	1.50E+00	8.40E-05	NC	8.40E-05
Copper	8,028		2.53E-01	NC	4.00E-02	6.32E+00	NC	**6.32E+00**
Iron	1,058		3.33E-02	NC	7.00E-01	4.76E-02	NC	4.76E-02
Lead	10		3.15E-04	NC	NA	NC	NC	NC
Manganese	5,537		1.74E-01	NC	2.00E-02	8.72E+00	NC	**8.72E+00**
Nickel	58		1.83E-03	NC	2.00E-02	9.14E-02	NC	9.14E-02
Zinc	9,855		3.11E-01	NC	3.00E-01	1.04E+00	NC	**1.04E+00**
							TOTAL	**20**

Parameter	Symbol	Unit	Value
Chemical Concentration in Groundw	Cgw	ug/L	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	mg/ug	1E-03
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	Ll/day	2.3
Ingestion Rate(adjusted)	IFWadj	L* yr] / [kg* day	1.1
Exposure Time	ET	hr/day	0.58
Skin Surface Area Available for Contact	SA	cm^2/event	18,000
Dermal permeability coefficient of compound in water	Kp	cm/hr	Chemical specific

(1) Monitoring wells are screened in the shallow alluvial aquifer
   This aquifer is not expected to be used as drinking water/
(2) Total concentrations are not available for the
   majority of monitoring wells

Intake Equations: Oral   Cgw x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
                   Dermal   Cgw x CF1 x SA x ET x Kp x EF x ED x 1/BW x 1/AT
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral

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Table 35
Adult Resident Risks for Groundwater Via Ingestion and Dermal Contact - Monitoring Wells
Avoca Mining Site

COPCs	Maximum Dissolved Concentration, Monitoring Well (1) (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	SF_oral (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway Ingestion	Cancer Risk By Exposure Pathway Dermal	CANCER RISK
Carcinogenic Exposure METALS								
Arsenic (1)	27	0.001	4.07E-04	1.65E-03	1.50E+00	6.10E-04	2.48E-03	3.09E-03
Lead	231		NC	NC	NA	NC	NC	NC
							TOTAL	**3.09E-03**

COPCs	Maximum Dissolved Concentration, Monitoring Well (1) (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	RfD_oral (mg/kg-day)	Hazard Quotient Ingestion	Hazard Quotient Dermal	Hazard Index
Noncarcinogenic Exposure METALS								
Aluminum	1,300,000		4.10E+01	NC	1.00E+00	4.10E+01	NC	**4.10E+01**
Arsenic (1)	27	0.001	8.51E-04	3.86E-03	3.00E-04	2.84E+00	12.87	**1.57E+01**
Cadmium	294		9.27E-03	NC	5.00E-04	1.85E+01	NC	**1.85E+01**
Chromium III	370		1.17E-02	NC	1.50E+00	7.77E-03	NC	7.77E-03
Chromium IV	370		1.17E-02	NC	1.50E+00	7.77E-03	NC	7.77E-03
Copper	85,460		2.69E+00	NC	4.00E-02	6.73E+01	NC	**6.73E+01**
Iron	136,000		4.28E+00	NC	7.00E-01	6.12E+00	NC	6.12E+00
Lead	231		7.28E-03	NC	NA	NC	NC	NC
Manganese	51,310		1.62E+00	NC	2.00E-02	8.08E+01	NC	**8.08E+01**
Nickel	575		1.81E-02	NC	2.00E-02	9.06E-01	NC	9.06E-01
Zinc	137,700		4.34E+00	NC	3.00E-01	1.45E+01	NC	**1.45E+01**
							TOTAL	**244.86**

Parameter	Symbol	Unit	Value
Chemical Concentration in Groundv	Cgw	ug/L	see above
Averaging Time - Carcinogenic	At$_c$	days	25550
Averaging Time - Noncarcinogenic	At$_n$	days	10950
Body Weight	BW	kg	70
Conversion Factor 1	CF1	mg/ug	1E-03
Exposure Duration	ED	years	30
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	Ll/day	2.3
Ingestion Rate(adjusted)	IFWadj	L* yr] / [kg* day	1.1
Exposure Time	ET	hr/day	0.58
Skin Surface Area Available for Contact	SA	cm^2/event	18,000
Dermal permeability coefficient of compound in water	Kp	cm/hr	Chemical specific

(1) Monitoring wells are screened in the shallow alluvial aquifer
This aquifer is not expected to be used as drinking water/
Total concentrations are not available for the
majority of monitoring wells

Intake Equations: Oral   Cgw x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal   Cgw x CF1 x SA x ET x Kp x EF x ED x 1/BW x 1/AT
Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral

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Table 36
Child Resident Risks for Groundwater Via Ingestion and Dermal Contact
Avoca Mining Site

COPCs	Maximum Concentration, Monitoring Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	SF_oral (mg/kg-day)$^{-1}$	Cancer Risk By Exposure Pathway Ingestion	Cancer Risk By Exposure Pathway Dermal	CANCER RISK
Carcinogenic Exposure METALS								
Arsenic (1)	ND	0.001	NC	NC	1.50E+00	NC	NC	NC
Lead	10		8.22E-05	NC	NA	NC	NC	NC
							TOTAL	**0.00E+00**

COPCs	Maximum Concentration, Monitoring Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	RfD_oral (mg/kg-day)	Hazard Quotient Ingestion	Hazard Quotient Dermal	Hazard Index
Noncarcinogenic Exposure METALS								
Aluminum	62,440		5.99E+00	NC	1.00E+00	5.99E+00	NC	**5.99E+00**
Arsenic (1)	ND	0.001	NC	NC	3.00E-04	NC	NC	NC
Cadmium	30		2.88E-03	NC	5.00E-04	5.75E+00	NC	**5.75E+00**
Chromium III	4		3.84E-04	NC	1.50E-04	2.56E-04	NC	2.56E-04
Chromium IV	4		3.84E-04	NC	1.50E+00	2.56E-04	NC	2.56E-04
Copper	8,028		7.70E-01	NC	4.00E-02	1.92E+01	NC	**1.92E+01**
Iron	1,058		1.01E-01	NC	7.00E-01	1.45E-01	NC	1.45E-01
Lead	10		9.59E-04	NC	NA	NC	NC	NC
Manganese	5,537		5.31E-01	NC	2.00E-02	2.65E+01	NC	**2.65E+01**
Nickel	58		5.56E-03	NC	2.00E-02	2.78E-01	NC	2.78E-01
Zinc	9,855		9.45E-01	NC	3.00E-01	3.15E+00	NC	**3.15E+00**
							TOTAL	**61**

Parameter	Symbol	Unit	Value
Chemical Concentration in Groundw	Cgw	ug/L	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2190
Body Weight	BW	kg	15
Conversion Factor 1	CF1	mg/ug	1E-03
Exposure Duration	ED	years	6
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	Ll/day	1.5
Exposure Time	ET	hr/day	1
Skin Surface Area Available for Contact	SA	cm^2/event	6,600
Dermal permeability coefficient of compound in water	Kp	cm/hr	Chemical specific

Intake Equations:	Oral	Cgw x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
	Dermal	Cgw x CF1 x SA x ET x Kp x EF x ED x 1/BW x 1/AT
Cancer Risk:	=(Oral Intake+ Dermal Intake) x SF_oral	
Hazard Quotient:	=(Oral Intake+ Dermal Intake) / RfD_oral	

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Table 37
Child Resident Risks for Groundwater Via Ingestion and Dermal Contact
Avoca Mining Site

COPCs	Maximum Concentration, Monitoring Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	SF_oral (mg/kg-day)[-1]	Cancer Risk By Exposure Pathway Ingestion	Cancer Risk By Exposure Pathway Dermal	CANCER RISK
Carcinogenic Exposure METALS								
Arsenic (1)	27	0.001	2.22E-04	9.76E-04	1.50E+00	3.33E-04	0.001464658	1.80E-03
Lead	231		1.90E-03	NC	NA	NC	NC	NC
							TOTAL	**1.80E-03**

COPCs	Maximum Concentration, Monitoring Well (ug/L)	Kp	Intake (mg/kg-day) Ingestion	Intake (mg/kg-day) Dermal	RfD_oral (mg/kg-day)	Hazard Quotient Ingestion	Hazard Quotient Dermal	Hazard Index
Noncarcinogenic Exposure METALS								
Aluminum	1300000		1.25E+02	NC	1.00E+00	1.25E+02	NC	**1.25E+02**
Arsenic (1)	27	0.001	2.59E-03	1.14E-02	3.00E-04	8.63E+00	3.80E+01	4.66E+01
Cadmium	294.3		2.82E-02	NC	5.00E-04	5.64E+01	NC	**5.64E+01**
Chromium III	370		3.55E-02	NC	1.50E+00	2.37E-02	NC	2.37E-02
Chromium IV	370		3.55E-02	NC	1.50E+00	2.37E-02	NC	2.37E-02
Copper	85460		8.19E+00	NC	4.00E-02	2.05E+02	NC	**2.05E+02**
Iron	136000		1.30E+01	NC	7.00E-01	1.86E+01	NC	1.86E+01
Lead	231		2.22E-02	NC	NA	NC	NC	NC
Manganese	51310		4.92E+00	NC	2.00E-02	2.46E+02	NC	**2.46E+02**
Nickel	575		5.51E-02	NC	2.00E-02	2.76E+00	NC	2.76E+00
Zinc	137700		1.32E+01	NC	3.00E-01	4.40E+01	NC	**4.40E+01**
							TOTAL	**744**

Parameter	Symbol	Unit	Value
Chemical Concentration in Groundw	Cgw	ug/L	see above
Averaging Time - Carcinogenic	At_c	days	25550
Averaging Time - Noncarcinogenic	At_n	days	2190
Body Weight	BW	kg	15
Conversion Factor 1	CF1	mg/ug	1E-03
Exposure Duration	ED	years	6
Exposure Frequency	EF	days/year	350
Ingestion Rate	InR	Ll/day	1.5
Exposure Time	ET	hr/day	1
Skin Surface Area Available for Contact	SA	cm^2/event	6,600
Dermal permeability coefficient of compound in water	Kp	cm/hr	Chemical specific

(1) Monitoring wells are screened in the shallow alluvial aquifer
This aquifer is not expected to be used as drinking water/
Total concentrations are not available for the
majority of monitoring wells

Intake Equations:
Oral: Cgw x CF1 x InR x BAF x EF x ED x 1/BW x 1/AT
Dermal: Cgw x CF1 x SA x ET x Kp x EF x ED x 1/BW x 1/AT

Cancer Risk: =(Oral Intake+ Dermal Intake) x SF_oral
Hazard Quotient: =(Oral Intake+ Dermal Intake) / RfD_oral

CDM

Appendix D
Lead Model

Appendix D-1
IEUBK Model

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                     LEAD MODEL FOR WINDOWS Version 1.0

=================================================================================
Model Version: 1.0 Build 261
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Research Bioavailability = 1%
=================================================================================
The time step used in this model run: 1 - Every 4 Hours (6 times a day).


****** Air ******


Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age          Time         Ventilation        Lung          Outdoor Air
            Outdoors         Rate          Absorption        Pb Conc
            (hours)        (m^3/day)          (%)          (ug Pb/m^3)
-------------------------------------------------------------------------
.5-1        1.000           2.000           32.000           0.100
1-2         2.000           3.000           32.000           0.100
2-3         3.000           5.000           32.000           0.100
3-4         4.000           5.000           32.000           0.100
4-5         4.000           5.000           32.000           0.100
5-6         4.000           7.000           32.000           0.100
6-7         4.000           7.000           32.000           0.100


****** Diet ******


Age     Diet Intake(ug/day)
------------------------------------
.5-1        5.530
1-2         5.780
2-3         6.490
3-4         6.240
4-5         6.010
5-6         6.340
6-7         7.000


****** Drinking Water ******


Water Consumption:
Age     Water (L/day)
------------------------------------
.5-1        0.200
1-2         0.500
2-3         0.520
3-4         0.530
4-5         0.550
5-6         0.580
6-7         0.590


Drinking Water Concentration: 4.000 ug Pb/L


****** Soil & Dust ******


Multiple Source Analysis Used
Average multiple source concentration: 7314.500 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700
Outdoor airborne lead to indoor household dust lead concentration: 100.000
Use alternate indoor dust Pb sources? No


Age          Soil (ug Pb/g)        House Dust (ug Pb/g)
------------------------------------------------------------
.5-1            10435.000             7314.500
1-2             10435.000             7314.500
2-3             10435.000             7314.500
```

```
3-4              10435.000              7314.500
4-5              10435.000              7314.500
5-6              10435.000              7314.500
6-7              10435.000              7314.500


****** Alternate Intake ******

Age       Alternate (ug Pb/day)
-----------------------------------
.5-1      0.000
1-2       0.000
2-3       0.000
3-4       0.000
4-5       0.000
5-6       0.000
6-7       0.000


****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

*****************************************
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
*****************************************

Year          Air              Diet            Alternate      Water
            (ug/day)         (ug/day)          (ug/day)      (ug/day)
---------------------------------------------------------------------------
.5-1          0.021            2.479            0.000          0.359
1-2           0.034            2.556            0.000          0.884
2-3           0.062            2.912            0.000          0.933
3-4           0.067            2.843            0.000          0.966
4-5           0.067            2.813            0.000          1.030
5-6           0.093            2.997            0.000          1.097
6-7           0.093            3.325            0.000          1.121

 Year       Soil+Dust           Total            Blood
            (ug/day)           (ug/day)          (ug/dL)
-----------------------------------------------------------
.5-1          6.645            9.504             5.1
1-2          10.409           13.884             5.7
2-3          10.561           14.468             5.4
3-4          10.724           14.598             5.1
4-5           8.161           12.071             4.3
5-6           7.419           11.606             3.7
6-7           7.040           11.580             3.3
```
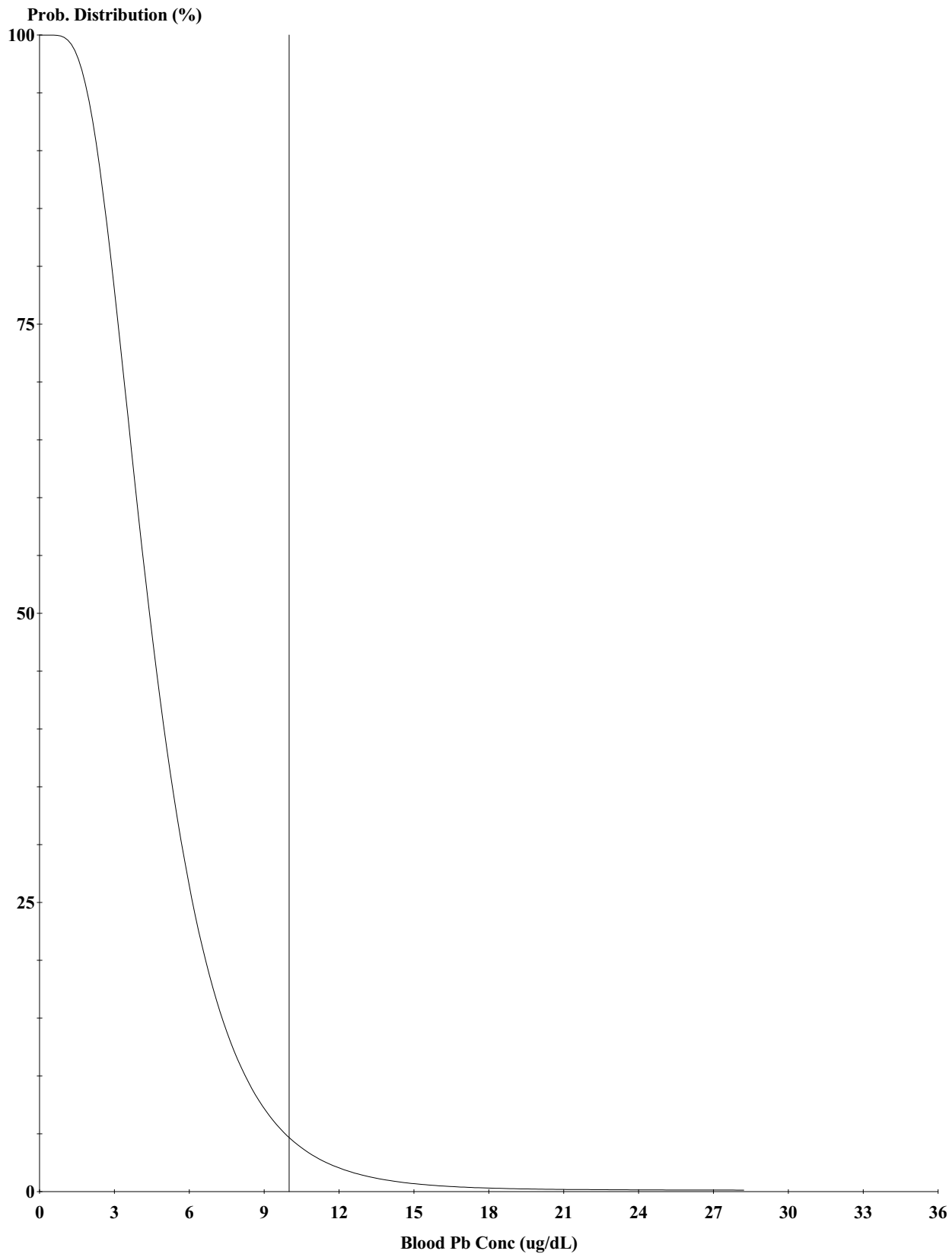
Prob. Distribution (%)

Blood Pb Conc (ug/dL)

Cutoff = 10.000 ug/dl
Geo Mean = 4.616
GSD = 1.600
% Above = 5.000

Age Range = 0 to 84 months
Time Step = Every 4 Hours
Run Mode = Research
Comment = Ground Water

```
                    LEAD MODEL FOR WINDOWS Version 1.0

=============================================================================
Model Version: 1.0 Build 261
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Research Bioavailability = 3%
=============================================================================
The time step used in this model run: 1 - Every 4 Hours (6 times a day).


****** Air ******


Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age         Time          Ventilation          Lung          Outdoor Air
           Outdoors          Rate           Absorption         Pb Conc
           (hours)        (m^3/day)            (%)           (ug Pb/m^3)
-----------------------------------------------------------------------
.5-1        1.000           2.000             32.000            0.100
1-2         2.000           3.000             32.000            0.100
2-3         3.000           5.000             32.000            0.100
3-4         4.000           5.000             32.000            0.100
4-5         4.000           5.000             32.000            0.100
5-6         4.000           7.000             32.000            0.100
6-7         4.000           7.000             32.000            0.100


****** Diet ******


Age     Diet Intake(ug/day)
------------------------------------
.5-1        5.530
1-2         5.780
2-3         6.490
3-4         6.240
4-5         6.010
5-6         6.340
6-7         7.000


****** Drinking Water ******


Water Consumption:
Age     Water (L/day)
------------------------------------
.5-1        0.200
1-2         0.500
2-3         0.520
3-4         0.530
4-5         0.550
5-6         0.580
6-7         0.590


Drinking Water Concentration: 4.000 ug Pb/L


****** Soil & Dust ******


Multiple Source Analysis Used
Average multiple source concentration: 2441.800 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700
Outdoor airborne lead to indoor household dust lead concentration: 100.000
Use alternate indoor dust Pb sources? No


Age          Soil (ug Pb/g)         House Dust (ug Pb/g)
-----------------------------------------------------------
.5-1             3474.000               2441.800
1-2              3474.000               2441.800
2-3              3474.000               2441.800
```

```
3-4             3474.000            2441.800
4-5             3474.000            2441.800
5-6             3474.000            2441.800
6-7             3474.000            2441.800


****** Alternate Intake ******

Age      Alternate (ug Pb/day)
-----------------------------------
.5-1     0.000
1-2      0.000
2-3      0.000
3-4      0.000
4-5      0.000
5-6      0.000
6-7      0.000


****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

*******************************************
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
*******************************************

Year        Air             Diet            Alternate      Water
           (ug/day)        (ug/day)         (ug/day)       (ug/day)
-------------------------------------------------------------------------
.5-1        0.021           2.479            0.000          0.359
1-2         0.034           2.556            0.000          0.884
2-3         0.062           2.912            0.000          0.933
3-4         0.067           2.843            0.000          0.966
4-5         0.067           2.813            0.000          1.030
5-6         0.093           2.997            0.000          1.097
6-7         0.093           3.325            0.000          1.121

 Year     Soil+Dust          Total           Blood
          (ug/day)          (ug/day)         (ug/dL)
-------------------------------------------------------------
.5-1        6.645            9.505            5.1
1-2        10.409           13.884            5.7
2-3        10.562           14.468            5.4
3-4        10.724           14.599            5.1
4-5         8.162           12.071            4.3
5-6         7.419           11.606            3.7
6-7         7.040           11.580            3.3
```

Prob. Distribution (%)

Blood Pb Conc (ug/dL)

Cutoff = 10.000 ug/dl
Geo Mean = 4.616
GSD = 1.600
% Above = 5.000

Age Range = 0 to 84 months
Time Step = Every 4 Hours
Run Mode = Research
Comment = Ground Water

```
                    LEAD MODEL FOR WINDOWS Version 1.0

================================================================================
Model Version: 1.0 Build 261
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Research Bioavailability = 3.9%
================================================================================
The time step used in this model run: 1 - Every 4 Hours (6 times a day).


****** Air ******


Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age          Time          Ventilation          Lung          Outdoor Air
           Outdoors           Rate           Absorption         Pb Conc
           (hours)         (m^3/day)            (%)           (ug Pb/m^3)
--------------------------------------------------------------------------
.5-1        1.000            2.000             32.000            0.100
1-2         2.000            3.000             32.000            0.100
2-3         3.000            5.000             32.000            0.100
3-4         4.000            5.000             32.000            0.100
4-5         4.000            5.000             32.000            0.100
5-6         4.000            7.000             32.000            0.100
6-7         4.000            7.000             32.000            0.100


****** Diet ******


Age     Diet Intake(ug/day)
------------------------------------
.5-1       5.530
1-2        5.780
2-3        6.490
3-4        6.240
4-5        6.010
5-6        6.340
6-7        7.000


****** Drinking Water ******


Water Consumption:
Age     Water (L/day)
------------------------------------
.5-1       0.200
1-2        0.500
2-3        0.520
3-4        0.530
4-5        0.550
5-6        0.580
6-7        0.590


Drinking Water Concentration: 4.000 ug Pb/L


****** Soil & Dust ******


Multiple Source Analysis Used
Average multiple source concentration: 1879.350 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700
Outdoor airborne lead to indoor household dust lead concentration: 100.000
Use alternate indoor dust Pb sources? No


Age           Soil (ug Pb/g)        House Dust (ug Pb/g)
-----------------------------------------------------------
.5-1              2670.500              1879.350
1-2               2670.500              1879.350
2-3               2670.500              1879.350
```

```
3-4            2670.500              1879.350
4-5            2670.500              1879.350
5-6            2670.500              1879.350
6-7            2670.500              1879.350


****** Alternate Intake ******

Age      Alternate (ug Pb/day)
------------------------------------
.5-1     0.000
1-2      0.000
2-3      0.000
3-4      0.000
4-5      0.000
5-6      0.000
6-7      0.000


****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

******************************************
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
******************************************
```

Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.021	2.479	0.000	0.359
1-2	0.034	2.556	0.000	0.884
2-3	0.062	2.912	0.000	0.933
3-4	0.067	2.843	0.000	0.966
4-5	0.067	2.813	0.000	1.030
5-6	0.093	2.997	0.000	1.097
6-7	0.093	3.325	0.000	1.121

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	6.645	9.504	5.1
1-2	10.408	13.883	5.7
2-3	10.560	14.467	5.4
3-4	10.723	14.598	5.1
4-5	8.161	12.070	4.3
5-6	7.418	11.605	3.7
6-7	7.040	11.579	3.3
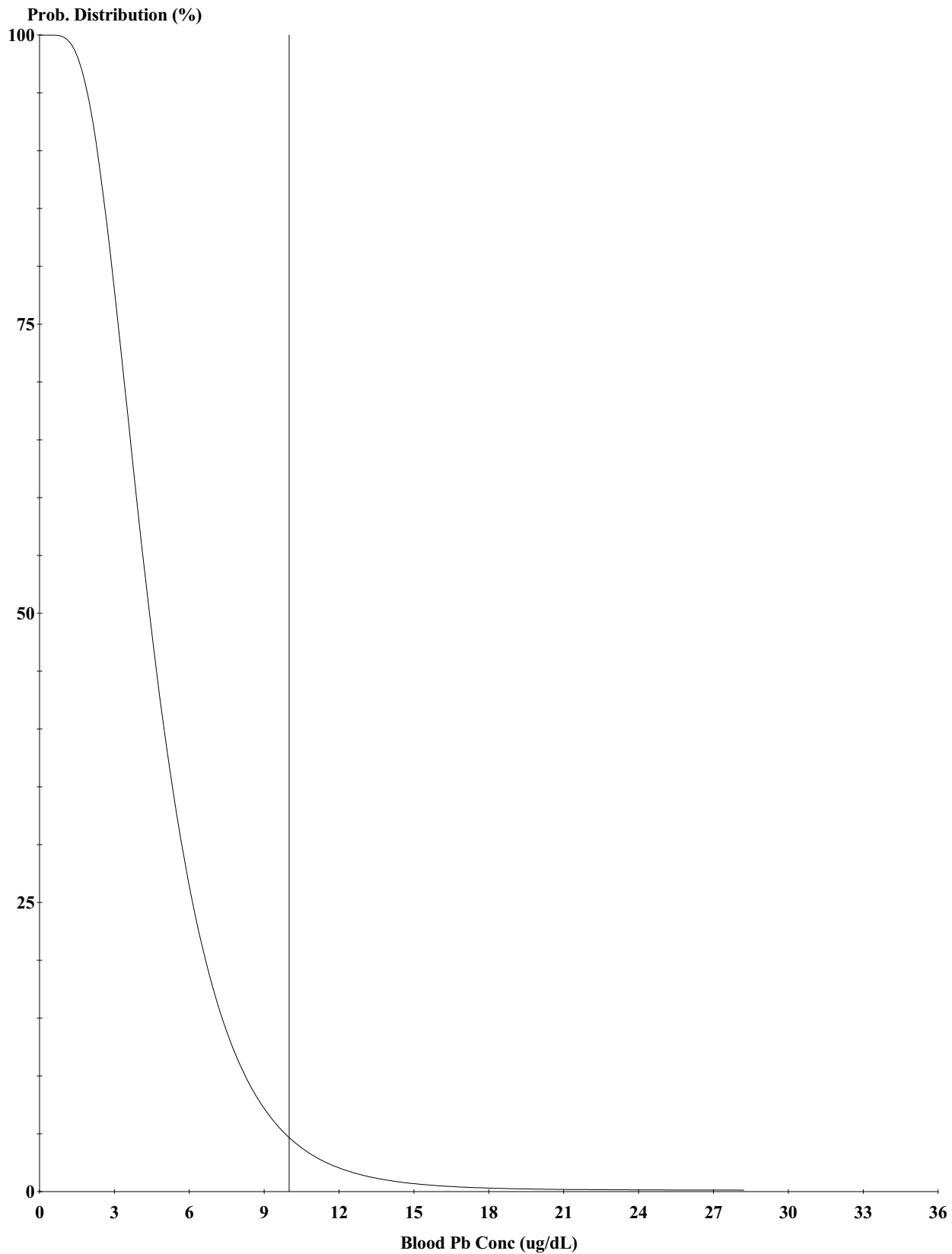
Prob. Distribution (%)

Blood Pb Conc (ug/dL)

Cutoff = 10.000 ug/dl   Age Range = 0 to 84 months
Geo Mean = 4.616   Time Step = Every 4 Hours
GSD = 1.600   Run Mode = Research
% Above = 4.999   Comment = Ground Water

```
                    LEAD MODEL FOR WINDOWS Version 1.0

===============================================================================
Model Version: 1.0 Build 261
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Research  Bioavailability = 6%
===============================================================================
The time step used in this model run: 1 - Every 4 Hours (6 times a day).


****** Air ******


Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age         Time         Ventilation        Lung          Outdoor Air
          Outdoors         Rate          Absorption         Pb Conc
          (hours)        (m^3/day)          (%)           (ug Pb/m^3)
-------------------------------------------------------------------------
.5-1        1.000          2.000           32.000            0.100
1-2         2.000          3.000           32.000            0.100
2-3         3.000          5.000           32.000            0.100
3-4         4.000          5.000           32.000            0.100
4-5         4.000          5.000           32.000            0.100
5-6         4.000          7.000           32.000            0.100
6-7         4.000          7.000           32.000            0.100


****** Diet ******


Age     Diet Intake(ug/day)
------------------------------------
.5-1        5.530
1-2         5.780
2-3         6.490
3-4         6.240
4-5         6.010
5-6         6.340
6-7         7.000


****** Drinking Water ******


Water Consumption:
Age     Water (L/day)
------------------------------------
.5-1        0.200
1-2         0.500
2-3         0.520
3-4         0.530
4-5         0.550
5-6         0.580
6-7         0.590


Drinking Water Concentration: 4.000 ug Pb/L


****** Soil & Dust ******


Multiple Source Analysis Used
Average multiple source concentration: 1223.800 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700
Outdoor airborne lead to indoor household dust lead concentration: 100.000
Use alternate indoor dust Pb sources? No


Age          Soil (ug Pb/g)        House Dust (ug Pb/g)
-----------------------------------------------------------
.5-1            1734.000              1223.800
1-2             1734.000              1223.800
2-3             1734.000              1223.800
```

```
3-4              1734.000              1223.800
4-5              1734.000              1223.800
5-6              1734.000              1223.800
6-7              1734.000              1223.800


****** Alternate Intake ******

Age      Alternate (ug Pb/day)
----------------------------------

.5-1     0.000
1-2      0.000
2-3      0.000
3-4      0.000
4-5      0.000
5-6      0.000
6-7      0.000


****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

*******************************************
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
*******************************************

Year        Air              Diet            Alternate        Water
          (ug/day)         (ug/day)          (ug/day)        (ug/day)
---------------------------------------------------------------------------
.5-1        0.021            2.479             0.000           0.359
1-2         0.034            2.556             0.000           0.884
2-3         0.062            2.912             0.000           0.933
3-4         0.067            2.842             0.000           0.966
4-5         0.067            2.813             0.000           1.030
5-6         0.093            2.997             0.000           1.097
6-7         0.093            3.325             0.000           1.121

 Year     Soil+Dust           Total             Blood
          (ug/day)          (ug/day)          (ug/dL)
------------------------------------------------------------
.5-1        6.646            9.506              5.1
1-2        10.411           13.885              5.7
2-3        10.563           14.470              5.4
3-4        10.725           14.600              5.1
4-5         8.163           12.072              4.3
5-6         7.420           11.607              3.7
6-7         7.042           11.581              3.3
```
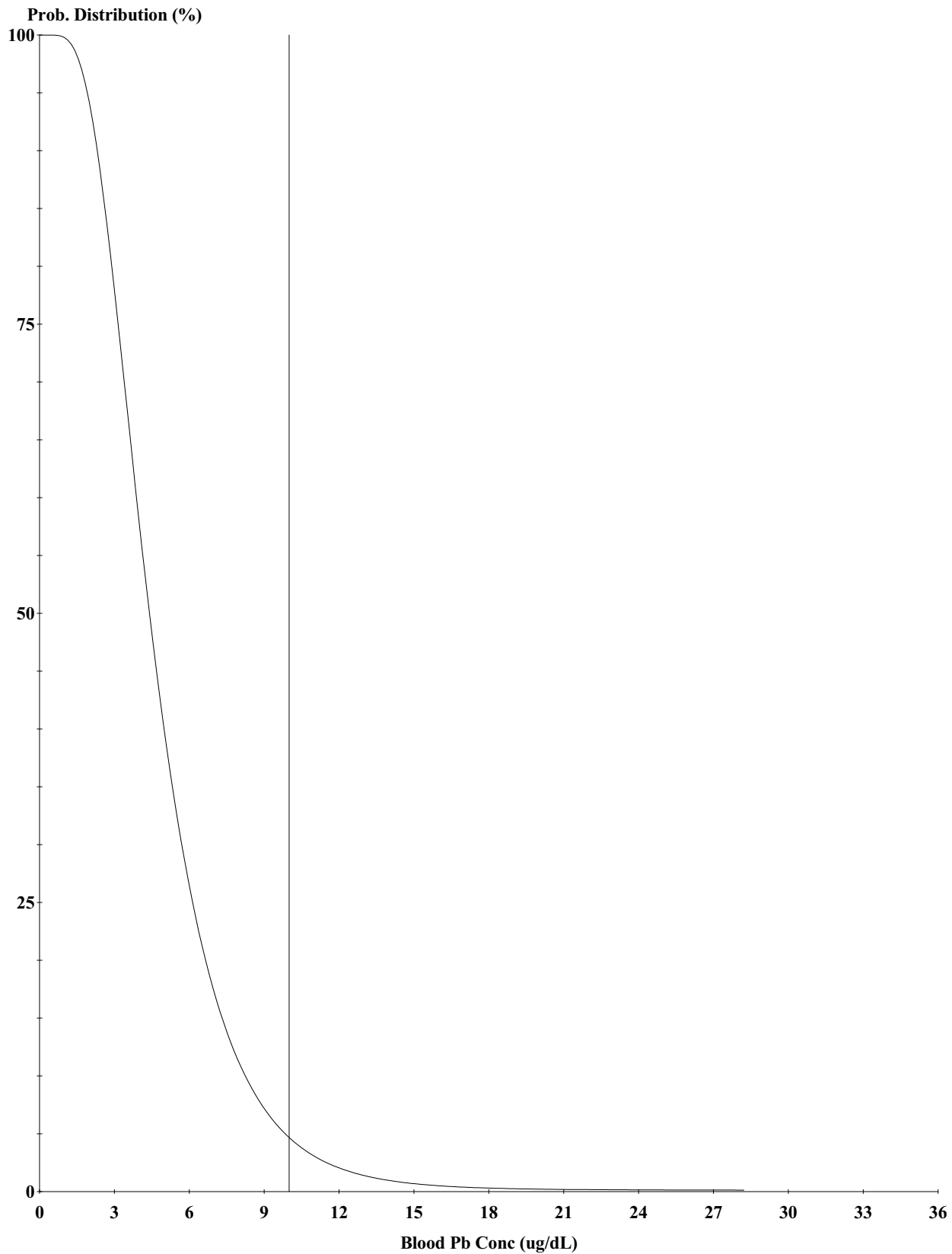
Prob. Distribution (%)

Blood Pb Conc (ug/dL)

Cutoff = 10.000 ug/dl   Age Range = 0 to 84 months
Geo Mean = 4.616   Time Step = Every 4 Hours
GSD = 1.600   Run Mode = Research
% Above = 5.002   Comment = Ground Water

```
                    LEAD MODEL FOR WINDOWS Version 1.0

=============================================================================
Model Version: 1.0 Build 261
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Research Bioavailability 14%
=============================================================================
The time step used in this model run: 1 - Every 4 Hours (6 times a day).


****** Air ******

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age          Time         Ventilation        Lung          Outdoor Air
           Outdoors         Rate          Absorption        Pb Conc
           (hours)        (m^3/day)          (%)          (ug Pb/m^3)
--------------------------------------------------------------------------
.5-1        1.000           2.000           32.000           0.100
1-2         2.000           3.000           32.000           0.100
2-3         3.000           5.000           32.000           0.100
3-4         4.000           5.000           32.000           0.100
4-5         4.000           5.000           32.000           0.100
5-6         4.000           7.000           32.000           0.100
6-7         4.000           7.000           32.000           0.100


****** Diet ******

Age      Diet Intake(ug/day)
-----------------------------------
.5-1        5.530
1-2         5.780
2-3         6.490
3-4         6.240
4-5         6.010
5-6         6.340
6-7         7.000


****** Drinking Water ******

Water Consumption:
Age      Water (L/day)
-----------------------------------
.5-1        0.200
1-2         0.500
2-3         0.520
3-4         0.530
4-5         0.550
5-6         0.580
6-7         0.590


Drinking Water Concentration: 4.000 ug Pb/L


****** Soil & Dust ******

Multiple Source Analysis Used
Average multiple source concentration: 527.510 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700
Outdoor airborne lead to indoor household dust lead concentration: 100.000
Use alternate indoor dust Pb sources? No

Age          Soil (ug Pb/g)        House Dust (ug Pb/g)
-----------------------------------------------------------
.5-1            739.300               527.510
1-2             739.300               527.510
2-3             739.300               527.510
```

```
3-4                739.300              527.510
4-5                739.300              527.510
5-6                739.300              527.510
6-7                739.300              527.510


****** Alternate Intake ******

Age       Alternate (ug Pb/day)
-----------------------------------
.5-1      0.000
1-2       0.000
2-3       0.000
3-4       0.000
4-5       0.000
5-6       0.000
6-7       0.000


****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

******************************************
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
******************************************

Year          Air              Diet           Alternate      Water
           (ug/day)          (ug/day)          (ug/day)     (ug/day)
------------------------------------------------------------------------
.5-1          0.021            2.479            0.000        0.359
1-2           0.034            2.556            0.000        0.884
2-3           0.062            2.912            0.000        0.933
3-4           0.067            2.843            0.000        0.966
4-5           0.067            2.813            0.000        1.030
5-6           0.093            2.997            0.000        1.097
6-7           0.093            3.325            0.000        1.121

 Year      Soil+Dust           Total            Blood
           (ug/day)          (ug/day)          (ug/dL)
-------------------------------------------------------------
.5-1          6.646            9.505            5.1
1-2          10.410           13.884            5.7
2-3          10.562           14.469            5.4
3-4          10.724           14.599            5.1
4-5           8.162           12.071            4.3
5-6           7.419           11.606            3.7
6-7           7.041           11.580            3.3
```

Prob. Distribution (%)

Blood Pb Conc (ug/dL)

Cutoff = 10.000 ug/dl   Age Range = 0 to 84 months
Geo Mean = 4.616   Time Step = Every 4 Hours
GSD = 1.600   Run Mode = Research
% Above = 5.001   Comment = Ground Water

```
                    LEAD MODEL FOR WINDOWS Version 1.0

================================================================================
Model Version: 1.0 Build 261
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Research Bioavailability 30%
================================================================================
The time step used in this model run: 1 - Every 4 Hours (6 times a day).


****** Air ******


Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age          Time          Ventilation        Lung          Outdoor Air
           Outdoors           Rate         Absorption         Pb Conc
           (hours)         (m^3/day)          (%)          (ug Pb/m^3)
--------------------------------------------------------------------------
.5-1         1.000           2.000           32.000           0.100
1-2          2.000           3.000           32.000           0.100
2-3          3.000           5.000           32.000           0.100
3-4          4.000           5.000           32.000           0.100
4-5          4.000           5.000           32.000           0.100
5-6          4.000           7.000           32.000           0.100
6-7          4.000           7.000           32.000           0.100


****** Diet ******


Age      Diet Intake(ug/day)
------------------------------------
.5-1         5.530
1-2          5.780
2-3          6.490
3-4          6.240
4-5          6.010
5-6          6.340
6-7          7.000


****** Drinking Water ******


Water Consumption:
Age      Water (L/day)
------------------------------------
.5-1         0.200
1-2          0.500
2-3          0.520
3-4          0.530
4-5          0.550
5-6          0.580
6-7          0.590


Drinking Water Concentration: 4.000 ug Pb/L


****** Soil & Dust ******


Multiple Source Analysis Used
Average multiple source concentration: 249.050 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700
Outdoor airborne lead to indoor household dust lead concentration: 100.000
Use alternate indoor dust Pb sources? No


Age           Soil (ug Pb/g)        House Dust (ug Pb/g)
------------------------------------------------------------
.5-1             341.500               249.050
1-2              341.500               249.050
2-3              341.500               249.050
```

```
3-4                    341.500                    249.050
4-5                    341.500                    249.050
5-6                    341.500                    249.050
6-7                    341.500                    249.050


****** Alternate Intake ******

Age      Alternate (ug Pb/day)
------------------------------------
.5-1     0.000
1-2      0.000
2-3      0.000
3-4      0.000
4-5      0.000
5-6      0.000
6-7      0.000


****** Maternal Contribution: Infant Model ******

Maternal Blood Concentration: 2.500 ug Pb/dL

*******************************************
CALCULATED BLOOD LEAD AND LEAD UPTAKES:
*******************************************

Year        Air              Diet            Alternate        Water
          (ug/day)         (ug/day)          (ug/day)        (ug/day)
-----------------------------------------------------------------------------
.5-1        0.021            2.479             0.000           0.359
1-2         0.034            2.556             0.000           0.884
2-3         0.062            2.912             0.000           0.933
3-4         0.067            2.843             0.000           0.966
4-5         0.067            2.813             0.000           1.030
5-6         0.093            2.997             0.000           1.097
6-7         0.093            3.325             0.000           1.121


 Year      Soil+Dust           Total            Blood
          (ug/day)          (ug/day)          (ug/dL)
-------------------------------------------------------------
.5-1        6.646            9.505              5.1
1-2        10.410           13.885              5.7
2-3        10.562           14.469              5.4
3-4        10.725           14.599              5.1
4-5         8.162           12.071              4.3
5-6         7.419           11.607              3.7
6-7         7.041           11.580              3.3
```
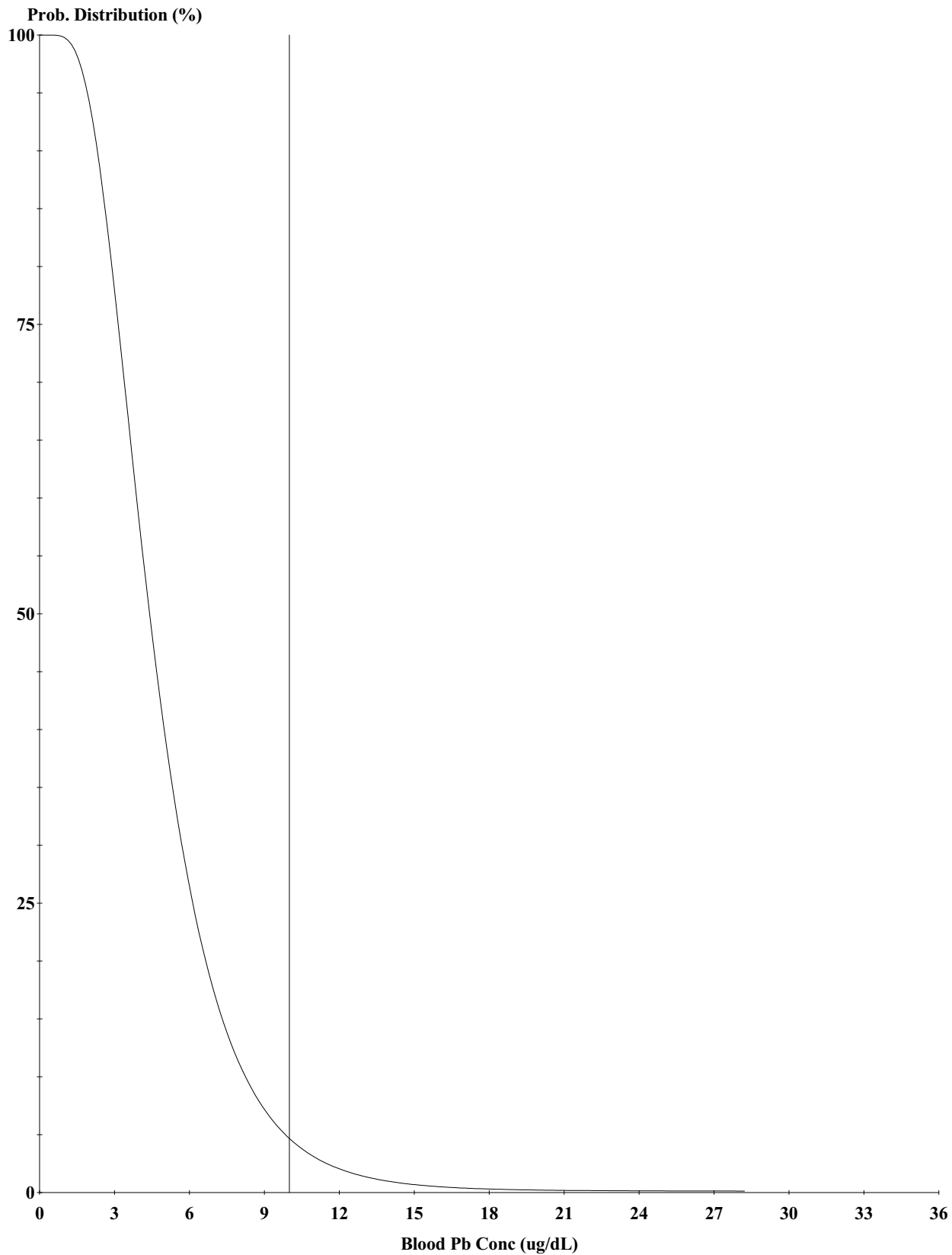
Prob. Distribution (%)

Blood Pb Conc (ug/dL)

Cutoff = 10.000 ug/dl   Age Range = 0 to 84 months
Geo Mean = 4.616   Time Step = Every 4 Hours
GSD = 1.600   Run Mode = Research
% Above = 5.001   Comment = Ground Water

Appendix D-2
Adult Lead Model

Table 1
Summary of Lead PRGs for Adults and Older Children
Avoca Mining Site

Exposure Area		95th % UCL Absolute Bioavailability Estimate	Recreational Visitor (Adults and Older Children)	Commercial/ Industrial Worker	Construction Worker
EA-1	Connary	6.64%	5,876	2,444	1,424
EA-2	Mount Platt/ Cronebane	1.00%	39,017	16,231	9,459
EA-3	East Avoca/Tigroney West	4.85%	8,045	3,347	1,950
EA-4	Ore bins Tigroney West	1.30%	30,013	12,485	7,276
EA-5	Deep Adit Area	1.30%	30,013	12,485	7,276
EA-6	West Avoca	13.94%	2,799	1,164	679
	(1)	3.59%	10,868	4,521	2,635
EA-7	Shelton Abbey	NA	NA	NA	NA

(1)   95TH UCL for absolute bioavailability excludes anomalous high

Appendix D-2
Adult Lead Model
Recreational Visitor

Table 1 Summary Lead PRGs for Recreational Visitors

	Exposure Area	95th % UCL Absolute Bioavailability Estimate	PRG (mg/Kg) for Recreational Visitor (1)
EA-1	Connary	6.64%	5,876
EA-2	Mount Platt/ Cronebane	1.00%	39,017
EA-3	East Avoca/Tigroney West	4.85%	8,045
EA-4	Ore bins Tigroney West	1.30%	30,013
EA-5	Deep Adit Area	1.30%	30,013
EA-6	West Avoca	13.94%	2,799
		3.59%	10,868
EA-7	Shelton Abbey	NA	NA

(1)   PRG for lead calculated in the ALM

(1)   95TH UCL for absolute bioavailability excludes anomalous high absolute

Table 2 Summary of Adult Lead Model For Recreational Visitors

Exposure Area		Statistic	EPC mg/kg	95th % UCL Absolute Bioavailability	PbB of recreational visitor, geometric mean	Probability that fetal PbB > PbB$_t$, assuming lognormal distribution
						GSDi = Hom
EA-1	Connary	95th UCL	34,525	6.64%	12.0	**53.9%**
		Mean	17,430	6.64%	6.8	**25.3%**
EA-2	Mount Platt/ Cronbane	95th UCL	13,768	1.00%	2.1	1.3%
		Mean	4,274	1.00%	1.7	0.6%
EA-3	East Avoca/ Tigroney West	95th UCL	5,221	4.85%	2.7	2.7%
		Mean	3,385	4.85%	2.2	1.6%
EA-4	Ore bins At Tigroney West	95th UCL	70,792	1.30%	5.7	**18.4%**
		Mean	19,675	1.30%	2.7	2.7%
EA-5	Deep Adit Area	95th UCL	10,834	1.30%	2.1	1.3%
		Mean	7,845	1.30%	2.0	1.0%
EA-6	West Avoca	95th UCL	3,808	13.94%	3.9	**8.0%**
		Mean	2,165	13.94%	2.9	3.4%
		95th UCL (1)	3,808	3.59%	1.9	0.8%
EA-7	Shelton Abbey	95th UCL	NA	NA	NA	NA
		Mean	NA	NA	NA	NA

(1)   95TH UCL for absolute bioavailability excludes anomalous high absolute bioavailability value

Calculations of Preliminary Remediation Goals (PRGs)

Table 3
EA-1 Connary
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	17,430	17,430	17,430	17,430
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	6.8	7.0	6.8	7.0
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	20.7	24.7	20.7	24.7
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	25.3%	28.8%	25.3%	28.8%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

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Calculations of Preliminary Remediation Goals (PRGs)

Table 4
EA-1 Connary
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	34525	34525	34525	34525
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	**ug/dL**	**12.0**	**12.2**	**12.0**	**12.2**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	**ug/dL**	**36.5**	**43.0**	**36.5**	**43.0**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	**ug/dL**	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	**%**	**53.9%**	**54.3%**	**53.9%**	**54.3%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS \cdot BKSF \cdot IR_{S+D} \cdot AF_{S,D} \cdot EF_S / AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} \cdot (GSD_i^{1.645} \cdot R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS \cdot BKSF \cdot ([(IR_{S+D}) \cdot AF_S \cdot EF_S \cdot W_S] + [K_{SD} \cdot (IR_{S+D}) \cdot (1-W_S) \cdot AF_D \cdot EF_D]) / 365 + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} \cdot (GSD_i^{1.645} \cdot R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil
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Calculations of Preliminary Remediation Goals (PRGs)

Table 5
EA-2 Mount Platt/Cronebane
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	4,274	4,274	4,274	4,274
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.004	0.004	0.004	0.004
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	1.7	1.9	1.7	1.9
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	5.2	6.7	5.2	6.7
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	0.6%	1.7%	0.6%	1.7%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 6
EA-2 Mount Platt/Cronebane
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	13768	13768	13768	13768
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.00	0.00	0.00	0.00
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**2.1**	**2.3**	**2.1**	**2.3**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**6.5**	**8.2**	**6.5**	**8.2**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB$_t$, assuming lognormal distribution**	%	**1.3%**	**3.0%**	**1.3%**	**3.0%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-2	
$AF_{S, D}$	adult absorption		
	0.4	0.01	0.004

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 7
EA-3 East Avoca, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,385	3,385	3,385	3,385
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.2	2.4	2.2	2.4
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	6.9	8.7	6.9	8.7
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	1.6%	3.5%	1.6%	3.5%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 8
EA-3 East Avoca, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Het	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	5221	5221	5221	5221
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.7	2.9	2.7	2.9
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	8.1	10.1	8.1	10.1
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	2.7%	5.1%	2.7%	5.1%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-3	
$AF_{S, D}$	adult absorption		
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

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Calculations of Preliminary Remediation Goals (PRGs)

Table 9
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	19,675	19,675	19,675	19,675
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.7	2.9	2.7	2.9
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	8.1	10.2	8.1	10.2
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	2.7%	5.2%	2.7%	5.2%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 10
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	70792	70792	70792	70792
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	5.7	5.9	5.7	5.9
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	17.4	20.9	17.4	20.9
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	18.4%	22.3%	18.4%	22.3%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$		0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4		
	0.4	0.013	0.0052	

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 11
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	7845.6	7845.6	7845.6	7845.6
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.0	2.2	2.0	2.2
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	6.0	7.7	6.0	7.7
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	1.0%	2.5%	1.0%	2.5%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 12
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Het	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	10,834	10,834	10,834	10,834
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.1	2.3	2.1	2.3
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	6.5	8.3	6.5	8.3
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	1.3%	3.1%	1.3%	3.1%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 13
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	2,165	2,165	2,165	2,165
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.9	3.1	2.9	3.1
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	8.8	10.9	8.8	10.9
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	3.4%	6.2%	3.4%	6.2%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-6	
$AF_{S, D}$	adult absorption		
	0.4	0.1394	0.05576

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 14
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,808	3,808	3,808	3,808
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	3.9	4.1	3.9	4.1
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	12.0	14.6	12.0	14.6
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	8.0%	11.7%	8.0%	11.7%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

  When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 15
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	2,165	2,165	2,165	2,165
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	1.9	2.1	1.9	2.1
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	5.7	7.3	5.7	7.3
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	0.8%	2.1%	0.8%	2.1%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-6	
$AF_{S, D}$	adult absorption		
	0.4	0.0359	0.01436

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 16
Calculations of Preliminary Remediation Goals (PRGs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**5,876**	**3,710**	**5,876**	**3,710**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 17
Calculations of Preliminary Remediation Goals (PRGs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal,\,0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\,D}$	X	X	Absorption fraction (same for soil and dust)	--	0.00	0.00	0.00	0.00
$EF_{S,\,D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S,\,D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**39,017**	**24,634**	**39,017**	**24,634**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\,D}$	0.2	0.6	0.12
$AF_{S,\,D}$	adult absorption	95% UCL absolute bioavailablity for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 18
Calculations of Preliminary Remediation Goals (PRGs)   **EA-3**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario
					Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**8,045**	**5,079**	**8,045**	**5,079**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

Calculations of Preliminary Remediation Goals (PRGs)

Table 19
Calculations of Preliminary Remediation Goals (PRGs)   **EA-4**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal,\,0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\,D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S,\,D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S,\,D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**30,013**	**18,949**	**30,013**	**18,949**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\,D}$	0.2	0.6	0.12
$AF_{S,\,D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 20
Calculations of Preliminary Remediation Goals (PRGs)   **EA-5**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**30,013**	**18,949**	**30,013**	**18,949**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

   When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 21
Calculations of Preliminary Remediation Goals (PRGs)   **EA-6**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**2,799**	**1,767**	**2,799**	**1,767**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 22
Calculations of Preliminary Remediation Goals (PRGs)   **EA-6**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	104	104	104	104
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**10,868**	**6,862**	**10,868**	**6,862**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

   When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.0359	0.01436

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Calculations of Preliminary Remediation Goals (PRGs)

U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal,\ 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.050	0.050	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.050	0.050
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\ D}$	X	X	Absorption fraction (same for soil and dust)	--	0.12	0.12	0.12	0.12
$EF_{S,\ D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	219	219	219	219
$AT_{S,\ D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**1,235**	**780**	**1,235**	**780**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	750	750	750	750
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.050	0.050	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.050	0.050
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.12	0.12	0.12	0.12
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	219	219	219	219
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}	**PbB of adult worker, geometric mean**			ug/dL	**2.6**	**2.8**	**2.6**	**2.8**
$PbB_{fetal, 0.95}$	**95th percentile PbB among fetuses of adult workers**			ug/dL	**7.9**	**9.8**	**7.9**	**9.8**
PbB_t	**Target PbB level of concern (e.g., 10 ug/dL)**			ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$	**Probability that fetal PbB > PbB_t, assuming lognormal distribution**			%	**2.5%**	**4.8%**	**2.5%**	**4.8%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

0.2   0.6   0.12

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Appendix D-2
Adult Lead Model
Commercial/Industrial Worker

Table 1 Summary Lead PRGs for Commercial/Industrial Workers

Exposure Area		95th % UCL Absolute Bioavailability Estimate	PRG (mg/Kg) for Commercial/Industrial Worker (1)
EA-1	Connary	6.64%	2,444
EA-2	Mount Platt/ Cronebane	1.00%	16,231
EA-3	East Avoca/Tigroney West	4.85%	3,347
EA-4	Ore bins Tigroney West	1.30%	12,485
EA-5	Deep Adit Area	1.30%	12,485
EA-6	West Avoca	13.94%	1,164
	(2)	3.59%	4,521
EA-7	Shelton Abbey	NA	NA

(1)   PRG for lead calculated in the ALM
(2)   95TH UCL for absolute bioavailability excludes anomalous high absolute

Table 2 Summary of Adult Lead Model For Commercial/Industrial Workers

Exposure Area		Statistic	EPC mg/kg	95th % UCL Absolute Bioavailability	PbB of commercial/ industrial worker, geometric	Probability that fetal PbB > PbB$_t$, assuming lognormal distribution GSDi = Hom
EA-1	Connary	95th UCL	34,525	6.64%	26.6	**88.1%**
		Mean	17,430	6.64%	14.2	**62.9%**
EA-2	Mount Platt/ Cronbane	95th UCL	13,768	1.00%	3.0	3.9%
		Mean	4,274	1.00%	2.0	1.0%
EA-3	East Avoca/ Tigroney West	95th UCL	5,221	4.85%	4.3	9.9%
		Mean	3,385	4.85%	3.3	5.1%
EA-4	Ore bins At Tigroney West	95th UCL	70,792	1.30%	11.6	**52.2%**
		Mean	19,675	1.30%	4.3	**10.1%**
EA-5	Deep Adit Area	95th UCL	10,834	1.30%	3.0	4.0%
		Mean	7,845	1.30%	2.6	2.6%
EA-6	West Avoca	95th UCL	3,808	13.94%	7.3	28.7%
		Mean	2,165	13.94%	4.8	**12.9%**
		95th UCL (1)	3,808	3.59%	3.0	3.9%
EA-7	Shelton Abbey	95th UCL	NA	NA	NA	NA
		Mean	NA	NA	NA	NA

(1)   95TH UCL for absolute bioavailability excludes anomalous high absolute bioavailability

Calculations of Preliminary Remediation Goals (PRGs)

Table 3
EA-1 Connary
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Het	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	34525	34525	34525	34525
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	26.6	26.8	26.6	26.8
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	81.2	95.0	81.2	95.0
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	88.1%	85.5%	88.1%	85.5%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Calculations of Preliminary Remediation Goals (PRGs)

Table 4
EA-1 Connary
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	17,430	17,430	17,430	17,430
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	14.2	14.4	14.2	14.4
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	43.3	50.9	43.3	50.9
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	62.9%	62.2%	62.9%	62.2%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS \cdot BKSF \cdot IR_{S+D} \cdot AF_{S,D} \cdot EF_S / AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} \cdot (GSD_i^{1.645} \cdot R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS \cdot BKSF \cdot ([(IR_{S+D}) \cdot AF_S \cdot EF_S \cdot W_S] + [K_{SD} \cdot (IR_{S+D}) \cdot (1-W_S) \cdot AF_D \cdot EF_D])/365 + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} \cdot (GSD_i^{1.645} \cdot R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 5
EA-2 Mount Platt/Cronebane
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Het	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	13768	13768	13768	13768
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.00	0.00	0.00	0.00
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	3.0	3.2	3.0	3.2
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	9.2	11.4	9.2	11.4
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	3.9%	6.8%	3.9%	6.8%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 6
EA-2 Mount Platt/Cronebane
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	4,274	4,274	4,274	4,274
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.004	0.004	0.004	0.004
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**2.0**	**2.2**	**2.0**	**2.2**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**6.0**	**7.7**	**6.0**	**7.7**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	%	**1.0%**	**2.5%**	**1.0%**	**2.5%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).
When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 7
EA-3 East Avoca, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	5221	5221	5221	5221
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	4.3	4.5	4.3	4.5
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	13.0	15.9	13.0	15.9
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	9.9%	13.7%	9.9%	13.7%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 8
EA-3 East Avoca, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,385	3,385	3,385	3,385
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	3.3	3.5	3.3	3.5
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	10.1	12.4	10.1	12.4
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	5.1%	8.3%	5.1%	8.3%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

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Calculations of Preliminary Remediation Goals (PRGs)

Table 9
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	70792	70792	70792	70792
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	11.6	11.8	11.6	11.8
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	35.3	41.7	35.3	41.7
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	52.2%	52.8%	52.2%	52.8%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Calculations of Preliminary Remediation Goals (PRGs)

Table 10
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Het	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	19,675	19,675	19,675	19,675
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	4.3	4.5	4.3	4.5
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	13.1	16.0	13.1	16.0
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	10.1%	13.9%	10.1%	13.9%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 11
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	10,834	10,834	10,834	10,834
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	3.0	3.2	3.0	3.2
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	9.3	11.5	9.3	11.5
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	%	4.0%	7.0%	4.0%	7.0%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Calculations of Preliminary Remediation Goals (PRGs)

Table 12
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	7845.6	7845.6	7845.6	7845.6
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**2.6**	**2.8**	**2.6**	**2.8**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**8.0**	**10.0**	**8.0**	**10.0**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	%	**2.6%**	**5.0%**	**2.6%**	**5.0%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 13
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)]
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,808	3,808	3,808	3,808
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**7.3**	**7.5**	**7.3**	**7.5**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**22.3**	**26.6**	**22.3**	**26.6**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	%	**28.7%**	**31.9%**	**28.7%**	**31.9%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

95% Soil Pb conc with high bio

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Calculations of Preliminary Remediation Goals (PRGs)

Table 14
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	2,165	2,165	2,165	2,165
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**4.8**	**5.0**	**4.8**	**5.0**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**14.7**	**17.7**	**14.7**	**17.7**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	%	**12.9%**	**16.9%**	**12.9%**	**16.9%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When IR_S = IR_{S+D} and W_S = 1.0, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

Mean Soil Pb Concentration with max bio

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 15
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,808	3,808	3,808	3,808
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**3.0**	**3.2**	**3.0**	**3.2**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**9.1**	**11.3**	**9.1**	**11.3**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	%	**3.9%**	**6.7%**	**3.9%**	**6.7%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.0359	0.01436

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil
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Calculations of Preliminary Remediation Goals (PRGs)

Table 16
Calculations of Preliminary Remediation Goals (PRGs)   **EA-1**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal,\,0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\,D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S,\,D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S,\,D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**2,444**	**1,543**	**2,444**	**1,543**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\,D}$	0.2	0.6	0.12
$AF_{S,\,D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 17
Calculations of Preliminary Remediation Goals (PRGs)   **EA-2**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Het	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.00	0.00	0.00	0.00
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**16,231**	**10,248**	**16,231**	**10,248**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

   When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL	
$AF_{S, D}$		absolute bioavailablity	
	adult absorption	for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 18
Calculations of Preliminary Remediation Goals (PRGs)   **EA-3**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal,\ 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\ D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S,\ D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S,\ D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**3,347**	**2,113**	**3,347**	**2,113**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\ D}$	0.2	0.6	0.12
		95% UCL absolute	
$AF_{S,\ D}$	adult absorption	bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

Calculations of Preliminary Remediation Goals (PRGs)

Table 19
Calculations of Preliminary Remediation Goals (PRGs)　　　　　　　　**EA-4**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
$PbB_{fetal,\ 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\ D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S,\ D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S,\ D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**12,485**	**7,883**	**12,485**	**7,883**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

　　When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\ D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-4	
$AF_{S,\ D}$	adult absorption		
	0.4	0.013	0.0052

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 20
Calculations of Preliminary Remediation Goals (PRGs)   **EA-5**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**12,485**	**7,883**	**12,485**	**7,883**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL	
		absolute	
$AF_{S, D}$	adult absorption	bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

Calculations of Preliminary Remediation Goals (PRGs)

Table 21
Calculations of Preliminary Remediation Goals (PRGs)　　　　　　　**EA-6**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**1,164**	**735**	**1,164**	**735**

[1]　Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

　　When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 22
Calculations of Preliminary Remediation Goals (PRGs)　　　　　　**EA-6**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1]		Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
	1*	2**			GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.100	0.100	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.100	0.100
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	250	250	250	250
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**4,521**	**2,854**	**4,521**	**2,854**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

　　When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-6	
$AF_{S, D}$	adult absorption		
	0.4	0.0359	0.01436

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Calculations of Preliminary Remediation Goals (PRGs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Het	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Het
$PbB_{fetal,\ 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.050	0.050	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.050	0.050
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\ D}$	X	X	Absorption fraction (same for soil and dust)	--	0.12	0.12	0.12	0.12
$EF_{S,\ D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	219	219	219	219
$AT_{S,\ D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**1,235**	**780**	**1,235**	**780**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Appendix D-2
Adult Lead Model
Construction Worker

Table 1 Summary Lead PRGs for Construction Workers

Exposure Area		95th % UCL Absolute Bioavailability Estimate	PRG (mg/Kg) for Commercial/Industrial Worker (1)
EA-1	Connary	6.64%	1,424
EA-2	Mount Platt/ Cronebane	1.00%	9,459
EA-3	East Avoca/Tigroney West	4.85%	1,950
EA-4	Ore bins Tigroney West	1.30%	7,276
EA-5	Deep Adit Area	1.30%	7,276
EA-6	West Avoca	13.94%	679
	(2)	3.59%	2,635
EA-7	Shelton Abbey	NA	NA

(1)   PRG for lead calculated in the ALM

(2)   95TH UCL for absolute bioavailability excludes anomalous high absolute

Table 2 Summary of Adult Lead Model For Construction Workers

Exposure Area		Statistic	EPC mg/kg	95th % UCL Absolute Bioavailability	PbB of construction worker, geometric mean	Probability that fetal PbB > PbB$_t$, assuming lognormal distribution
						GSDi = Hom
EA-1	Connary	95th UCL	34,525	6.64%	44.6	**97.0%**
		Mean	17,430	6.64%	23.3	**84.0%**
EA-2	Mount Platt/	95th UCL	13,768	1.00%	4.1	8.9%
	Cronbane	Mean	4,274	1.00%	2.3	1.7%
EA-3	East Avoca/	95th UCL	5,221	4.85%	6.3	**22.0%**
	Tigroney West	Mean	3,385	4.85%	4.6	**11.7%**
EA-4	Ore bins At Tigroney West	95th UCL	70,792	1.30%	18.8	**76.1%**
		Mean	19,675	1.30%	6.3	**22.3%**
EA-5	Deep Adit Area	95th UCL	10,834	1.30%	4.1	9.2%
		Mean	7,845	1.30%	3.4	5.6%
EA-6	West Avoca	95th UCL	3,808	13.94%	11.5	**51.8%**
		Mean	2,165	13.94%	7.2	**27.8%**
		95th UCL (1)	3,808	3.59%	4.1	8.8%
EA-7	Shelton Abbey	95th UCL	NA	NA	NA	NA
		Mean	NA	NA	NA	NA

GSDi = Hom Geometric Standard Deviation for homogenous populations

(1)   95TH UCL for absolute bioavailability excludes anomalous high absolute bioavailability

Table 3
EA-1 Connary
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	34525	34525	34525	34525
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	44.6	44.8	44.6	44.8
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	136.1	158.7	136.1	158.7
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB$_t$, assuming lognormal distribution	%	97.0%	95.3%	97.0%	95.3%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Table 4
EA-1 Connary
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Het	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	17,430	17,430	17,430	17,430
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	**23.3**	**23.5**	**23.3**	**23.5**
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	**71.0**	**83.1**	**71.0**	**83.1**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB$_t$, assuming lognormal distribution**	%	**84.0%**	**81.5%**	**84.0%**	**81.5%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S.D}*EF_S/AT_{S.D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Table 5
EA-2 Mount Platt/Cronebane
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	13768	13768	13768	13768
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.00	0.00	0.00	0.00
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	4.1	4.3	4.1	4.3
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	12.5	15.2	12.5	15.2
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB$_t$, assuming lognormal distribution	%	8.9%	12.7%	8.9%	12.7%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-2	
$AF_{S, D}$	adult absorption		
	0.4	0.01	0.004

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Table 6
EA-2 Mount Platt/Cronebane
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	4,274	4,274	4,274	4,274
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.004	0.004	0.004	0.004
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	2.3	2.5	2.3	2.5
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	7.0	8.9	7.0	8.9
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	1.7%	3.7%	1.7%	3.7%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil
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Table 7
EA-3 East Avoca, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario			
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	5221	5221	5221	5221
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	ug/dL	6.3	6.5	6.3	6.5
$PbB_{fetal, 0.95}$			**95th percentile PbB among fetuses of adult workers**	ug/dL	19.1	22.9	19.1	22.9
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB$_t$, assuming lognormal distribution**	%	22.0%	25.8%	22.0%	25.8%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Table 8
EA-3 East Avoca, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,385	3,385	3,385	3,385
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	4.6	4.8	4.6	4.8
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	14.0	17.0	14.0	17.0
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB$_t$, assuming lognormal distribution	%	11.7%	15.6%	11.7%	15.6%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Table 9
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	70792	70792	70792	70792
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	18.8	19.0	18.8	19.0
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	57.4	67.3	57.4	67.3
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	76.1%	74.0%	76.1%	74.0%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Table 10
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	19,675	19,675	19,675	19,675
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	6.3	6.5	6.3	6.5
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	19.2	23.1	19.2	23.1
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	22.3%	26.0%	22.3%	26.0%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

   When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Table 11
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	10,834	10,834	10,834	10,834
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	4.1	4.3	4.1	4.3
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	12.7	15.4	12.7	15.4
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB$_t$, assuming lognormal distribution	%	9.2%	13.0%	9.2%	13.0%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Table 12
EA-4 Ore Bins, Tigroney West
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Het	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Hom	Values for Non-Residential Exposure Scenario Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	7845.6	7845.6	7845.6	7845.6
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	3.4	3.6	3.4	3.6
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	10.4	12.8	10.4	12.8
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	5.6%	8.9%	5.6%	8.9%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

Table 13
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,808	3,808	3,808	3,808
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	11.5	11.7	11.5	11.7
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	35.0	41.4	35.0	41.4
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	51.8%	52.4%	51.8%	52.4%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

95% Soil Pb conc with high bio

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

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Table 14
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Het	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Hom	Values for Non-Residential Exposure Scenario — Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	2,165	2,165	2,165	2,165
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	7.2	7.4	7.2	7.4
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	21.9	26.1	21.9	26.1
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	27.8%	31.1%	27.8%	31.1%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

Mean Soil Pb Concentration with max bio

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Table 15
EA-6 West Avoca
Calculations of Blood Lead Concentrations (PbBs)
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Values — Using Equation 1 — GSDi = Het	Values — Using Equation 2 — GSDi = Hom	Values — Using Equation 2 — GSDi = Het
PbS	X	X	Soil lead concentration	ug/g or ppm	3,808	3,808	3,808	3,808
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{s+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			PbB of adult worker, geometric mean	ug/dL	4.1	4.3	4.1	4.3
$PbB_{fetal, 0.95}$			95th percentile PbB among fetuses of adult workers	ug/dL	12.4	15.1	12.4	15.1
PbB_t			Target PbB level of concern (e.g., 10 ug/dL)	ug/dL	10.0	10.0	10.0	10.0
$P(PbB_{fetal} > PbB_t)$			Probability that fetal PbB > PbB_t, assuming lognormal distribution	%	8.8%	12.5%	8.8%	12.5%

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.0359	0.01436

*Equation 1, based on Eq. 1, 2 in USEPA (1996).

$PbB_{adult} =$	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S,D}) + PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

**Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).

$PbB_{adult} =$	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal, 0.95} =$	$PbB_{adult} * (GSD_i^{1.645} * R)$

Calculations of Preliminary Remediation Goals (PRGs)

Table 16
Calculations of Preliminary Remediation Goals (PRGs)   **EA-1**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario — Using Equation 1 — GSDi = Hom	Using Equation 1 — GSDi = Het	Using Equation 2 — GSDi = Hom	Using Equation 2 — GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.03	0.03	0.03	0.03
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**1,424**	**899**	**1,424**	**899**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL	
$AF_{S, D}$		absolute bioavailablity	
	adult absorption	for EA-1	
	0.4	0.0664	0.02656

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 17
Calculations of Preliminary Remediation Goals (PRGs)   **EA-2**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.00	0.00	0.00	0.00
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**9,459**	**5,972**	**9,459**	**5,972**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL absolute	
$AF_{S, D}$		bioavailablity	
	adult absorption	for EA-2	
	0.4	0.01	0.004

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 18
Calculations of Preliminary Remediation Goals (PRGs)   **EA-3**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal,\,0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\,D}$	X	X	Absorption fraction (same for soil and dust)	--	0.02	0.02	0.02	0.02
$EF_{S,\,D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S,\,D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**1,950**	**1,231**	**1,950**	**1,231**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\,D}$	0.2	0.6	0.12
		95% UCL absolute	
$AF_{S,\,D}$	adult absorption	bioavailablity for EA-3	
	0.4	0.0485	0.0194

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 19
Calculations of Preliminary Remediation Goals (PRGs)   **EA-4**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario				
					Using Equation 1		Using Equation 2	
					GSDi = Hom	GSDi = Het	GSDi = Hom	GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**7,276**	**4,594**	**7,276**	**4,594**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Source: U.S. EPA (1996). Recommendations of the Technical Review Workgroup for Lead
for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil

Calculations of Preliminary Remediation Goals (PRGs)

Table 20
Calculations of Preliminary Remediation Goals (PRGs)   **EA-5**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**7,276**	**4,594**	**7,276**	**4,594**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
		95% UCL	
$AF_{S, D}$		absolute bioavailablity	
	adult absorption	for EA-4	
	0.4	0.013	0.0052

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 21
Calculations of Preliminary Remediation Goals (PRGs)   **EA-6**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	PRG Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	Using Equation 1 GSDi = Het	Using Equation 2 GSDi = Hom	Using Equation 2 GSDi = Het
$PbB_{fetal, 0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S, D}$	X	X	Absorption fraction (same for soil and dust)	--	0.06	0.06	0.06	0.06
$EF_{S, D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S, D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**679**	**428**	**679**	**428**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S, D}$	0.2	0.6	0.12
$AF_{S, D}$	adult absorption	95% UCL absolute bioavailablity for EA-6	
	0.4	0.1394	0.05576

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Calculations of Preliminary Remediation Goals (PRGs)

Table 22
Calculations of Preliminary Remediation Goals (PRGs)   **EA-6**
U.S. EPA Technical Review Workgroup for Lead, Adult Lead Committee

Version date 05/19/03

Exposure Variable	PRG Equation[1] 1*	2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1 GSDi = Hom	GSDi = Het	Using Equation 2 GSDi = Hom	GSDi = Het
$PbB_{fetal,\,0.95}$	X	X	95th percentile PbB in fetus	ug/dL	10	10	10	10
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil ingestion rate (including soil-derived indoor dust)	g/day	0.330	0.330	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.330	0.330
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\,D}$	X	X	Absorption fraction (same for soil and dust)	--	0.01	0.01	0.01	0.01
$EF_{S,\,D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	130	130	130	130
$AT_{S,\,D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PRG			**Preliminary Remediation Goal**	**ppm**	**2,635**	**1,663**	**2,635**	**1,663**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same PRG.

$AF_{S,\,D}$	0.2	0.6	0.12
		95% UCL absolute bioavailablity for EA-6	
$AF_{S,\,D}$	adult absorption		
	0.4	0.0359	0.01436

*Equation 1, based on Eq. 4 in USEPA (1996).

$$PRG = \frac{([PbB_{95}fetal/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*(IR_{S+D}*AF_{S,D}*EF_{S,D})}$$

**Equation 2, alternate approach based on Eq. 4 and Eq. A-19 in USEPA (1996).

$$PRG = \frac{([PbB_{fetal,0.95}/(R*(GSD_i^{1.645})])-PbB_0)*AT_{S,D}}{BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])}$$

Appendix E
PRG Calculations

Table 1
Summary of Preliminary Human Health Risk-Based Cleanup Levels for Spoils
Avoca Mine Site

Chemical of Potential Concern	Target Risk or HI	Preliminary Remediation Goal (mg/kg)			Maximum Exposure Point Concentration for Onsite Areas [2] (mg/kg)	Location of Maximum
		Recreational Visitor [1]	Commercial/Industrial Worker	Construction Worker		
Arsenic	1×10^{-6}	571	221	3,925	1,622	West Avoca
Antimony	1	772	409	235	203	Deep Adit
Cobalt	1	37,348	13,345	10,103	1,217	Deep Adit
Copper	1	77,212	40,880	23,462	4,803	Ore Bins
Iron	1	100,000 (4)	715,400	410,583	224,969	Deep Adit
Lead	(3)	10,012	4,165	2,427	70,792	Ore Bins
Manganese	1	38,604	20,429	11,729	839	West Avoca
Thallium	1	147	78	45	404	Deep Adit (4)
Vanadium	1	1,930	1,022	587	48	West Avoca

(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children

(2) The maximum exposure point concentration is the maximum 95th UCL from all exposure areas.

(3) PRGs for receptors were calculated using the USEPA Adult Lead Model, based on 95%UCL of absolute bioavailability estimate
for all exposure areas (3.95%)

(4) PRG is a ceiling limit equivalent to a chemical representing 10% by weight of the soil sample.
The risk based PRG exceeds unity (>1,000,000 mg/kg) which is not possible.

(5) Analytical results for thallium are available for the Deep Adit only and are XRF measurements

CDM

Table 2
Summary of Preliminary Human Health Risk-Based Cleanup Levels for Soil,
Avoca Mine Site

Chemical of Potential Concern	Target Risk or HI	Preliminary Remediation Goal (mg/kg) Offsite Resident [1]	Maximum Concentration for Offsite Areas [2] (mg/kg)	Location of Maximum
Arsenic	1×10^{-6}	134	276	TMF1
Antimony	1	31	2	TMF1
Cobalt	1	1,381	32	TMF2
Copper	1	3,129	575	TMF1
Iron	1	54,750	11	TMF2
Lead [2]	(2)	2,671	818	GMF
Manganese	1	1,564	2,345	PHF
Thallium	1	6	NA	NA
Vanadium	1	78	128	TMF2

NA = Not available

(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children

(2) The maximum exposure point concentration is the maximum 95th UCL from all exposure areas.

(3) For Offsite Resident PRG was calculated using IEUBK Model for young children, based on 95%UCL of absolute bioavailability estimate for all exposure areas (3.95%)

CDM

Table 3
Potential Remediation Goals (PRGs) for Soil/Spoils Based on Cancer Risk for the Adult Recreational Visitor Land Use AssumptionsSite
Avoca Mine Site

Equation Definition: CS = [TR x BW x AT] / [EF x ED x [(CSFo x IRo x CF x FI) + (CSFd x CF x SA x AF x ABS) + (CSFi x IRi x ET x 1/PEF)]]			Chemical of Potential Concern	ABS	BAF	CSFo (mg/kg-day)$^{-1}$	CSFd (mg/kg-day)$^{-1}$	CSFi (mg/kg-day)$^{-1}$	Cancer Risk Level = 1x10^{-6} PRG (mg/kg)
Parameter	Definition	Value	Inorganics						
CS	chemical concentration in soil (mg/kg)		Arsenic	0.03	0.006	1.5E+00	1.4E+00	1.5E+01	571
TR	target risk	1E-06							
BW	body weight (kg)	70							
AT	averaging time (day)	25,550							
EF	exposure frequency (day/yr)	104							
ED	exposure duration (yrs)	30							
CSFo	cancer slope factor (oral)	Chemical Specific							
IRo	ingestion rate (mg/day)	100							
CF	conversion factor (kg/mg)	1E-06							
FI	fraction ingested from source (unitless)	1							
CSFd	cancer slope factor (dermal)	Chemical Specific							
SA	surface area per event (cm^2/day)	3,300							
AF	adherence factor (mg/cm^2)	0.1							
ABS	dermal absorption factor	Chemical Specific							
CSFi	cancer slope factor (inhalation)	Chemical Specific							
IRi	inhalation rate (m^3/hr)	0.8							
ET	exposure time (hr/day)	2							
PEF	particulate emissions factor (m^3/kg)	1.32E+09							

Potential cleanup levels based on oral, dermal contact, and inhalation exposure

Table 4
Potential Risk-Based Cleanup Levels for Soil Based on Non-Cancer Hazard, Child Recreational Visitor Land Use Assumptions
Avoca Mine Site

Equation Definition: CS = [THI x BW x AT] / [EF x ED x [(1/RfDo x IRo x CF x FI) + (1/RfDd x CF x SA x AF X ABS)+(1/RfDi x IRi x ET x 1/PEF)]]			Chemical of Potential Concern	ABS	RfDo (mg/kg-day)	RfDd (mg/kg-day)	RfDi (mg/kg-day)	Hazard Quotient Level (mg/kg)	
								HQ=0.1	HQ=1
Parameter	**Definition**	**Value**	**Inorganics**						
CS	chemical concentration in soil (mg/kg)		Antimony	NA	4.00E-04	NA	NA	77	772
THI	target hazard index	1	Arsenic	0.03	3.0E-04	3.0E-04	8.57E-06	8,090	80,895
BW	body weight (kg)	55	Cobalt	NA	2.0E-02	NA	5.7E-06	3,735	37,348
AT	averaging time (day)	2,920	Copper	NA	4.0E-02	NA	NA	7,721	77,212
EF	exposure frequency (day/yr)	104	Iron	NA	0.7	NA	NA	135,120	1,351,202
ED	exposure duration (yrs)	8	Lead	NA	NA	NA	NA	NA	NA
RfDo	reference dose (oral)		Manganese	NA	2.0E-02	NA	5.7E-03	3,860	38,604
IRo	ingestion rate (mg/day)	100	Thallium	NA	7.6E-05	NA	NA	15	147
CF	conversion factor (kg/mg)	1E-06	Vanadium	NA	1.00E-03	NA	NA	193	1,930
FI	fraction ingested from source (unitless)	1							
BAF	Bioavailabiity estimate for arsenic	0.006							
RfDd	reference dose (dermal)								
SA	surface area per event (cm^2/day)	4,570							
AF	adherence factor (mg/cm^2)	0.1							
ABS	dermal absorption factor								
RfDi	reference dose (inhalation)								
IRi	inhalation rate (m^3/hr)	0.63							
ET	exposure time (hr/day)	2							
PEF	particulate emissions factor (m^3/kg)	1.32E+09							

Potential cleanup levels based on oral, dermal contact, and inhalation exposure

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Table 5
Potential Risk-Based Cleanup Levels for Soil Based on Cancer Risk, Commercial Industrial Worker Land Use Assumptions
Avoca Mine Site

Equation Definition: CS = [TR x BW x AT] / [EF x ED x [(CSFo x IRo x CF x FI) + (CSFd x CF x SA x AF x ABS) + (CSFi x IRi x ET x 1/PEF)]]			Chemical of Potential Concern	ABS	BAF	CSFo (mg/kg-day)$^{-1}$	CSFd (mg/kg-day)$^{-1}$	CSFi (mg/kg-day)$^{-1}$	Cancer Risk Level (mg/kg) 1x10^{-6}
Parameter	Definition	Value	Inorganics						
CS	chemical concentration in soil (mg/kg)		Arsenic	0.03	0.006	1.5E+00	1.4E+00	1.5E+01	221
TR	target risk	1E-06							
BW	body weight (kg)	70							
AT	averaging time (day)	25,550							
EF	exposure frequency (day/yr)	250							
ED	exposure duration (yrs)	25							
CSFo	cancer slope factor (oral)								
IRo	ingestion rate (mg/day)	100							
CF	conversion factor (kg/mg)	1E-06							
FI	fraction ingested from source (unitless)	1							
CSFd	cancer slope factor (dermal)								
SA	surface area per event (cm^2/day)	3,300							
AF	adherence factor (mg/cm^2)	0.2							
ABS	dermal absorption factor								
CSFi	cancer slope factor (inhalation)								
IRi	inhalation rate (m^3/hr)	2.5							
ET	exposure time (hr/day)	8							
PEF	particulate emissions factor (m^3/kg)	1.32E+09							

Potential cleanup levels based on oral, dermal contact, and inhalation exposure

Table 6
Potential Risk-Based Cleanup Levels for Soil Based on Non-Cancer Hazard, Commercial Industrial Worker Land Use Assumptions
Avoca Mine Site

Equation Definition: CS = [THI x BW x AT] / [EF x ED x [(1/RfDo x IRo x CF x FI) + (1/RfDd x CF x SA x AF X ABS)+(1/RfDi x IRi x ET x 1/PEF)]]			Chemical of Potential Concern	ABS	RfDo (mg/kg-day)	RfDd (mg/kg-day)	RfDi (mg/kg-day)	Hazard Quotient Level (mg/kg)	
Parameter	Definition	Value	Inorganics					HQ=0.1	HQ=1
CS	chemical concentration in soil (mg/kg)		Antimony	NA	4.00E-04	NA	NA	41	409
THI	target hazard index	1	Arsenic	0.03	3.0E-04	3.0E-04	8.57E-06	2,455	24,546
BW	body weight (kg)	70	Cobalt	NA	2.0E-02	NA	5.7E-06	1,335	13,345
AT	averaging time (day)	9,125	Copper	NA	4.0E-02	NA	NA	4,088	40,880
EF	exposure frequency (day/yr)	250	Iron	NA	0.7	NA	NA	71,540	715,400
ED	exposure duration (yrs)	25	Lead	NA	NA	NA	NA	NA	NA
RfDo	reference dose (oral)		Manganese	NA	2.0E-02	NA	5.7E-03	2,043	20,429
IRo	ingestion rate (mg/day)	100	Thallium	NA	7.6E-05	NA	NA	8	78
CF	conversion factor (kg/mg)	1E-06	Vanadium	NA	1.00E-03	NA	NA	102	1,022
FI	fraction ingested from source (unitless)	1							
BAF	Bioavailabiity estimate for arsenic	0.006							
RfDd	reference dose (dermal)								
SA	surface area per event (cm^2/day)	3,300							
AF	adherence factor (mg/cm^2)	0.2							
ABS	dermal absorption factor								
RfDi	reference dose (inhalation)								
IRi	inhalation rate (m^3/hr)	2.50							
ET	exposure time (hr/day)	8							
PEF	particulate emissions factor (m^3/kg)	1.32E+09							

Potential cleanup levels based on oral, dermal contact, and inhalation exposure

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Table 7
Potential Risk-Based Cleanup Levels for Soil Based on Cancer Risk
Construction Worker Land Use Assumptions
Avoca Mine Site

Equation Definition: CS = [TR x BW x AT] / [EF x ED x [(CSFo x IRo x CF x FI) + (CSFd x CF x SA x AF x ABS) + (CSFi x IRi x ET x 1/PEF)]]			Chemical of Potential Concern	ABS	BAF	CSFo (mg/kg-day)$^{-1}$	CSFd (mg/kg-day)$^{-1}$	CSFi (mg/kg-day)$^{-1}$	Cancer Risk Level (mg/kg) 1x10^{-6}
Parameter	**Definition**	**Value**	Inorganics						
CS	chemical concentration in soil (mg/kg)		Arsenic	0.03	0.006	1.5E+00	1.4E+00	1.5E+01	3,925
TR	target risk	1E-06							
BW	body weight (kg)	70							
AT	averaging time (day)	25,550							
EF	exposure frequency (day/yr)	132							
ED	exposure duration (yrs)	1							
CSFo	cancer slope factor (oral)								
IRo	ingestion rate (mg/day)	330							
CF	conversion factor (kg/mg)	1E-06							
FI	fraction ingested from source (unitless)	1							
CSFd	cancer slope factor (dermal)								
SA	surface area per event (cm^2/day)	3,300							
AF	adherence factor (mg/cm^2)	0.3							
ABS	dermal absorption factor								
CSFi	cancer slope factor (inhalation)								
IRi	inhalation rate (m^3/hr)	2.5							
ET	exposure time (hr/day)	8							
PEF	particulate emissions factor (m^3/kg)	1.32E+09							

Potential cleanup levels based on oral, dermal contact, and inhalation exposure

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Table 8
Potential Risk-Based Cleanup Levels for Soil Based on Non-Cancer Hazard
Construction Worker Land Use Assumptions
Avoca Mine Site

Equation Definition:

$$CS = [THI \times BW \times AT] / [EF \times ED \times [(1/RfDo \times IRo \times CF \times FI) + (1/RfDd \times CF \times SA \times AF \times ABS)+(1/RfDi \times IRi \times ET \times 1/PEF)]]$$

Parameter	Definition	Value	Chemical of Potential Concern	ABS	RfDo (mg/kg-day)	RfDd (mg/kg-day)	RfDi (mg/kg-day)	Hazard Quotient Level (mg/kg) HQ=0.1	Hazard Quotient Level (mg/kg) HQ=1
			Inorganics						
CS	chemical concentration in soil (mg/kg)		Antimony	NA	4.00E-04	NA	NA	23	235
THI	target hazard index	1	Arsenic	0.03	3.0E-04	3.0E-04	8.57E-06	2,160	21,599
BW	body weight (kg)	70	Cobalt	NA	2.0E-02	NA	5.7E-06	1,010	10,103
AT	averaging time (day)	365	Copper	NA	4.0E-02	NA	NA	2,346	23,462
EF	exposure frequency (day/yr)	132	Iron	NA	0.7	NA	NA	41,058	410,583
ED	exposure duration (yrs)	1	Lead	NA	NA	NA	NA	NA	NA
RfDo	reference dose (oral)		Manganese	NA	2.0E-02	NA	5.7E-03	1,173	11,729
IRo	ingestion rate (mg/day)	330	Thallium	NA	7.6E-05	NA	NA	4	44.58
CF	conversion factor (kg/mg)	1E-06	Vanadium	NA	1.00E-03	NA	NA	59	587
FI	fraction ingested from source (unitless)	1							
BAF	Bioavailabiity estimate for arsenic	0.006							
RfDd	reference dose (dermal)								
SA	surface area per event (cm^2/day)	3,300							
AF	adherence factor (mg/cm^2)	0.3							
ABS	dermal absorption factor								
RfDi	reference dose (inhalation)								
IRi	inhalation rate (m^3/hr)	2.50							
ET	exposure time (hr/day)	8							
PEF	particulate emissions factor (m^3/kg)	1.32E+09							

Potential cleanup levels based on oral, dermal contact, and inhalation exposure

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The Department of Communications, Energy and Natural Resources

Feasibility Study for Management and Remediation of the Avoca Mining Site

Ecological Risk Assessment (Phases 1 and 2)

October 2008

Report

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Section 1
Introduction

The primary purpose of this Phase 1 Preliminary Ecological Risk Assessment (ERA) is to generally identify and describe conditions stemming from releases of mining-related and other chemical contaminants that can result in adverse effects to present or future ecological receptors associated with the Avoca River and adjacent riparian and terrestrial habitats. These evaluations will then be used to identify any additional information needs (data gaps) to complete a final ERA and focus additional field investigations (Phase 2). The results of the ERA will be used to help select appropriate remedial and management goals at the site. The evaluation areas are defined as the Avoca River site, and generally include the Avoca River and valley from Meeting of the Waters downstream to Arklow Bay. Figure 1-1 depicts the watershed and includes the identification of locations used in spring 2007 as screening level biological sampling stations. This study area includes much of the area identified by the Ireland EPA as Hydrometric Area (HA) 10, the Avoca – Vartry HA, which is in the Eastern River Basin District. This HA is identified by EPA as seriously polluted due to mining-related contaminants.

The Avoca River is not currently one of the 34 rivers designated as salmonid rivers, but restoration efforts are focused on reestablishment of this river as one that supports salmonid survival, growth, and reproduction. Therefore, the effects of mining-related metals and other related stressors on salmonid fish is a major concern. Also of concern are the effects of mining-related contaminants on terrestrial receptors (e.g., peregrine falcons, several species of bats, and livestock) and on other ecologically important aquatic biota. For example, benthic macroinvertebrates (BMI) are important for nutrient recycling and serve as prey for fish and other aquatic biota. BMI are also commonly used as indicators of water quality, and are used in this preliminary ERA to help characterize the overall conditions of aquatic habitats at various locations within the study area.

1.1 Approach and Report Organization

ERAs evaluate the likelihood that adverse ecological effects may occur or are occurring at a site as a result of exposure to single or multiple chemical stressors. Effects result from contacts between ecological receptors (e.g., plants and animals) and stressors (e.g., contaminants) that are of sufficiently long duration and of sufficient intensity to elicit adverse effects. Following U.S. Environmental Protection Agency (USEPA) Superfund Guidance (EPA 1997) and similar guidance from other agencies, ERAs can be performed at either a screening level or at a baseline level. Screening level ERAs (SLERAs) are most often used to estimate risks using a conservative approach based on existing data. This approach preliminarily identifies chemicals of potential concern (COPCs), important receptors, and significant and complete exposure pathways.

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Figure 1-1 Biological Sampling Stations (Spring 2007)

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A baseline ERA (BERA) generally relies on additional site-specific data and analyses, and is a more detailed effort that:

- Refines the list of COPCs to identify final chemicals of concern (COCs)

- Identifies ecological receptors and selects a subset of representative receptors for full assessment

- Estimates risks to representative ecological receptors using a less conservative approach based on multiple lines of evidence

This preliminary ERA conducted for the Avoca River watershed most closely resembles a SLERA, supplemented by inclusion of recent site-specific observations and analyses of recently collected media quality (e.g., sediment) data. This preliminary ERA therefore can be viewed as an expanded SLERA with inclusion of certain BERA components and details.

The primary components of this preliminary ERA are Problem Formulation, Analysis Phase, Risk Characterization, and Data Gaps. Problem Formulation (Section 2) serves as the descriptive and planning stage of the ERA, where the site-associated habitats and ecological receptors or receptor groups are generally described, COPCs are identified, and major exposure pathways are characterized and revealed using a site conceptual exposure model (SCEM).

The Analysis Phase (Section 3) is divided into Exposure Assessment (Section 3.1) and Effects Assessment (Section 3.2), which presents the nature and extent of chemical contamination (Exposure Assessment) and the ecotoxicity of COPCs (Effects Assessment).

Risk Characterization (Section 4) integrates the exposure and effects information to estimate risks to ecological receptors. A component of Risk Characterization is Uncertainty Analysis, which describes the degree of confidence associated with the preliminary ERA data, approach and methods used, and conclusions of the preliminary ERA. Section 5 identifies Data Gaps that will help focus Phase 2 assessments and field investigations. Section 6 presents the References used in the completion of the ERA.

Section 2
Problem Formulation

The Problem Formulation phase of this preliminary ERA establishes the goals and describes the scope and focus of the assessment. This phase of the preliminary ERA also considers site-specific regulatory and policy issues and requirements, and identifies potential stressors (e.g., COPCs) and ecological resources potentially at risk. An important outcome of Problem Formulation is the SCEM, which describes potential exposure scenarios, including contaminant sources, transport mechanisms, exposure media, exposure routes, and receptors. The SCEM is depicted on Figures 2-1 and 2-2. Figure 2-1 illustrates the connections between mining-related contaminant sources and the ecological receptors, via the various components of exposure pathways (e.g., sources, release mechanisms, exposure routes, etc.). Figure 2-2 illustrates a general ecological food web for the Avoca River site. Linked to the SCEM are descriptions of the relationship between chemical stressors, ecological receptors, assessment endpoints, measurement endpoints, and remedial action objectives. Each of these components are defined and described in the following sections.

2.1 Stressor Identification

Ecological stressors are defined as physical, chemical, or biological entities or conditions that adversely affect or have potential to adversely affect ecological receptors directly or indirectly. This preliminary ERA is focused on the potential ecological effects associated with chemical contamination, primarily mining-related contaminants in surface water, sediment, and surface soils at or associated with the historic mining areas.

Chemical contamination is considered to be the primary focus of this preliminary ERA because of (1) the current magnitude and distribution of mining-related chemicals in abiotic media, and (2) the toxicity and bioaccumulation potential of mining-related chemicals. Chemical contamination can influence fish and invertebrate communities via direct toxicity, indirect toxicity via food web effects, and by contributing to chemical barriers that may be avoided by species sensitive to one or more contaminants in surface water.

Other stressors, including physical (non-chemical) stressors such as habitat disturbance or degradation, may also contribute to adverse ecological effects. For example, poor quality habitat may influence fish migration under certain conditions. Physical barriers to fish migration, if present, can impair fish migration regardless of water quality, and for this reason such barriers should be identified. Phase 2 of this assessment will address this issue.

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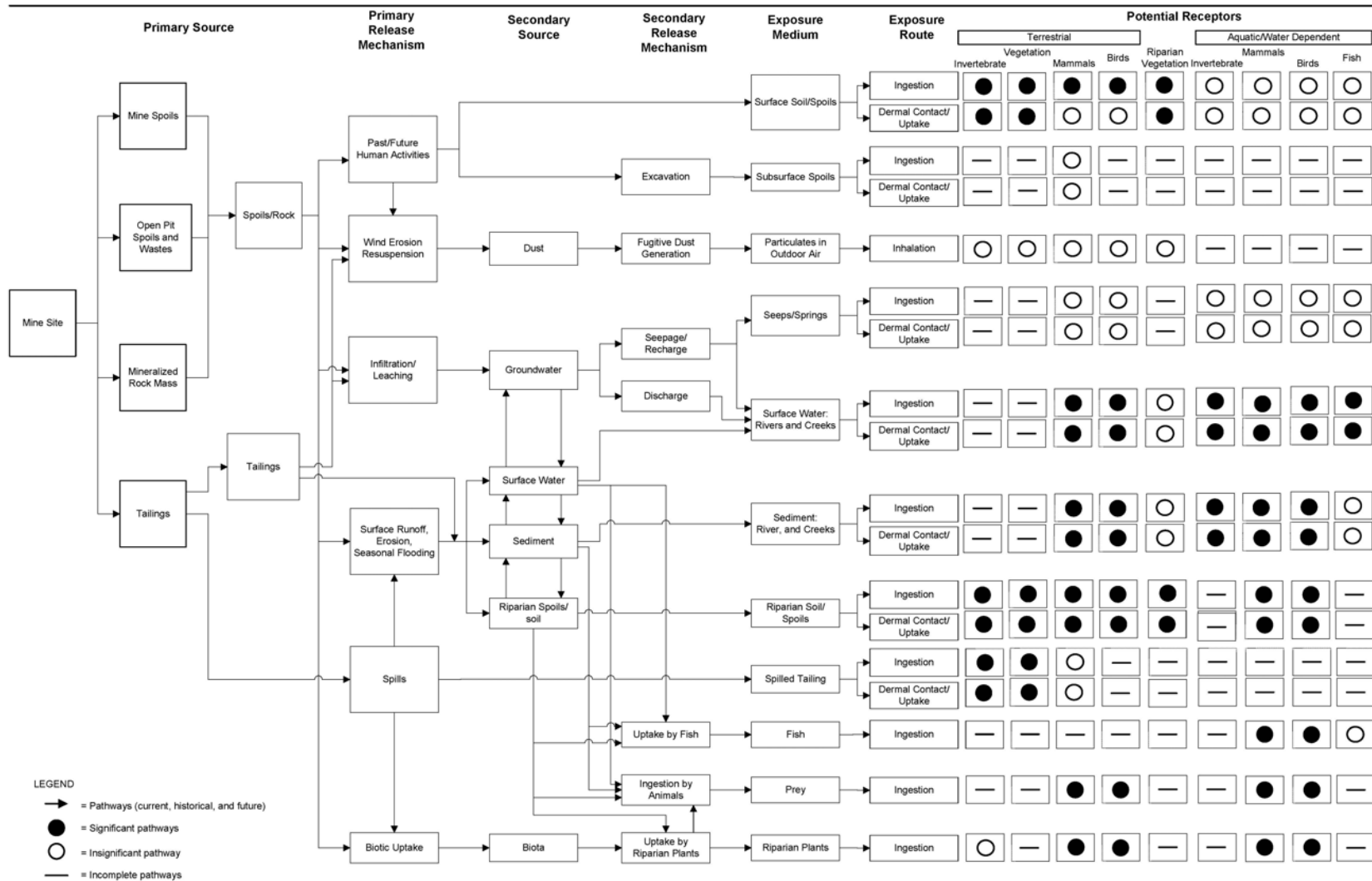
Figure 2-1   Ecological Site Conceptual Exposure Model
Part 1- Avoca Mine Site, Ireland

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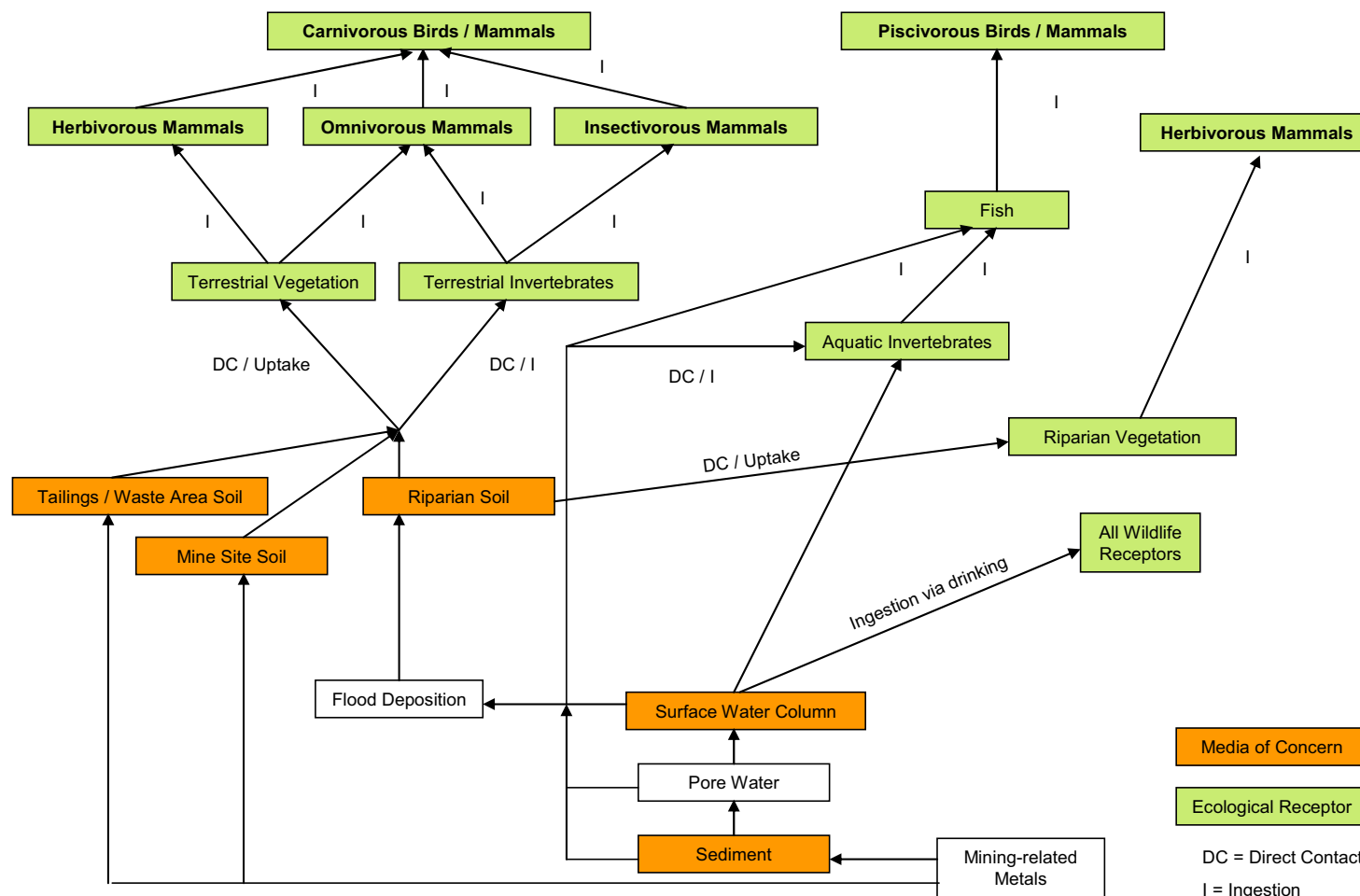
Figure 2-2 Ecological Site Conceptual Exposure Model (SCEM) – Part 2
Food Web – Avoca River, County Wicklow, Ireland

2.1.1 Chemicals of Potential Concern

Recent (2001-2003) water quality survey data for the Avoca River indicate that the Avoca River is seriously polluted with copper, zinc, and to a lesser extent lead. All 16 samples collected and analyzed during the 2001-2002 water quality survey (Toner et al. 2004) exceeded the Dangerous Substances Regulations [Water Quality (Dangerous Substances) Regulations, S.I. No. 12 of 2001] limit for at least one of the above metals. Copper, zinc, and lead are therefore preliminarily identified as the primary COPCs for the Avoca River.

The substances of greatest concern to aquatic-dependent and terrestrial wildlife are those that are persistent and bioaccumulative. The COPCs initially identified for Avoca River surface water (copper, lead, and zinc) are all persistent and are bioaccumulative. Lead is only minimally bioaccumulative compared to copper and zinc due to lower bioavailability. Both copper and zinc are essential elements; therefore, finding copper and zinc in biological tissues is expected. Toxicity can occur when levels of copper and zinc exceed those required for biological function.

2.1.2 Refinement of Chemicals of Potential Concern

The list of surface water COPCs initially developed from existing reports (Toner et al. 2004) was supplemented by limited (n = 4) instream sediment and more extensive surface soil/spoils collection and analysis conducted in spring 2007. The analyses of these sediment and surface soil/spoils samples, based on XRAY fluorescence (XRF) technology, resulted in the addition of other COPCs based on exceedance of conservative ecological screening levels (ESLs) for sediment and surface soil. Final COPCs retained for the full assessment following these screening steps are termed COCs, and the risks potentially associated with these are quantitatively estimated in the final ERA.

Screening of surface water COPCs is based on comparing maximum concentrations of dissolved copper, lead, and zinc measured in Avoca River surface water (2001 to 2003) to Ireland EPA regulatory limits for Dangerous Substances in surface water. Maximum values for screening surface water COPCs are based on the highest values from (1) Toner et al. (2004), based on 16 samples collected in 2002-2003 from a single location downstream of the former fertilizer plant, or (2) Eastern Regional Fisheries Board data collected in 2001 and 2002 at the Avoca Bridge (10 samples).

Screening of sediment, surface soil, and mine waste (spoils) sampling data is based on direct comparisons of measured concentrations of metals in these media from 2007 sampling to conservative numerical ESLs that are derived for sediment and surface soil.

Nontoxic metals such as calcium and magnesium are not evaluated further in this assessment. Also eliminated at this stage of the preliminary ERA are (1) chemicals for which the maximum detected value remains below the ESL (cobalt and iron in sediment); (2) chemicals for which toxicity data are sparse, generally considered to be

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of low toxicity, and not attributable to mining activities (thallium and vanadium in sediment); and (3) chemicals in surface water that have not been previously identified as COCs for surface water (all chemicals other than copper, lead, and zinc in surface water). Finally, cadmium is retained as a COC in sediment even though it was not detected above the detection limit (5 mg/kg) in the four samples taken. Retention of cadmium as a COC is based on the following: 1) only four sediment samples were collected and analyzed, 2) cadmium is among the most toxic of metals to ecological receptors, and 3) use of lower detection limits would likely result in detections at levels that may be associated with toxicity. The results of Phase 2 sampling will be used to confirm COCs and may be used to add other COCs to the current (Phase 1) list of those warranting further evaluation.

Based on the site-wide maximum values measured in site sediments and soils/spoils, conservative ESLs are used at this COPC-screening stage to ensure that all potentially toxic chemicals in sediment and surface soil from anywhere within the entire study area are retained for further investigation. The maximum values are divided by the ESL to calculate a screening level Hazard Quotient (HQ). Table 2-1 presents the results of the screening of surface water, sediment, and surface soil, based on recent (2001 - 2003) surface water data and on sediment and soil/spoil samples collected in April 2007.

Table 2-1 Screening of Media-specific COPCs

Surface Water (µg/L)				
COPC	Max Conc	ESL	ESL Source	Screening HQ
Copper	28	5	1	**5.6**
Lead	28	5	1	**5.6**
Zinc	390	50	1	**7.8**

ESL Source:
1 - Ireland EPA Dangerous Substances Regulations Limit for surface water

Sediment (mg/kg)				
COPC	Max Conc	ESL	ESL Source	Screening HQ
Arsenic	10.7	9.79	1	**1.1**
Cadmium		0.99	1	0.0
Chromium	71.3	43.4	1	**1.6**
Cobalt	7.6	50	1	0.2
Copper	77.1	31.6	1	**2.4**
Iron	44,495	188,400	2	0.2
Lead	103.1	35.8	1	**2.9**
Manganese	3,480	630	2	**5.5**
Mercury	4.5	0.174	1	**25.9**
Nickel	25.5	22.7	1	**1.1**
Zinc	158	121	1	**1.3**

ESL Source:
1 - USEPA Region 5 RCRA ESL for sediment
    Effects Level (*Hyalella azteca*), in Buchman 1999 (NOAA SQuiRTS Table)

Table 2-1 Screening of Media-specific COPCs

Surface Soil/Spoil (mg/kg)				
COPC	Max Conc	ESL	ESL Source	Screening HQ
Arsenic	1,482	5.7	1	**260**
Cadmium	33.8	2.22	1	**15**
Chromium	421	0.4	1	**1,053**
Copper	7,253	5.4	1	**1,343**
Lead	24,314	0.0537	1	**452,775**
Manganese	9,449	100	2	**94**
Mercury	52.9	0.1	1	**529**
Nickel	765	13.6	3	**56**
Silver	66.7	4.04	1	**17**
Zinc	7,111	6.62	1	**1,074**

ESL Source:
1 - USEPA Region 5 RCRA ESL for surface soil
2 - ORNL Screening Benchmark for soil microorganisms and microbial processes
3 - ORNL Screening Benchmark for phytotoxicity

The conservative ESLs selected for screening chemicals in sediment and soil/spoil and presented on Table 2-1 are listed below in order of preference:

Surface Water ESLs

Water Quality (Dangerous Substances) Regulations, S.I. No. 12 of 2001, Minister of State at the Department of the Environment and Local Government, Ireland:

■ Applicable to arsenic, chromium, copper, lead, nickel, and zinc in surface waters

Sediment ESLs

USEPA Region 5 Resource Conservation and Recovery Act (RCRA) ESL for sediment (USEPA 2003):

■ Applicable to all sediment chemicals subject to screening except iron and manganese

Lowest Assessment and Remediation of Contaminated Sediments (ARCS) Program Threshold Effects Level (*Hyalella azteca*, freshwater amphipod), in Buchman 1999 (National Oceanic and Atmospheric Administration [NOAA] SQuiRTS Table):

■ Applicable to iron and manganese

Surface Soil/Spoils ESLs

USEPA Region 5 RCRA ESL for surface soil (USEPA 2003):

■ Applicable to all sediment chemicals subject to screening except manganese and nickel

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Lowest of the following:

Oak Ridge National Laboratory (ORNL) Screening Benchmark for Phytotoxicity (Efroymson, Will, Suter II, and Wooten 1997):

- Applicable to nickel

ORNL Screening Benchmark for Soil and Litter Invertebrates and Heterotrophic Process (includes separate benchmarks for soil invertebrates and for soil microbes; Efroymson, Will, and Suter II 1997):

- Applicable to manganese (soil microbe benchmark)

Final COCs for this assessment are presented below:

- **Surface Water COCs** – copper, lead, and zinc

- **Sediment COCs** – arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc

- **Surface Soil/Spoils COCs** – arsenic, cadmium, chromium, copper, lead, manganese, mercury, silver, and zinc

2.2 Exposure Areas (EAs)

Exposure areas (EAs) are defined for the purpose of this preliminary ERA as discreet locations where ecological receptors may be exposed to a specific set of conditions or chemical stressors. Designations of individual media-specific EAs are based primarily on available media quality data, presence of or relationship to known or suspected contaminant source areas, and unique features that can affect exposure (e.g., major tributaries, industrial sites, etc.). Each designated EA is considered to be sufficiently different from other EAs of the same media type to warrant independent evaluation. Media-specific EAs are described below.

2.2.1 Surface Water (SW, 10 Stations) and Sediment (SED, 4 Stations) EAs

- EA-1 – Avoca River from Meeting of the Waters downstream to White's Bridge (primary REFERENCE, SW only)

- EA-2 – Avoca River at White's Bridge to just upstream of confluence of Deep Adit discharge and Avoca River (SW and SED)

- EA-3 – Confluence of Deep Adit discharge and Avoca River downstream to just upgradient of Road Adit discharge (SW and SED)

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- EA-4 – Confluence of Road Adit discharge and Avoca River downstream to just downstream of Avoca Bridge (SW only)

- EA-5 – Avoca River downstream of Avoca Bridge downstream to just upgradient of confluence with Aughrim River (along Woodinbridge Golf Course, SW only)

- EA-6 – Aughrim River just upstream of confluence with Avoca River (along Woodinbridge Golf Course, secondary REFERENCE, SW only)

- EA-7 – Confluence of Aughrim and Avoca Rivers downstream to just above Shelton Abbey Tailings (SW only)

- EA-8 – Avoca River at upper boundary of Shelton Abbey tailings downstream to just above former Fertilizer Plant (SW and SED)

- EA-9 – Avoca River at upper boundary of former Fertilizer Plant to downstream boundary of former Fertilizer Plant (SW only)

- EA-10 – Avoca River at downstream boundary of former Fertilizer Plant to Arklow (SW and SED)

2.2.2 Surface Soil/Spoils EAs

The following main sampling locations are identified as soil/spoils EAs. Most of the samples collected from these locations are mine waste (spoils) samples.

- EA-1 - West Avoca
- EA-2 - Shelton Tailings
- EA-3 – Connary
- EA-4 - Mount Platt
- EA-5 - East Avoca
- EA-6 - Tigroney West
- EA-7 - Ore bins at Tigroney West

2.3 Ecological Resources at Risk

Ecological resources evaluated in this preliminary ERA include the aquatic and terrestrial habitats and ecological receptors that have potential to be affected by mining-related contaminants. These resources are described below.

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2.3.1 Habitats

Of concern to this ERA are aquatic and terrestrial habitats that support or have potential to support important ecological receptors. These habitats include aquatic habitats within the mining-affected watershed, riparian habitats along water courses, and terrestrial habitats associated with past mining activities or affected by mine wastes.

2.3.1.1 Aquatic and Riparian Habitats

Aquatic habitats most relevant to this study are those associated with the Avoca River, primarily those areas near and downgradient of contaminant source areas related to past mining activities. Also important are upgradient and tributary (e.g., Aughrim River) waters that provide insight into reference conditions with little or no mining-related impacts. Finally, of secondary concern are far downgradient surface waters that may be subject to mining-related contaminant migration and non-mining sources of contamination, such as wastewater treatment plant (WWTP) effluent, agricultural impacts, and disturbances related to residential or urban environments. These are of concern primarily because of the potential for migrating salmonid fish to be adversely affected (e.g., through avoidance or chemical barriers) in the lower reaches of the Avoca River watershed. This situation could restrict or limit fish migration into the upper watershed areas subject to restoration/remediation.

Most of the Avoca River is characterized as a medium sized stream with cobble and gravel substrates, little silt for fine grained sediment, iron staining of the substrates in areas most affected by low pH and elevated metals concentrations, little channelization and, in spring 2007, mostly runs with riffles in the more shallow areas and infrequent pools. Average depth in mid channel in spring 2007 was about 0.7 m, often with one bank having a deeper channel (>1.5 m) and the opposite bank being shallow (<0.5 m). River widths varied from about five meters to over 15 meters. Braiding within the channel was uncommon in spring 2007, mostly limited to the area adjacent to the Shelton Abbey tailings where several side channels and backwater areas were observed.

The land uses in the Avoca River valley adjacent to the river are diverse, and include historic mining areas where mine wastes/spoils and/or mine tailings has been deposited, agricultural uses, residential areas and small communities such as Avoca Village, past industrial uses such as the former Fertilizer Plant, current light industrial uses such as the new automobile storage facilities at the site of the former Fertilizer Plant, institutional use (e.g., the prison at the former Shelton Abbey), landfills or capped waste areas with known and unknown (e.g., on the property of the former Fertilizer Plant) types of contaminants, and recreational areas (e.g., golf course at Woodinbridge and public riparian walking trails along the south bank of the river northwest of Arklow.

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Much of the riparian corridor is well vegetated with a variety of grasses, forbs, shrubs, and mostly small trees. The upper reaches of the study area are especially well vegetated, with considerable shading of stream banks by mostly deciduous and fewer coniferous trees. The lower reaches of the riparian corridor are, in general, more open and developed, with fewer and small areas of natural vegetation.

2.3.1.2 Terrestrial/Upland Habitats

Little natural vegetation is observed in the upland areas. Much of the upland terrestrial environment of concern to this study is highly disturbed by past mining activities. These areas include open pits, waste/spoils piles, highly eroded surface areas, covered and uncovered tailings, and roads. Beyond the highly disturbed areas are mostly residential properties with grass, planted shrubs and trees as well as agricultural areas subject to small scale farming and grazing. In some cases, agricultural land uses extend into the riparian corridor, and in fact grazing or farming up to the river edge is observed in a few locations.

Plant communities in the undeveloped portions of the upland areas that are not within the most severely mining-degraded areas are dominated by pasture grasses, blackberry vines or bramble (*Rubus* sp.) and gorse (*Ulex europaeus*). Gorse is a nitrogen-fixing legume that is considered by many to be a noxious weed. Gorse is difficult to control but grazing by goats appears to be a commonly applied approach in the Avoca River watershed. Apparently gorse can change soil chemistry and prevent nutrient exchange (Hoshovsky 1989), and according to some, can bind calcium. This latter trait can affect soil pH by reducing acid buffering capability—important where acid mine wastes affect soil quality.

2.3.2 Ecological Receptors

Ecological receptors are defined for this preliminary ERA as the plants and animals that have potential to be adversely affected by mining-related contaminants and other contaminants that may affect the goals and objectives of mining related remediation. Clearly not all receptors can be fully evaluated in the ERA and, therefore, specific representative receptors or receptor groups are selected for evaluation.

2.3.2.1 Aquatic Receptors

Aquatic or water-dependent receptors for this study include benthic invertebrates, water column aquatic invertebrates, amphibians, fish, fish-eating birds, fish-eating mammals, aquatic insect-eating birds, and aquatic insect-eating mammals.

The fish community in the Avoca River is currently neither abundant nor diverse, primarily as a result of mine-related contamination. The types of fish that currently occur in nearby waters or those that have potential to occur most abundantly in the Avoca River are salmonid fish. These include brown and sea trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*). Brown and sea trout are fish of the same species, but the sea trout form is anadromous while the brown trout form is largely restricted to

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freshwater. Sea trout, like most (but not all) populations of Atlantic salmon, spend much of their lives in the sea, migrating to natal freshwater streams only to reproduce. Both forms may coexist in the same river and may be genetically identical. Reestablishing conditions suitable for salmonid fish survival, growth, and reproduction is an important remediation endpoint for the Avoca River.

BMI are important aquatic organisms from the standpoint of serving as prey for fish and other water-dependent wildlife (e.g., insectivorous birds) and as useful indicators of water quality. BMI are often used as water quality indicators because they integrate water quality over time; their life history requires months to a year or more as aquatic forms. Therefore, the abundance and diversity of BMI indicate long term water quality conditions. Also, they are not very mobile in most cases, and can therefore be used to indicate *local* conditions (water, sediment, habitat, etc.). BMI have been collected from the Avoca River in support of numerous past studies of the river. BMI were also collected in spring 2007 specifically to provide current data for use in this ERA. The results of these collections are provided in Section 4 (Risk Characterization).

The only amphibians and reptiles expected to occur within the study area, based on geographic range and habitat availability, are common frog (*Rana temporia*) and common lizard (*Lacerta vivipara*). Larvae (tadpoles) of common frog (presumptive identification) were observed in a vernal pool adjacent to the Shelton tailings in April 2007. Common lizards were observed at two locations (at East Avoca and near Woodinbridge golf course) within the study area in April 2007.

Piscivorous birds and mammals (e.g., introduced mink and native otter) are unlikely to find much suitable habitat along the Avoca River. Even if suitable habitat was present, the low numbers of fish that can serve as prey would likely limit the numbers of piscivorous birds and mammals. For these reasons, these types of receptors are probably not significantly exposed to mining-related contaminants in river water, sediments, or prey.

2.3.2.2 Terrestrial Receptors

Mammals associated with the upland terrestrial ecosystems within the study area are likely to include rabbits, hares, mice, rats, voles, squirrels, and red deer. Rabbits and pheasants were abundant during the site survey of the Shelton Tailings area in April 2007. Pheasants were also commonly seen throughout the study area in April 2007. Many of these are introduced forms that have adapted well to human-influenced environments, while others such as red deer are unlikely to be common anywhere within the study area. Domesticated mammals dominate the terrestrial lands near the mining sites and other upland areas within the study area. These include sheep, goats, and cattle. Most of the mammals with potential to be exposed to mining-related contaminants are herbivores, and metals uptake by plants is therefore an important exposure pathway that warrants evaluation.

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2.3.2.3 Species of Special Concern

Protected Irish fauna include a variety of invertebrates, amphibians, reptiles, birds, and mammals. Some of these are known to occur or have potential to occur within the area of interest to this study. Others are not known to occur or are unlikely to occur within the study area because, for example, of limited geographic range or lack of suitable habitat.

Those with low potential to occur near the Avoca mine sites and related areas of contamination include the otter (*Lutra lutra*, protected by Wildlife Acts of 1976 and 2000 and the European Communities Regulations 1997); badger (*Meles meles*, protected by Wildlife Acts of 1976 and 2000); natterjack toad (*Bufo calamita*) and common newt (*Triturus vulgaris*, both protected by Wildlife Acts of 1976 and 2000); and white-clawed crayfish (*Austropotamobius pallipes*, protected by the European Communities Regulations 1997). These protected taxa, and several of the bird species known to occur in Ireland are either not reported from County Wicklow or are unlikely to find suitable habitat or prey (e.g., piscivorous birds and mammals) in the study area.

In contrast to the above, several species protected in Ireland have been observed or reported from the study area. Others have significant potential to be found within the study area based on geographic range and habitat requirements, but occurrence has not be documented.

These include 10 species of bats within the families *Vespertilionidae* and *Rhinolophidae*, all protected by the Wildlife Act (1976), the Convention on the Conservation of Migratory Species of Wild Animals (1979), the Convention on the Conservation of European Wildlife and Natural Habitats (1982), the European Communities Regulations (1997). Bats of unknown taxa have been reported from the adits and open pits associated with past mining activities in the study area.

Also, peregrine falcon (*Falco peregrinus*) have been reported (but were not observed in April 2007) to utilize the walls of the open mine pits within the study area. The common lizard (*Lacerta vivipara*, protected by the Wildlife Acts of 1976 and 2000) was observed at the golf course in Woodinbridge and at the East Avoca Pit in April 2007 (one individual at each location). Electronic reports of these observations were submitted to the Irish Wildlife Trust (IWT) in April 2007, as requested by the IWT. Finally, all wild bird species in Ireland are protected under the Wildlife Acts of 1976 and 2000.

2.4 Endpoints and Risk Questions/Hypotheses

This preliminary ERA is focused primarily on assessing population-level risks associated with mining-related contamination in abiotic media and biota. In general, risks are assessed by comparing COPC concentrations in abiotic media to concentrations associated with adverse effects. Guiding the estimation of risks are two

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types of endpoints–assessment endpoints and measurement endpoints. These endpoints are discussed in Sections 2.3.1 and 2.3.2. Risk questions and hypotheses are developed to test assumptions regarding relationships between selected assessment endpoints, measurement endpoints, and potential exposures to representative receptors. These risk questions/hypotheses are discussed in Section 2.3.3. Table 2-2 shows assessment and measurement endpoints. Table 2-3 relates the risk questions/hypotheses to each assessment and measurement endpoint.

2.4.1 Assessment Endpoints

Assessment endpoints identify the ecological values to be protected (e.g., abundance and diversity of aquatic macroinvertebrates or fish). Assessment endpoints are directly related to remedial action goals and objectives determined for the site. Appropriate assessment endpoints are developed by risk assessors and guidance from relevant regulatory agencies.

ERA-related remedial action goals and objectives for the Avoca mine site study area have not been specifically determined at this time but general goals and objectives are likely to include the following:

> *The establishment and maintenance of a healthy and diverse aquatic and riparian ecosystem adjacent to and downstream of the areas currently impacted by mining-related contamination*

> *The reestablishment of a viable self-reproducing migratory salmonid fish population in the Avoca River from the current mine sites downgradient to Arklow Bay*

> *Reductions in concentrations of site-related metals in aquatic biota such that upper trophic level consumers (e.g., piscivorous birds and mammals) are not adversely affected at the population or community level*

> *The establishment and maintenance of a healthy and diverse terrestrial ecosystem at and adjacent to the contaminated areas where such establishment is possible*

> *Reductions in concentrations of site-related metals in terrestrial biota such that upper trophic level consumers (e.g., peregrine falcons) are not adversely affected at the population or community level*

The ERA is designed to support decisions related to remedial action goals and objectives. This support consists of selecting appropriate assessment endpoints and evaluating risks related to these endpoints. The characteristics of the site, contaminants of concern, toxic mechanisms, and exposure pathways were used to select the following assessment endpoints.

Table 2-2 Assessment and Measurement Endpoints

Receptor	Assessment Endpoint	Representative Receptor Species	Measurement Endpoint
Surface Water And Sediment			
Aquatic invertebrates	Survival, Growth, and Reproduction	Water-column aquatic invertebrates (e.g., cladocerans)	Surface water chemistry compared to surface water TRVs
Benthic invertebrates	Survival, Growth, and Reproduction	Benthic aquatic insects and other aquatic invertebrates	Sediment chemistry compared to sediment TRVs (all non-GSI sites)
			Benthic invertebrate community structure (abundance and diversity)
Fish	Survival, Growth, and Reproduction	Brown trout, Atlantic salmon	Surface water chemistry compared to surface water TRVs
			Surface water chemistry compared to trout-based surface water TRVs
			Fish community status (surveys)
Water-dependent (piscivorous/insectivorous) birds and mammals	Survival, Growth, and Reproduction	Dipper, kingfisher, otter	Concentrations of site-related metals in fish and aquatic invertebrates (estimated/qualitative assessment)

Receptor	Assessment Endpoint	Representative Receptor Species	Measurement Endpoint
Soil/Spoils			
Terrestrial plants	Survival, Growth, and Reproduction	Native grasses, forbs, trees	Soil chemistry compared to soil TRVs
			Native plant community structure
Terrestrial invertebrates	Survival, Growth, and Reproduction	Insects, oligiochaetes, arachnids, other arthropods	Survival, growth, and reproduction of earthworm *Eisenia foetida* (28-d test)
			Bioaccumulation test using the earthworm Eisenia foetida (28-d test)
			Soil chemistry compared to soil TRVs
			Contaminant concentrations in earthworm tissue from the field
			Terrestrial invertebrate community structure
Carnivorous birds and mammals	Survival, Growth, and Reproduction	Peregrine falcon	Concentrations of site-related metals in terrestrial invertebrates, birds, and small mammals (estimated/qualitative assessment)

Receptor	Assessment Endpoint	Representative Receptor Species	Measurement Endpoint
Surface Water, Sediment, And Soil/Spoils			
Amphibians	Survival, Growth, and Reproduction	Common frog	Qualitative Assessment Only
Reptiles	Survival, Growth, and Reproduction	Common lizard	Qualitative Assessment Only

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Table 2-3 Relationships Between Endpoints and Risk Questions

Assessment Endpoint	Risk Questions (Testable Hypotheses)	Measurement Endpoints
Survival and Growth of Terrestrial Plants	Are the levels of contaminants in soils from the soil exposure areas greater than the soil TRVs for the survival and growth of terrestrial plants?	Concentrations of contaminants in soils (i.e., reported on a dry weight basis, relative to soil quality benchmarks for survival and growth)
Survival, Growth, and Reproduction of Terrestrial Invertebrates	Are the levels of contaminants in soils from the soil exposure areas greater than the soil TRVs for the survival and growth of terrestrial invertebrates?	Concentrations of contaminants in soils (i.e., reported on a dry weight basis, relative to soil quality benchmarks for survival, growth, or reproduction)
Survival, Growth, and Reproduction of Carnivorous Birds and Mammals	Are the levels of contaminants in soils from the soil exposure areas sufficiently elevated to contribute to adverse effects in consumers of terrestrial invertebrates, birds, and/or small mammals?	Screening level assessment based on literature-derived trophic transfer factors
Survival, Growth, and Reproduction of Aquatic Invertebrates	Are the levels of contaminants in whole sediments from the Avoca River exposure areas greater than the sediment TRVs for the survival, growth, or reproduction of benthic invertebrates?	Concentrations of contaminants in whole sediments (i.e., reported on a dry weight basis, relative to sediment TRVs for survival, growth, or reproduction).
	Is the structure of benthic macroinvertebrate communities in Avoca River sediments significantly different than that from reference locations?	Abundance and diversity metrics (screening level assessment)
Survival, Growth, and Reproduction of Fish	Are the concentrations of contaminants in water from the Avoca River greater than the surface water TRVs for the survival, growth, and reproduction of fish?	Concentrations of contaminants in river water (i.e., relative to the surface water TRVs and trout-specific TRVs)
Survival, Growth, and Reproduction of Water Dependent Birds and Mammals	Are the concentrations of contaminants in water from the Avoca River sufficiently elevated to contribute to adverse effects in upper trophic level (ecological) consumers of fish and adult life stages of aquatic invertebrates?	Screening level assessment based on literature-derived trophic transfer factors

2.4.1.1 Surface Water and Sediment Based Assessment Endpoints

Protection of water-column and benthic invertebrate receptors from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in sediment and surface water.

Protection of fish from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in surface water.

Protection of insectivorous, piscivorous, and carnivorous avian receptors from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in prey, sediment, and surface water.

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Protection of omnivorous and piscivorous mammalian receptors from the toxic effects (on survival, growth, and reproduction) of site-related chemicals present in prey, sediment, and surface water.

2.4.1.2 Soil/Spoils-based Assessment Endpoints

Protection of terrestrial plants and invertebrate communities from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in soil/spoils.

Protection of amphibians and reptiles from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in surface water, sediment, and soil/spoils.

Protection of omnivorous and carnivorous avian receptors from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in prey and soil/spoils.

Protection of herbivorous, omnivorous, and insectivorous mammalian receptors from the toxic effects (on survival, growth, or reproduction) of site-related chemicals present in food items and soil/spoils.

2.4.2 Measurement Endpoints

Assessment endpoints are often difficult to measure or evaluate directly. For example, we cannot predict with certainty the conditions necessary to ensure the survival and successful reproduction of salmonid fish in surface waters adjacent to or downstream of the site. Such critical concentrations are site-specific and depend on innumerable factors. However, toxicity data based on experimental studies or those designated as critical thresholds by regulatory agencies can often help predict the likely outcome of expected exposures. Measurement endpoints are for the most part toxicity reference values (TRVs) selected from or based on accepted sources such as Ireland's EPA, USEPA, and other relevant regulatory agencies. Section 3.2 presents the medium-specific TRVs selected for estimating risks to ecological receptors.

Measurement endpoints are used where assessment endpoints cannot be directly measured or evaluated. Measurement endpoints are quantitative expressions of observed or measured biological responses to stressors relevant to selected assessment endpoints. For example, survival and growth of aquatic invertebrates (an assessment endpoint) can be evaluated using aquatic toxicity data based on an appropriate measurement endpoint. As a more specific example, concentrations of dissolved copper in surface water can be compared to concentrations in laboratory tests with surface water that resulted in observed ecologically significant effects to sensitive and relevant test species [i.e., the sensitive water flea (*Ceriodaphnia dubia*)]. This example expresses the relationship between a relevant measurement endpoint (chronic effects concentration of metals in surface water) that is directly related to the assessment endpoints of aquatic invertebrate survival and growth. Measurement

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endpoints selected for this ERA include information from appropriate aquatic ecology/toxicology studies and water quality studies.

Ecologically significant effects are defined as those affecting survival, growth, or reproduction of selected receptors. Other endpoints such as effects on behavior or histopathological effects are not considered because these cannot be easily linked to ecologically significant endpoints that can impair populations or communities. Protection of populations and communities is a major goal of the ERA, while protection of individual organisms is warranted for species of special concern (e.g., threatened or endangered species).

Because of the potential for certain metals to accumulate in biological tissues and exert adverse effects in upper trophic level biota, this preliminary ERA also considers bioaccumulation and adverse effects in upper trophic level organisms (due to ingestion of contaminated prey). Effects on upper trophic level receptors are preliminarily evaluated using literature-based data to identify the potential for such effects to occur.

2.4.3 Risk Questions/Hypotheses

Hypotheses or risk questions are used to test assumptions regarding relationships between selected assessment endpoints, measurement endpoints, and potential exposures for selected representative receptors. The hypotheses identified for this preliminary ERA are based on the selected ecological receptors and the major exposure scenarios linked to these receptors. Some receptor groups, although considered important, are not included in the following hypotheses because assessment data are sparse or lacking. For example, protection of local amphibian populations is considered important but data are lacking to assess the potential impacts on these receptors. A primary goal of the ERA is to answer the following risk questions with sufficient confidence to allow appropriate decision making with regard to site remediation.

> *Are the levels of contaminants in soils/spoils from the soil/spoils exposure areas greater than the soil TRVs for the survival and growth of terrestrial plants?*

> *Are the levels of contaminants in soils/spoils from the soil/spoils exposure areas greater than the soil TRVs for the survival and growth of terrestrial invertebrates?*

> *Are the levels of contaminants in soils/spoils from the soil/spoils exposure areas sufficiently elevated to contribute to adverse effects in consumers of terrestrial invertebrates, birds, and/or small mammals?*

> *Are the levels of contaminants in whole sediments from the Avoca River exposure areas greater than the sediment TRVs for the survival, growth, or reproduction of benthic invertebrates?*

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> *Is the structure of benthic macroinvertebrate communities in Avoca River sediments significantly different than that from reference locations?*

> *Are the concentrations of contaminants in water from the Avoca River greater than the surface water TRVs for the survival, growth, and reproduction of fish?*

> *Are the concentrations of contaminants in water from the Avoca River sufficiently elevated to contribute to adverse effects in upper trophic level (ecological) consumers of fish and adult life stages of aquatic invertebrates?*

2.5 Site Conceptual Exposure Model

The SCEM for the ERA (Figure 2-1) is a visual presentation that summarizes key components related to potential ecological exposures resulting from site-related chemical contamination. The SCEM is the primary output of the Problem Formulation phase of the ERA, and summarizes exposure scenarios and is used to help develop a series of testable null hypotheses for the Site, as presented in this section. In addition, the SCEM is used to support the selection of appropriate assessment and measurement endpoints.

The SCEM presents the potential exposure pathways for representative ecological receptors exposed to site-related contaminants. These potential pathways indicate how the ecological resources can co-occur or come in contact with contaminants, and include contaminant sources, fate and transport processes, and exposure routes.

For the ERA, the SCEM consists of two components. First, Figure 2-1 presents all the components of the SCEM for the mining related source areas and related areas of contamination. Included on this figure are symbols representing various assumptions about exposure pathways. Solid black dots represent complete and significant exposure pathways that are evaluated quantitatively. Dashed lines represent incomplete exposure pathways that are not evaluated. Open circles represent exposure pathways that are either insignificant (but complete) or those for which data are lacking.

Figure 2-2 graphically depicts a simplified aquatic and terrestrial food web for the site, and reveals the specific receptor groups linked to direct exposures. Figure 2-2 also reveals the major dietary items for upper trophic level receptors. The dietary items presented do not include all potential dietary components for each receptor, but instead include major representative food/prey categories.

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Section 3
Analysis Phase

The Analysis Phase of the ERA includes two major components, Exposure Assessment and Effects Assessment. Each of these is discussed below.

3.1 Exposure Assessment

Exposure Assessment evaluates and summarizes available exposure data, including COC concentrations in abiotic and (where available) biological media as well as exposure-related information for potential ecological receptors. The primary output of exposure assessment is an exposure profile that presents the magnitude (e.g., concentration) and distribution of COCs to which ecological receptors may be exposed. Exposure profiles serve as input into the final stage of risk assessment, Risk Characterization.

3.1.1 Chemicals of Concern

The primary chemical stressors identified for this site are inorganic metals and metalloids (arsenic). As discussed previously, the final COCs for this site include the following:

- Surface Water COCs – copper, lead, and zinc

- Sediment COCs – arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc

- Surface Soil/Spoils COCs – arsenic, cadmium, chromium, copper, lead, manganese, mercury, silver, and zinc

3.1.2 Contaminant Fate and Transport

This section of the ERA presents important chemical properties for the COCs identified at the site. Each of these properties is discussed below.

3.1.2.1 Environmental Persistence

Environmental persistence indicates whether a chemical is likely to be long-lasting in the environment or, alternatively, be degraded by natural processes. Of concern to this preliminary ERA is the persistence of metals in the environment. Metals are not significantly degraded by any biological or abiotic process, so reductions in concentrations over time are not expected. However, some *apparent* reductions in concentrations can occur via physical process such as covering of contaminated sediments by clean sediments.

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3.1.2.2 Bioconcentration Potential

Bioconcentration potential indicates whether a chemical is likely to be retained in biological tissues after it is taken in by ingestion or other means. Retention of chemicals is not in itself an appropriate measurement endpoint unless it is associated with adverse ecological effects. Retention is, however, useful for verifying exposure and for evaluating bioavailability and the potential for food web effects.

There are differences in the ability of different types of biota to detoxify and/or eliminate certain chemicals following initial uptake. Inorganic COPCs include those that are essential for life and therefore are physiologically regulated (e.g., copper and zinc), as well as those with no known biological function (e.g., cadmium and mercury). Whether or not a metal is accumulated and retained in biological tissues depends on the metal, the receptor, and the chemical form in which the metal occurs.

Retention of metals in biological tissues can be a necessary function for essential elements but, for other non-essential metals, can cause adverse effects. Accumulation of metals in biological tissues (bioaccumulation) is therefore important to ecological risk assessment. Bioaccumulation is often determined using some type of bioaccumulation factor or BAF. BAFs are based on uptake via both food and water, and field-derived site-specific BAFs are the preferred data for assessing bioaccumulation potential. Because field-derived site-specific BAFs are unavailable for receptors of concern for this preliminary ERA, literature-based BAFs or bioconcentration factors (BCFs) are used to evaluate accumulation of metals. Bioaccumulative metals have been identified by various regulatory agencies, and these include cadmium, chromium, copper, lead, mercury, nickel, and zinc. Not all of these potentially bioaccumulative metals are identified as COCs for this study.

3.1.2.3 Bioavailability

Bioavailable chemicals are defined as those that exist in a form that have the ability to cause adverse ecological effects or bioaccumulate. As stated previously, bioaccumulation may not in itself constitute a significant ecological effect, but provides important evidence of both exposure and potential for causing adverse effects to multiple trophic levels under certain conditions.

For some contaminants, chemical form and thus toxicity can change rather rapidly under changing environmental conditions (e.g., fluctuations in pH or other conditions related to seasonal conditions such as high rainfall). Measurements of total organic carbon (TOC) in soil and sediment can be used to generally describe the bioavailable portion of many organic and some inorganic chemicals. Higher levels of TOC in soil and sediment can reduce bioavailability and toxicity due to binding of contaminants with organic carbon. The expectation that certain COCs are likely to be accumulated in the tissues of aquatic and terrestrial biota collected from the site supports the preliminary assumption that some of these COCs are indeed bioavailable. This is not surprising for some COCs since they are essential elements and uptake is required. For others, uptake and accumulation may pose a hazard worth investigating.

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Similarly, chemicals found in surface waters can vary with regard to bioavailability and toxicity depending on chemical form and water quality characteristics. Factors affecting contaminant bioavailability and toxicity in surface water can include the following:

- Hardness (primarily Ca and Mg concentrations)
- Sulfate (affects Se toxicity)
- Alkalinity
- Salinity
- Temperature
- Dissolved oxygen
- Total dissolved solids
- Suspended particulates
- Organic carbon
- pH
- Oxidation-reduction potential

Of these, hardness (measured as calcium carbonate or $CaCO_3$) is most important for affecting the toxicity of certain metals (Cd, Cr III, Cu, Pb, Ni, Ag, and Zn). Higher hardness levels in surface water decrease bioavailability and toxicity of these metals. The average and minimum hardness of the Avoca River is used to evaluate bioavailability and toxicity, primarily through adjusting toxicity reference values or TRVs.

Organic carbon content and the presence of particulates in surface water can substantially affect the bioavailability and toxicity of contaminants. Increases in organic carbon and particulates in surface water reduce the bioavailability of some chemicals, but particulates can also adversely affect filter feeding aquatic receptors. Finally, USEPA has recently adopted the Biotic Ligand Model (BLM) for copper. This approach is based on observations that organic carbon in surface water substantially influences the toxicity of dissolved copper in surface water.

3.1.3 Exposure Media

Exposure media for this ERA includes surface soil, sediment, and surface water. Abiotic media (soil, sediment, and water) can serve as exposure media for ecological receptors via direct contact or ingestion. Biota is considered an exposure medium for ecological receptors that consume contaminated food items (e.g., vegetation and prey), but COC concentrations in biological tissues are lacking. Therefore, biota are not considered a media type subject to quantitative analyses. Each of these primary media types is discussed below.

3.1.3.1 Surface Water

Avoca River water comprises the major source of surface water data for this ERA. Specific locations selected as surface water exposure areas based on the April 2007 site visit and screening level survey are described in Section 2.2.1.

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3.1.3.2 Sediment

Sediments are defined for this ERA as the finer grained (i.e., silt, sand, and gravel but not cobble or boulders) solid media underlying surface water at the time of sampling. Sediments that have been deposited along stream banks that are currently not covered by water are considered riparian soils and not sediments. Aquatic sediments were sampled from several locations within the Avoca River. Specific locations selected as sediment (and surface water) exposure areas based on the April 2007 site visit and screening level survey are described in Section 2.2.1.

3.1.3.3 Surface Soil/Spoils

Surface spoils were collected from a variety of locations to help determine risks to terrestrial ecological receptors. These samples were taken from three major categories based on location and/or general characteristics. These are (1) open pit or pit-related waste, (2) tailings, and (3) other mine waste and spoils. Specific locations selected as surface soil/spoils exposure areas based on the April 2007 site visit and screening level survey are described in Section 2.2.2.

3.1.4 Exposure Point Concentrations

EPCs are chemical concentrations representing the concentrations to which receptors may be exposed. EPCs serve as input into risk calculations, and are derived for all media-specific COCs for the ERA. These include EPCs for surface water, sediment, and surface soil.

Preferred EPCs are commonly based on upper range estimates of mean values, such as 95% upper confident limits on the arithmetic mean (95% UCL). However, calculation of reliable 95% UCLs requires at least 10 to 20 (preferred) samples per location and media type. Reliable 95% UCLs are calculated for surface soils/spoils at West Avoca (EA-1) and Mount Platt (EA-4). EPCs for other surface soil/spoils EAs are based on maximum values because of data limitations. For sediment, EPCs are based on single values (N = 1).

For surface water, EPCs are based on the highest mean and the highest maximum of those from two independent data sets. These are (1) Table 2.9, Toner et al. (2004), which depicts means and maximums for 16 samples collected downstream of the former fertilizer plant from 2001 to 2003, and (2) Eastern Regional Fisheries Board data collected from the Avoca Bridge in 2001 and 2002. Based on review of these two data sources, mean EPCs for copper and lead and the maximum EPC for lead are from Toner et al. (2004), based on 2002 and 2003 data. The mean EPC for zinc and the maximum EPC for copper and zinc are from the Eastern Regional Fisheries Board database for 2001 and 2002. These represent the highest means and maximums of those presented in the two datasets—an appropriately conservative approach for this preliminary assessment.

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Clearly, the representativeness of the data used at this screening level stage of the ERA varies by media. Phase 2 of the ERA will fill important data gaps to reduce the uncertainties associated with data limitations. The EPCs derived for this screening level ERA are shown in Table 3-1, by media and by location.

3.2 Effects Assessment

Quantitative risk estimates or hazard quotients (HQs) are calculated by comparing media- and COC-specific EPCs to toxicity reference values (TRVs). TRVs are used at this stage of the assessment in a manner similar to ESLs used at the screening stage (Section 2.1.2). TRVs essentially replace conservative ESLs to more accurately describe COC concentrations that may be associated with ecologically significant toxicity in site-relevant receptors. TRVs are derived for each media-specific COC for a relevant receptor group. Salmonid fish are identified as the primary receptor group of concern for surface water. Benthic macroinvertebrates serve as the representative receptor group for sediment TRVs. Preferred representative receptor groups for soil/spoils TRVs include terrestrial plants and soil-dwelling invertebrates. Selected TRVs for each media type are presented below.

3.2.1 Surface Water TRVs

The origin of the selected surface water TRVs is USEPA chronic criteria for dissolved copper, lead, and zinc, adjusted for site water hardness. A value of 10 mg/L CaCO3 is selected to represent a conservative hardness of Avoca River water. This selected hardness value is based on an estimate of the minimum value for samples taken from the Avoca Bridge using available data and is appropriately low to ensure conservative risk estimates. Calculated hardness values using the Eastern Regional Fisheries Board data at Avoca Bridge in 2001 and 2002 ranges from 9 to 28 mg/L $CaCO_3$ with a mean of 17.7 mg/L $CaCO_3$. The mean surface water hardness will be confirmed and modified as needed based on Phase 2 sampling and analyses. The hardness-adjusted USEPA chronic criteria are intended to protect 95 percent of U.S. aquatic species most of the time, and are based on toxicity data for a wide variety of fish, aquatic invertebrates, and in some cases larval amphibians and aquatic plants.

These values are further modified for use in this assessment by limiting the toxicity data to those associated with toxicity testing with salmonid fish. Also, the USEPA-recommended hardness slope (which is based on multiple fish and invertebrate test results) is recalculated based on only salmonid fish test results. The resulting hardness-adjusted chronic criteria are therefore specific for salmonid fish. Use of these salmonid specific TRVs should not affect protection of most other forms of aquatic life other than very sensitive water column invertebrates such as daphnids. The USEPA chronic criteria for copper, lead, and zinc are driven primarily by the most sensitive taxa tested, which for these metals is often salmonid fish and daphnids. Since daphnids are primarily lake or slow water organisms, eliminating them from the toxicity database should not affect protection of salmonid (and other less sensitive) fish and benthic invertebrates in the Avoca River.

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Table 3-1 Exposure Point Concentrations (EPCs)

Surface Water EPCs (µg/L)

Location	Cu	Pb	Zn
Avoca River (**mean**)	20[1]	7.0[1]	288[2]
Avoca River (**max**)	36[2]	28[1]	601[2]

[1] Table 2.9, Toner et al. 2004 (Water Quality in Ireland 2001-2003),
   (N = 16, all from bridge downstream of former fertilizer plant
[2] Eastern Regional Fisheries Board data, Avoca Bridge, 2001-2002 (N = 10)
Highest value from above sources used for preliminary screening

Sediment EPCs (mg/kg)

Location	As	Cd	Cr	Cu	Hg	Pb	Mn	Ni	Zn
EA-2 - DS White's Bridge	10.7	ND	71.3	77.1	4.5	103.1	2,428	25.5	154.0
EA-3 - DS WB, US Deep Adit	4.6	ND	ND	46.7	ND	65.3	3,480	17.7	110.0
EA-8 - DS Tailings, US Fert. Plant	ND	ND	52.8	72.9	ND	55.4	2,678	21.7	158.0
EA-10 - DS Fert. Plant	ND	ND	48.7	67.8	ND	73.0	1,535	18.5	151.5

ND - not detected (below detection limit)
All EPCs for sediment are based on N = 1 (mean = max)
DS - downstream
US – upstream

Surface Soil/Spoils EPCs (mg/kg)

Location	As	Cd	Cr	Cu	Hg	Pb	Mn	Ni	Ag	Zn
EA-1 - West Avoca	805	ND	285	306	15.9	726	671	188	10.6	41.3
EA-2 - Shelton Tailings	792	ND	139	387	4.6	962	1,082	225	1.7	25
EA-3 – Connary	1,386	ND	327	1,796	24.7	18,676	654	97.8	66.7	1,064
EA-4 - Mount Platt	549	10.1	173	955	12.3	3,225	624	243	28.7	350
EA-5 - East Avoca	1,482	ND	94.6	1,562	ND	24,314	ND	166	38.4	584
EA-6 - Tigroney West	629	ND	167	5,480	18.5	5,008	1,218	142	ND	174
EA-7 - Ore bins at Tigroney West	497	ND	165	7,253	ND	4,962	573	ND	ND	827

ND - not detected (below detection limit)
EPCs for West Avoca and Mount Platt are 95% UCLs
EPCs for all other surface soil EAs are maximums (number of samples insufficient to calculate reliable 95% UCLs)

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3.2.2 Sediment TRVs

Selected sediment TRVs are based on two sources. First, and preferred, are the consensus-based threshold effect concentrations (TECs) derived by MacDonald et al. (2000). These values are based on compilation and evaluation of recommended sediment toxicity thresholds from a wide variety of sources and agencies. Following evaluation for data quality and ability to predict toxicity, MacDonald et al. calculated a single value that is based on the consensus of all sources evaluated. These consensus-based TECs are commonly accepted as valuable thresholds for identifying sediments as either toxic or nontoxic, based on effects to benthic macroinvertebrates. Consensus-based TECs are available for all sediment COCs except manganese (As, Cd, Cr, Cu, Pb, Hg, Ni, and Zn).

For manganese, an alternative TRV source was identified. This source is National Oceanic and Atmospheric Administration (NOAA) SQuiRTS tables. These tables list a variety of toxicity and related benchmarks for various media. For manganese in sediment, the benchmark selected for use as a TRV in this ERA is the Lowest Assessment and Remediation of Contaminated Sediments (ARCS) Program Threshold Effects Level (TEL) for the sediment-dwelling amphipod *Hyalella azteca* (Buchman 1999).

3.2.3 Surface Soil/Spoils TRVs

Selected surface soil/spoils TRVs are also based on two sources. These two sources are considered equal in order of preference, differing only in the type of receptor forming the basis of the data. First is the Oak Ridge National Laboratory (ORNL) benchmark for phytotoxicity (Efroymson, Will, Suter II, and Wooten 1997). Second is the ORNL benchmark for soil invertebrate toxicity (primarily earthworm; Efroymson, Will, and Suter II 1997). For any given soil COC, both sources were consulted and the lowest of either the plant or earthworm benchmarks was selected as the soil TRV. This approach is based on the assumption that protection of both terrestrial plants and terrestrial soil-dwelling invertebrates is desirable. Plant benchmarks were selected as TRVs for As, Cd, Pb, Mn, Ni, Ag, and Zn. Earthworm benchmarks were selected as soil TRVs for Cr, Cu, and Hg. In both cases, the recommended benchmarks are based on the compilation and evaluation of multiple toxicity studies associated with a variety of taxa and test parameters (e.g., exposure duration, test conditions, endpoints). The final COC-specific benchmark recommended by ORNL also considered confidence in the test results.

In all cases, the EPC used to describe exposure concentrations are compared to the selected media-specific TRVs to produce quantitative risk estimates. This process is presented in the following section. Table 3-2 reveals the TRVs selected for comparison to EPCs and provides the sources of each TRV.

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Table 3-2 Ecological Toxicity Reference Values (TRVs)

Surface Water TRVs (µg/L)			
COC	**TRV**	**Receptor Group**	**Source**
copper (dissolved)	6	salmonid fish	1
lead (dissolved)	13	salmonid fish	1
zinc (dissolved)	99	salmonid fish	1

TRV Source:
1   USEPA chronic ambient water quality criterion (AWQC), hardness adjusted
Hardness slope and toxicity database are freshwater salmonid-specific
Avoca River water hardness assumed to average 10 mg/L CaCO$_3$
General equation from USEPA for chronic AWQC (2006) is:

$$AWQC_{chronic} = \exp\{mc[\ln(hardness)]+bc\}(CF)$$

mC and bC are model inputs from USEPA adjusted for salmonid fish only
CF is the total recoverable to dissolved conversion factor
ln hardness is the normal log of the site water hardness (assume = 10 mg/L)

CHRONIC AWQC - Salmonid Specific Adjustment						
SW COPC	**Diss. Chronic AWQC**	**mC**	**hardness**	**ln hardness**	**bC**	**CF**
Copper	6	0.5897	10	2.3	0.3979	0.960
Lead	13	1.2730	10	2.3	0.5004	1.127
Zinc	99	0.8806	10	2.3	2.5820	0.986

Hardness Adjustment Equations
[4] Dissolved Cu chronic = $0.960 \ast e^{0.5897[\ln(hardness)]+0.3979}$
[5] Dissolved Pb chronic = $(1.46203-[(\ln hardness)(0.145712)]) \ast e^{1.2730[\ln(hardness)]-0.5004}$
[8] Dissolved Zn chronic = $0.986 \ast e^{0.8806[\ln(hardness)]+2.5820}$

Sediment TRVs (mg/kg)			
COC	**TRV**	**Receptor Group**	**Source**
arsenic	9.79	benthic macroinvertebrates	1
cadmium	0.99	benthic macroinvertebrates	1
chromium	43.4	benthic macroinvertebrates	1
copper	31.6	benthic macroinvertebrates	1
lead	35.8	benthic macroinvertebrates	1
manganese	630	benthic macroinvertebrates	2
mercury	0.18	benthic macroinvertebrates	1
nickel	22.7	benthic macroinvertebrates	1
zinc	121	benthic macroinvertebrates	1

TRV Source:
1   Consensus based threshold effect concentration (MacDonald et al. 2000)
2   Lowest Assessment and Remediation of Contaminated Sediments (ARCS) Program Threshold Effects Level (

Surface Soil/Spoils TRVs (mg/kg)			
COC	**TRV**	**Receptor Group**	**Source**
arsenic	10.0	terrestrial plants	1
cadmium	4.0	terrestrial plants	1
chromium	0.4	earthworm	2
copper	50	earthworm	2
lead	50	terrestrial plants	1
manganese	500	terrestrial plants	1
mercury	0.1	earthworm	2
nickel	30	terrestrial plants	1
silver	2.0	terrestrial plants	1
zinc	50	terrestrial plants	1

Soil TRVs are lowest of relevant and available values for phytotoxicity and soil invertebrate toxicity

TRV Source:
1   ORNL phytotoxicity benchmark (Efroymson, Will, Suter II, and Wooten 1997)
2   ORNL soil invertebrate benchmark (Efroymson, Will, and Suter II 1997)

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Section 4
Risk Characterization

Risk characterization integrates information from the exposure and effects assessments to estimate risks to representative ecological receptors. Several approaches can be used to integrate exposure and effects data, with selected approaches often dependent on the availability of specific types of data. For example, the results of site-specific toxicity tests or surveys of certain components of aquatic or terrestrial ecological communities are useful types of information for assessing risk. Screening level survey data are available for certain receptor groups identified for this preliminary ERA. The results of these tests and surveys, provided in Section 4.2, are used to supplement the primary method of risk estimation—the HQ approach, described below.

4.1 Hazard Quotients

Risks based on direct exposure (direct contact and ingestion) to COC-contaminated media are assessed using HQ approach. This method of assessing risks is based on the ratio of an exposure concentration to an effects concentration. The general equation follows:

$$HQ = \frac{Exposure\ Concentration\ of\ COC}{Effects\ Concentration\ of\ COC}$$

More specifically, the HQ calculations for this preliminary ERA are based on the following:

$$HQ = \frac{EPC}{TRV}$$

Where: EPC = exposure point concentration (e.g., 95% UCL or max)
TRV = toxicity reference value

For example, the EPC for a given COC in sediment is compared to a sediment TRV for that COC. In most cases, the selected TRV represents a COC concentration associated with low but significant likelihood of adverse effects. The TRV is most appropriately a threshold concentration at which adverse effects begin to be observed but, depending on available data, may be a higher concentration at which adverse effects are usually or always observed in more sensitive life stages or taxa.

HQs greater than 1.0 (i.e., where the exposure concentration exceeds the effects concentration) indicate significant potential for adverse effects. HQs less than 1.0 are considered insignificant and adverse effects are unexpected. Higher HQs are not necessarily indicative of more severe effects, but instead, where confidence in TRVs is equal, suggest a greater likelihood of adverse effects.

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More specifically, the HQ calculations for this preliminary ERA are based on the following:

$$HQ = \frac{EPC}{TRV}$$

Where: EPC = exposure point concentration (e.g., 95% UCL or max)
TRV = toxicity reference value

For example, the EPC for a given COC in sediment is compared to a sediment TRV for that COC. In most cases, the selected TRV represents a COC concentration associated with low but significant likelihood of adverse effects. The TRV is most appropriately a threshold concentration at which adverse effects begin to be observed but, depending on available data, may be a higher concentration at which adverse effects are usually or always observed in more sensitive life stages or taxa.

HQs greater than 1.0 (i.e., where the exposure concentration exceeds the effects concentration) indicate significant potential for adverse effects. HQs less than 1.0 are considered insignificant and adverse effects are unexpected. Higher HQs are not necessarily indicative of more severe effects, but instead, where confidence in TRVs is equal, suggest a greater likelihood of adverse effects.

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4-1

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Table 4-1 presents the HQs calculated for media-specific COCs, by location. As can be seen on this table, data for surface water HQs are based on mean and maximum COC concentrations measured in Avoca River water collected from 2001, 2002, and 2003 from either the Avoca Bridge or from a location downstream of the former fertilizer plant. HQs for sediment are based on four sediment samples collected from Avoca River sediments in 2007 (n = 1 at each location). HQs for surface soil/spoils are based on COC concentrations measured in surface media collected from seven locations throughout the study area (95% UCLs or maximums). Together, these data are sufficient for preliminary risk evaluation and are used to guide more extensive Phase 2 sampling and analyses.

4.1.1 Surface Water HQs

All three surface water COCs identified (Cu, Pb, and Zn) are associated with elevated risks (HQs >1). The HQ based on the mean dissolved copper concentration is 3.3, while the HQ based on the maximum dissolved copper concentration is 6.0. The HQ based on the maximum concentration of dissolved lead in surface water also exceeds the 1.0 threshold (HQ = 2.2). The mean HQ for lead remains below 1.0. Finally, both mean (2.3) and maximum (6.1) HQs for dissolved zinc exceed the 1.0 threshold. Data limitations preclude making conclusions regarding the toxicity of Avoca River water at specific locations, but these data indicate that dissolved copper, lead, and zinc in the Avoca River water warrants concern.

4.1.2 Sediment HQs

HQs for sediment are based on single values for each of the four locations sampled. These values are used to represent exposure point concentrations but may not accurately reflect true maximums or upper range average exposure concentrations. Sediment HQs are presented below by location.

EA-2 (just downstream of White's Bridge)

HQs range from 1.1 (As and Ni) to 25 (Hg). Intermediate HQs are 1.3 (Zn), 1.6 (Cr), 2.4 (Cu), 2.9 (Pb), and 3.9 (Mn). Cadmium was not detected above the detection limit of 5.0 mg/kg, so no HQ could be derived.

EA-3 (downstream of White's Bridge but upstream of deep adit discharge)

HQs range from below 1.0 (As, Ni, and Zn) to 5.5 (Mn). Intermediate HQs are 1.5 (Cu) and 1.8 (Pb). Cadmium, chromium, and mercury were not detected above the detection limits, so HQs could not be derived.

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Table 4-1 Ecological Hazard Quotients (HQs)

Surface Water HQs		Avoca River			
COC	TRV	Mean EPC	Mean HQ	Max EPC	Max HQ
Copper	6	20	**3.3**	36	**6.0**
Lead	13	7	0.54	28	**2.2**
Zinc	99	228	**2.3**	601	**6.1**

all units are µg/L
HQs > 1 shown in **bold** type

Sediment HQs		EA-2		EA-3		EA-8		EA-10	
COC	TRV	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
Arsenic	9.79	10.7	**1.1**	4.6	0.47	ND	NA	ND	NA
Cadmium	0.99	ND	NA	ND	NA	ND	NA	ND	NA
Chromium	43.4	71.3	**1.6**	ND	NA	52.8	**1.2**	48.7	**1.1**
Copper	31.6	77.1	**2.4**	46.7	**1.5**	72.9	**2.3**	67.8	**2.1**
Lead	35.8	103.1	**2.9**	65.3	**1.8**	55.4	**1.5**	73.0	**2.0**
Manganese	630	2,428	**3.9**	3,480	**5.5**	2,678	**4.3**	1,535	**2.4**
Mercury	0.18	4.5	**25.0**	ND	NA	ND	NA	ND	NA
Nickel	22.7	25.5	**1.1**	17.7	0.78	21.7	0.96	18.5	0.81
Zinc	121	154	**1.3**	110	0.91	158	**1.3**	151.5	**1.3**

all units are mg/kg
ND - not detected (below detection limit)
NA - not applicable
HQs > 1 shown in **bold** type

EA-2 = DS White's Bridge
EA-3 = DS WB, US Deep Adit
EA-8 = DS Tailings, US Fert. Plant
EA-10 = DS Fert. Plant

Surface Soil/Spoils HQs		EA-1		EA-2		EA-3		EA-4		EA-5		EA-6		EA-7	
COC	TRV	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
Arsenic	10.0	805	**80.5**	792	**79.2**	1,386	**139**	549	**54.9**	1,482	**148**	629	**62.9**	497	**49.7**
Cadmium	4.0	ND	NA	ND	NA	ND	NA	10.1	**2.5**	ND	NA	ND	NA	ND	NA
Chromium	0.4	285	**713**	139	**348**	327	**818**	173	**433**	94.6	**237**	167	**418**	165	**413**
Copper	50	306	**6.1**	387	**7.7**	1,796	**35.9**	955	**19.1**	1,562	**31.2**	5,480	**110**	7,253	**145**
Lead	50	726	**14.5**	962	**19.2**	18,676	**374**	3,225	**64.5**	24,314	NA	5,008	**100**	4,962	NA
Manganese	500	671	**1.3**	1,082	**2.2**	654	**1.3**	624	**1.2**	ND	NA	1,218	**2.4**	573	**1.1**
Mercury	0.1	15.9	**159**	5	**46**	25	**247**	12.3	**123**	ND	NA	18.5	**185**	ND	NA
Nickel	30	188	**6.3**	225	**7.5**	97.8	**3.3**	243	**8.1**	166	**5.5**	142	**4.7**	ND	NA
Silver	2.0	10.6	**5.3**	1.7	0.85	66.7	**33.4**	28.7	**14.4**	38.4	**19.2**	ND	NA	ND	NA
Zinc	50	41.3	0.8	25	0.50	1,064	**21.3**	350	**7.0**	584	**11.7**	174	**3.5**	827	**16.5**

all units are mg/kg
ND - not detected (below detection limit)
NA - not applicable
HQs > 1 shown in **bold** type

EA-1 = West Avoca
EA-2 = Shelton Tailings
EA-3 = Connary
EA-4 = Mount Platt

EA-5 = East Avoca
EA-6 = Tigroney West
EA-7 = Ore bins at Tigroney West

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EA-8 (downstream of Shelton tailings but upstream of former fertilizer plant)

HQs range from below 1.0 (Ni) to 4.3 (Mn). Intermediate HQs are 1.2 (Cr), 1.3 (Zn), 1.5 (Pb), and 2.3 (Cu). Arsenic, cadmium, and mercury were not detected above the detection limits, so HQs could not be derived.

EA-10 (downstream of former fertilizer plant)

HQs range from below 1.0 (Ni) to 2.4 (Mn). Intermediate HQs are 1.1 (Cr), 1.3 (Zn), 2.0 (Pb), and 2.1 (Cu). Arsenic, cadmium, and mercury were not detected above the detection limits, so HQs could not be derived.

Based on a limited number of samples, the primary contaminants of concern in Avoca River sediments are copper, lead, manganese and, possibly, mercury. Lower detection limits will be required to more fully and accurately depict the risks associated with mercury in sediments. The TRV for manganese is associated with greater uncertainty than the TRVs for copper, lead, and mercury.

4.1.3 Surface Soil/Spoils HQs

Surface soil/spoils HQs are derived for each of the seven locations depicted on Table 4-1 and summarized below.

EA-1 (West Avoca)

HQs range from less than 1.0 (Zn) to 713 (Cr). HQs for other COCs, in decreasing order, are 159 (Hg), 80.5 (As), 14.5 (Pb), 6.3 (Ni), 6.1 (Cu), 5.3 (Ag), and 1.3 (Mn). Cadmium was not detected below the detection limit.

EA-2 (Shelton Tailings)

HQs range from less than 1.0 (Ag and Zn) to 348 (Cr). HQs for other COCs, in decreasing order, are 79.2 (As), 46 (Hg), 19.2 (Pb), 7.7 (Cu), 7.5 (Ni), and 2.2 (Mn). Cadmium was not detected below the detection limit.

EA-3 (Connary)

HQs range from 1.3 (Mn) to 818 (Cr). HQs for other COCs, in decreasing order, are 374 (Pb), 247 (Hg), 139 (As), 35.9 (Cu), 33.4 (Ag), 21.3 (Zn), and 3.3 (Ni). Cadmium was not detected below the detection limit. In general, this location had the highest surface soil/mine waste HQs of those calculated.

EA-4 (Mt. Platt)

HQs range from 1.2 (Mn) to 433 (Cr). HQs for other COCs, in decreasing order, are 123 (Hg), 64.5 (Pb), 54.9 (As), 19.1 (Cu), 14.4 (Ag), 8.1 (Ni), 7.0 (Zn), and 2.5 (Cd).

EA-5 (East Avoca)

HQs range from 5.5 (Ni) to 237 (Cr). HQs for other COCs, in decreasing order, are 148 (As), 31.2 (Cu), 19.2 (Ag), and 11.7 (Zn). Cadmium, manganese, and mercury were not detected below the detection limit.

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EA-6 (Tigroney West)

HQs range from 2.4 (Mn) to 418 (Cr). HQs for other COCs, in decreasing order, are 185 (Hg), 110 (Cu), 100 (Pb), 62.9 (As), 4.7 (Ni), and 3.5 (Zn). Cadmium and silver were not detected below the detection limit.

EA-7 (Ore bins at Tigroney West)

HQs range from 1.1 (Mn) to 413 (Cr). HQs for other COCs, in decreasing order, are 145 (Cu), 49.7 (As), and 16.5 (Zn). Cadmium, mercury, nickel, and silver were not detected below the detection limit.

Based on data collected in 2007, the primary contaminants of concern for mine spoils and related terrestrial media (e.g., tailings, contaminated soils) in the Avoca River watershed are arsenic, chromium, copper, lead, mercury, nickel, silver, and zinc. Risk estimates for some of these COCs are more uncertain or likely overestimated based on either limited data or on extremely conservative TRVs. This is most applicable to chromium and mercury. Also, cadmium, which is highly toxic, may be found to be of greater concern using lower detection limits, as anticipated in Phase 2 sampling and analyses. Lower detection limits will be required to more fully and accurately depict the risks associated with cadmium and in some cases other soil COCs. Finally, the Phase 2 task where mine waste COC concentrations are compared to COC concentrations in soils from selected reference locations will help interpret the risks associated with mine waste contamination. It is likely that, given the very low TRVs for some COCs (e.g., chromium), risk estimates will also be somewhat elevated for reference locations. Comparisons to reference data will therefore be an important component of Phase 2 assessments.

4.2 Supporting Information

Additional information on potential or actual impacts due to mining related sources is provided by biological surveys. For Phase 1 of this assessment, this additional information is limited to screening level benthic macroinvertebrate community metrics, based on the April 2007 site visit and screening level survey. This information is summarized below.

4.2.1 Benthic Macroinvertebrate Survey Data

During April 3-5, 2007, a screening level benthic macroinvertebrate survey was conducted within the Avoca River watershed. The method employed for this survey was timed (30 second) kick net sampling using a 500 um D-frame kick net. The preferred habitat for this sampling was riffle, followed by shallow run where riffles were not present. Three replicates (center channel, near left bank, near right bank) were collected, and data were evaluated both independently and pooled. Metrics included the following:

- Total number of organisms
- Total number of mayflies (Ephemeroptera)
- Total number of caddisflies (Trichoptera)

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- Total number of worms (oligochaetes)
- Total number of beetles (Coleoptera)
- Total number of dipterans (flies and midges)
- Total number of leeches
- Total number of ostracods
- Total number of snails (gastropods)

Most useful among these metrics are the first four, based on the assumption that greater numbers of organisms, mayflies, and caddisflies are generally a positive finding and greater numbers of worms (as well as dipterans, snails, etc.) signify a negative finding (indicative of some form of stress). These assumptions are not without uncertainty, given the fact that some mayfly and caddisfly taxa are known to be tolerant of various forms of pollution, including metals contamination and nutrient enrichment. However, the underlying general assumptions are sufficiently valid for a screening level assessment based on rapid field identification to the order level (e.g., Ephemeroptera, Trichoptera, Diptera, etc.).

Tables 4-2 through 4-5 present the raw data (numbers of each type of organisms) for each replicate, the total number of organisms based on combined replicates (Table 4-2), total number of mayflies based on combined replicates (Table 4-3), total number of caddisflies based on combined replicates (Table 4-4), and total number of worms based on combined replicates (Table 4-5). These four metrics and/or groups of organisms (total number of organisms, mayflies, caddisflies, and worms) represent the most useful metrics and most abundant types of benthic macroinvertebrates collected during the April 2007 surveys. Data for other taxa collected are also included on Tables 4-2 through 4-5, including aquatic beetles, dipterans, leeches, ostracods, and snails.

Each of these data tables are also associated with a graph (Figures 4-1 through 4-4) showing the combined (all replicates) totals for the key metric associated with each table, on an upstream to downstream (left to right) format. On each of these graphs, the leftmost station (downstream of Meeting of the Waters) and the Aughrim River station can be considered reference or at least minimally impacted stations. The other stations, from downstream of White's Bridge to downstream of the former fertilizer plant, are considered impacted or potentially impacted stations (primarily by mining-related contaminants).

4.2.1.1 Total Organisms (Table 4-2 and Figure 4-1)

Both reference stations are associated with a similar total number of organisms (140, 142). These substantially exceed the totals for all other impact stations upstream of the confluence with the Aughrim River (maximum 35 downstream of the Deep Adit). Totals increase beyond the reference values at two of the three stations below the Aughrim River. The reason for this increase is likely to include dilution of the Avoca River with comparatively clean water from the Aughrim. However, the lower two stations show increases in the types of taxa most commonly associated with nutrient enrichment (e.g., baetid mayflies, hydropsychid caddisflies, and worms). It appears

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that the former fertilizer plant or some other unidentified sources (e.g., septic systems, agricultural inputs) may be contributing excessive amounts of nitrogen or phosphorus to the lower Avoca River.

4.2.1.2 Total Mayflies (Table 4-3 and Figure 4-2)

The distribution of mayfly abundance is similar to that of total number of organisms, with both reference stations having high values (87 for both) compared to stations upstream of the Aughrim River. Totals remain well below the reference values until the most downstream location, where the total is more than twice that of the reference stations. Again, the high value shown for the station downstream of the former fertilizer plant may be due to nutrient enrichment. At this station, the mayfly population was dominated by baetid forms, which can be tolerant of nutrient enrichment.

4.2.1.3 Total Caddisflies (Table 4-4 and Figure 4-3)

The relative abundance of caddisflies is also shown to be similar to that of total number of organisms. The most upstream Avoca River reference station had 39 organisms while the Aughrim River station only had 12. None of the upper Avoca stations exceeded 9 caddisflies. Below the Avoca/Aughrim confluence, the number of caddisflies varied from 8 to 32. Again, the higher number (32) is associated with the station downstream of the former fertilizer plant. At this station, the dominant type of caddisflies was hydropsychid forms, which are known to be relatively tolerant of nutrient enrichment.

4.2.1.4 Total Worms (Table 4-5 and Figure 4-4)

Excessive numbers of worms often indicate nutrient enrichment. Surface waters without metals contamination are unlikely to support high numbers of worms unless the nutrient levels are sufficiently high. This assumption seems to be confirmed by the findings shown on this graph. Worm numbers are low at the upstream reference station (below Meeting of the Waters) as well as most upper Avoca stations with mining related contamination. Worm numbers increase in the Aughrim River sample and continue to increase more or less in a downstream fashion. Maximum numbers were observed at the station downstream of the Shelton Tailings. Note that the numbers of worms shown on the graph and in the associated table are not actual numbers counted but surrogate values. This is based on the approach where the numbers of worms were too numerous to count (TNTC) and the value "100" was used to represent TNTC findings. This applies only to the two most downgradient stations where worms were TNTC. These findings suggest nutrient enrichment below the Aughrim River confluence, with the greatest number of worms found at the two most downstream stations. Nutrient enrichment was not determined chemically at this time, and the apparent source has not yet been confirmed. Curiously, large numbers of midge larvae and other dipterans often indicative of nutrient enrichment were not observed at any location during the April 2007 surveys.

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Table 4-2 Avoca River Screening Level BMI Survey (April 3-5, 2007)

Location	Total No. Organisms	No. Mayflies			No. Caddisflies			No. Worms			No. Beetles		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters	140	12	33	42	12	7	20	6	2	5			
DS White's Bridge	29	3	10	3	2	7						1	1
DS Deep Adit	35	3	6	13	4	2	2	1					1
DS Road Adit	15	5		1	1		1		5	1			
DS Avoca Bridge	27	5	2	2		2	2		1	13			
Avoca R. US Aughrim R	4				2	1							1
Aughrim R.	142	42	29	16	4	6	2	8	16	18	1		
US Tailings	113	9	3	9	11	7	4		8	41	15	4	
DS Tailings	317	1	2	1	1	3	4	**100**	**100**	**100**		3	1
DS Fert. Plant	348	44	94	55	6	4	22	10	**100**	7	1		1

Location		No. Dipterans			No. Leeches			No. Ostracods			No. Snails		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters					1								
DS White's Bridge			1						1				
DS Deep Adit				1			1		1				
DS Road Adit		1											
DS Avoca Bridge													
Avoca R. US Aughrim R													
Aughrim R.													
US Tailings			1									1	
DS Tailings					1								
DS Fert. Plant				1	1	1	1						

Numbers shown in **bold** = surrogate for Too Numerous To Count (TNTC)   DS = Downstream   US = Upstream

Figure 4-1 Total Number Organisms

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Table 4-3 Avoca River Screening Level BMI Survey (April 3-5, 2007)

Location	Total No. Mayflies	No. Mayflies			No. Caddisflies			No. Worms			No. Beetles		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters	87	12	33	42	12	7	20	6	2	5			
DS White's Bridge	16	3	10	3	2	7						1	1
DS Deep Adit	22	3	6	13	4	2	2	1					1
DS Road Adit	6	5		1	1		1		5	1			
DS Avoca Bridge	9	5	2	2		2	2		1	13			
Avoca R. US Aughrim R	0				2	1							1
Aughrim R.	87	42	29	16	4	6	2	8	16	18	1		
US Tailings	21	9	3	9	11	7	4		8	41	15	4	
DS Tailings	4	1	2	1	1	3	4	**100**	**100**	**100**		3	1
DS Fert. Plant	193	44	94	55	6	4	22	10	**100**	7	1		1

Location		No. Dipterans			No. Leeches			No. Ostracods			No. Snails		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters					1								
DS White's Bridge			1						1				
DS Deep Adit				1			1		1				
DS Road Adit		1											
DS Avoca Bridge													
Avoca R. US Aughrim R													
Aughrim R.													
US Tailings			1									1	
DS Tailings					1								
DS Fert. Plant				1	1	1	1						

Numbers shown in **bold** = surrogate for Too Numerous To Count (TNTC)   DS = Downstream   US = Upstream

Figure 4-2 Total Number Mayflies

Table 4-4 Avoca River Screening Level BMI Survey (April 3-5, 2007)

Location	Total No. Caddisflies	No. Mayflies			No. Caddisflies			No. Worms			No. Beetles		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters	39	12	33	42	12	7	20	6	2	5			
DS Whitesbridge	9	3	10	3	2	7						1	1
DS Deep Adit	8	3	6	13	4	2	2	1					1
DS Road Adit	2	5		1	1		1		5	1			
DS Avoca Bridge	4	5	2	2		2	2		1	13			
Avoca R. US Aughrim R	3				2	1							1
Aughrim R.	12	42	29	16	4	6	2	8	16	18	1		
US Tailings	22	9	3	9	11	7	4		8	41	15	4	
DS Tailings	8	1	2	1	1	3	4	**100**	**100**	**100**		3	1
DS Fert. Plant	32	44	94	55	6	4	22	10	**100**	7	1		1

Location		No. Dipterans			No. Leeches			No. Ostracods			No. Snails		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters					1								
DS Whitesbridge			1						1				
DS Deep Adit				1			1	1					
DS Road Adit		1											
DS Avoca Bridge													
Avoca R. US Aughrim R													
Aughrim R.													
US Tailings			1									1	
DS Tailings					1								
DS Fert. Plant				1	1	1	1						

Numbers shown in **bold** = surrogate for Too Numerous To Count (TNTC)   DS = Downstream   US = Upstream

Figure 4-3 Total Number Caddisflies

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Table 4-5 Avoca River Screening Level BMI Survey (April 3-5, 2007)

Location	Total No. Worms	No. Mayflies			No. Caddisflies			No. Worms			No. Beetles		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters	13	12	33	42	12	7	20	6	2	5			
DS Whitesbridge	0	3	10	3	2	7						1	1
DS Deep Adit	1	3	6	13	4	2	2	1					1
DS Road Adit	6	5		1	1		1		5	1			
DS Avoca Bridge	14	5	2	2		2	2		1	13			
Avoca R. US Aughrim R	0				2	1							1
Aughrim R.	42	42	29	16	4	6	2	8	16	18	1		
US Tailings	49	9	3	9	11	7	4		8	41	15	4	
DS Tailings	300	1	2	1	1	3	4	**100**	**100**	**100**		3	1
DS Fert. Plant	117	44	94	55	6	4	22	10	**100**	7	1		1

Location		No. Dipterans			No. Leeches			No. Ostracods			No. Snails		
		Left	Center	Right	Left	Center	Right	Left	Center	Right	Left	Center	Right
DS Meet. Waters					1								
DS Whitesbridge			1						1				
DS Deep Adit				1			1		1				
DS Road Adit		1											
DS Avoca Bridge													
Avoca R. US Aughrim R													
Aughrim R.													
US Tailings			1									1	
DS Tailings					1								
DS Fert. Plant				1	1	1	1						

Numbers shown in **bold** = surrogate for Too Numerous To Count (TNTC)   DS = Downstream   US = Upstream

Figure 4-4 Total Number Worms

Finally, it is important to note that for all benthic invertebrate results shown on Tables 4-2 through 4-5, significant differences in number of organisms can be seen between replicates, i.e., the three locations at each sampling station). In some cases this seems to reflect different land uses on each bank. For example, at some stations there is agricultural use along one bank and residential along the opposite bank. It is likely that land use is associated with potential inputs to the river, such as fertilizers, pesticides, herbicides, septic inputs, etc. In contrast, in most cases where land use is similar along both banks, the benthic macroinvertebrate communities appear similar. These observations indicate the importance of viewing replicate data independently as well as combined.

4.2.2 Risk Summary

The risk questions introduced in Section 2.3 are repeated here and answered to provide a summary of the ecological risks identified in this first phase of the ERA.

Are the levels of contaminants in soils/spoils from the soil/spoils exposure areas greater than the soil/spoils TRVs for the survival and growth of terrestrial plants?

> **YES** – based on exceedance of phytotoxicity TRVs for one or more metals at surface soil/spoils EAs 1-7. Note that phytotoxicity TRVs are lower than soil/spoils invertebrate TRVs for As, Cd, Pb, Mn, Ni, Ag, and Zn. Soil invertebrate TRVs are lower than phytotoxicity TRVs for Cr, Cu, and Hg.

Are the levels of contaminants in soils/spoils from the soil/spoils exposure areas greater than the soil/spoils TRVs for the survival and growth of terrestrial invertebrates?

> **YES** – based on exceedance of soil/spoils invertebrate TRVs for one or more metals at surface soil/spoils EAs 1-7. Note that phytotoxicity TRVs are lower than soil/spoils invertebrate TRVs for As, Cd, Pb, Mn, Ni, Ag, and Zn. Soil/spoils invertebrate TRVs are lower than phytotoxicity TRVs for Cr, Cu, and Hg.

Are the levels of contaminants in soils/spoils from the soil/spoils exposure areas sufficiently elevated to contribute to adverse effects in consumers of terrestrial invertebrates, birds, and/or small mammals?

> **UNKNOWN** – this exposure route will be further assessed in Phase 2 of the assessment. It is likely that cadmium and mercury, and possibly other bioaccumulative COCs, are present at concentrations that can adversely affect upper trophic level consumers under certain exposure conditions (i.e., sufficient frequency and duration of exposure, specific dietary assumptions, etc.). These consumers may include omnivorous and herbivorous mammals, including livestock, as well as carnivorous and piscivorous birds and mammals. The representative receptors and the decisions regarding the need to perform food web modeling will be determined following analyses of Phase 2 media quality data.

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Are the levels of contaminants in whole sediments from the Avoca River exposure areas greater than the sediment TRVs for the survival, growth, or reproduction of benthic invertebrates?

> **YES** – COC concentrations in sediments exceed threshold TRVs for adverse effects in benthic invertebrates at all four of the locations sampled in the Phase 1 sampling. For the most part, however, the level of exceedance is fairly low (most HQs are less than 5).

Is the structure of benthic macroinvertebrate communities in Avoca River sediments significantly different than that from reference locations?

> **YES** – screening level benthic invertebrate community surveys (April 2007) indicate that the communities in the upper Avoca River below the mining-impacted areas are impaired relative to the reference stations (probably due to mining related contaminants). In addition, it appears that lower Avoca River benthic communities are also impaired relative to the reference stations, but more likely due to a different suite of stressors (assumed to include both mining-related metals and excessive levels of one or more nutrients).

Are the concentrations of contaminants in water from the Avoca River greater than the surface water TRVs for the survival, growth, and reproduction of fish?

> **YES** – based on exceedance of hardness-adjusted salmonid-specific chronic TRVs intended to protect the survival, growth, and reproduction of salmonid fish. These findings are based on recent (2001-2003) water quality data from only two locations in the Avoca River, and Phase 2 of the assessment will expand the surface water data set used to evaluate these exposures.

Are the concentrations of contaminants in water from the Avoca River sufficiently elevated to contribute to adverse effects in upper trophic level (ecological) consumers of fish and adult life stages of aquatic invertebrates?

> **UNKNOWN** – this exposure route will be further assessed in Phase 2 of the assessment. It is likely that cadmium and mercury, and possibly other bioaccumulative COCs, are present at concentrations that can adversely affect upper trophic level piscivorous consumers (e.g., kingfishers) under certain exposure conditions (i.e., sufficient frequency and duration of exposure, specific dietary assumptions, etc.). At present, it is likely that the fish communities in the Avoca River are sufficiently impaired (low total numbers) to preclude significant foraging by most piscivorous predators.

4.2.3 Preliminary Remediation Goals

The derivation of quantitative remedial goals, commonly termed Preliminary Remedial Goals or PRGs, can be useful to help determine which areas warrant remediation. Medium-specific and COC-specific PRGs can be derived for a variety of receptors or receptor groups using a variety of information sources. These can include regulatory limits or criteria (e.g., Ireland's Dangerous Substances Regulations for surface water toxics) and literature-based or site-specific toxicity-based data. Initial PRGs can also be derived from the results of this preliminary ERA. Site-specific COC concentration data, as well as literature-based toxicity data, can be used to establish PRGs protective of lower trophic level receptors primarily exposed via direct contact with COC-contaminated surface water, sediment, and surface soil. The medium-specific TRVs selected for use in this preliminary ERA are not intended to supplant regulatory limits but can serve as initial PRGs for assessing potential for impacts and the need for remediation of surface water, sediment, and soil. Finally, the use of TRVs as initial PRGs would need to consider reference area data. The PRGs presented here therefore are subject to revision based on reference or background conditions. This evaluation will be an important component of the Phase 2 assessment.

The use of TRVs as initial PRGs is most appropriate for TRVs that meet the following criteria:

- TRV should be relevant to receptors or receptor groups of concern to this site

- TRV should represent threshold COC concentrations at levels where adverse effects in survival, growth, or reproduction begin to be observed

- TRV should be applicable to protection of populations and communities

- TRVs should be based on COC concentrations in abiotic media of concern that are easily measurable and not on biological data such as tissue concentrations

Most of the medium-specific TRVs selected for use in this preliminary ERA meet those criteria. Those that do not include some TRVs for COCs that are not well-studied. In those selected cases, the TRV may not be based on toxicological information but instead may be more general (e.g., a regulatory target value for protecting multiple soil uses).

Table 4-6 shows the PRGs that are initially selected for surface water, sediment, and surface soil based on protection of specific receptor groups and on direct contact exposures. These PRGs do not consider bioaccumulation and food web effects. Those issues are discussed below.

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Table 4-6 Initial Ecological PRGs

Surface Water PRGs (μg/L, trout)		
COC	**PRG**	**Description / Comment**
Copper, dissolved	6	survival, growth, reproduction (salmonid fish)
Lead, dissolved	13	survival, growth, reproduction (salmonid fish)
Zinc, dissolved	99	survival, growth, reproduction (salmonid fish)
Sediment PRGs (mg/kg, benthic macroinvertebrates)		
Arsenic	9.79	CB TEC
Cadmium	0.99	CB TEC
Chromium	43.4	CB TEC
Copper	31.6	CB TEC
Lead	35.8	CB TEC
Manganese	630	Lowest ARCS TEL
Mercury	0.18	CB TEC
Nickel	22.7	CB TEC
Zinc	121	CB TEC
Surface Soil PRGs (mg/kg, plants and soil invertebrates)		
Arsenic	10	plant (ORNL benchmark)
Cadmium	4	plant (ORNL benchmark)
Chromium	0.4	earthworm (ORNL benchmark)
Copper	50	earthworm (ORNL benchmark)
Lead	50	plant (ORNL benchmark)
Manganese	500	plant (NOEC)
Mercury	0.1	earthworm (ORNL benchmark)
Nickel	30	plant (ORNL benchmark)
Silver	2	plant (ORNL benchmark)
Zinc	50	plant (ORNL benchmark)

See Table 3-2 for specific TRV reference

The food web models expected to be considered for use in the Phase 2 ERA can also be used to produce a NOAEL-to-LOAEL range of COC- and medium-specific PRGs that consider bioaccumulation, biomagnification, and adverse effects to upper trophic level birds and mammals, including livestock or taxa representative of livestock. These PRGs would be based on soil and sediment COC concentrations, and cannot be used to make decisions regarding surface water quality. As such, they are applicable only to selected upper trophic level receptors such as birds or mammals with life histories similar to those selected as model receptors. These model-based PRGs will be discussed in the Phase 2 ERA as appropriate.

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Section 5
Data Gaps

The results of the Phase 1 of the preliminary ERA confirm most assumptions regarding mining-related impacts to ecological receptors within the Avoca River watershed. Some data gaps are identified, however, that will be filled as a result of Phase 2 sampling and analyses. These include the following.

- Detection Limits – lower detection limits are needed for sediment and in some cases for soil/spoils samples

- Surface Water Samples – surface water samples are needed from multiple locations in the Avoca River, especially upstream and downstream of major features (e.g., tributaries) and potential source areas (e.g., mining waste inputs, tailings facilities, former fertilizer plant, landfills, residential communities). These samples should include dissolved metals, water hardness, nutrient levels (relevant forms of nitrogen and phosphorus), and total organic carbon.

- Sediment Samples – sediment samples are needed from multiple locations in the Avoca River, especially upstream and downstream of major features (e.g., tributaries) and potential source areas (e.g., mining waste inputs, tailings facilities, former fertilizer plant, landfills, residential communities). These samples should focus on total metals concentrations in finer grained materials.

- Reference Area Data – additional sampling of surface water, sediment, and soil/spoils from upgradient/non-impacted areas suitable for use as reference locations is required to better characterize background.

- Physical Barriers – any physical barriers or areas of poor quality habitat that could affect fish migration need to be identified.

- Potential sources of nutrient inputs to the Avoca River should be identified, in part by using water quality data collected from multiple locations within the river.

- Potential impacts to livestock – sheep are known to graze on areas associated with elevated levels of metals, such as at Connary. The potential impacts to livestock should be assessed by measuring concentrations of bioaccumulative metals in co-located soil and above-ground (unwashed) plant samples.

- Potential impacts to upper trophic level predators – potential impacts to upper trophic level birds and mammals (e.g., piscivorous and carnivorous receptors) should be assessed by evaluating concentrations of bioaccumulative metals in prey/food items. This can be done via modeling and use of literature-based bioaccumulation factors, supplemented by some site-specific data collection (see previous bullet).

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Section 6
Introduction

The Phase 2 ERA builds upon the Phase 1 data, assumptions, and results primarily by incorporating additional site-specific, abiotic media quality data into the analyses. These additional data collected during the Phase 2 site investigations include chemical data for surface water (rivers, tributaries, adits, springs, seeps), sediment, soil (primarily soils from agricultural fields), and mine spoils (e.g., waste rock, tailings, etc.), and supplement the more limited Phase 1 dataset. Phase 2 abiotic media quality data are discussed below in Section 7. In addition, surface water and sediment data from GSI sampling conducted in 2006 and 2007 are evaluated and quantitative risk estimates based on these data are also included.

For the most part, the Phase 2 ERA relies on the same or generally similar effects data to characterize risks as used in Phase 1. In some cases, especially where new COCs are identified in Phase 2, the effects data presented in the Phase 1 ERA are supplemented by additional effects data. These data are summarized in Section 8 below.

The Phase 2 Risk Characterization (Section 9) presents and discusses the Phase 2 risk estimates in the form of hazard quotients (HQs, Section 9.1). Section 9.2 briefly summarizes the quantitative risk estimates presented in the Phase 1 ERA and summarizes the results of the Phase 2 ERA based on the Phase 2 sampling. Additional supporting information for the Phase 2 ERA includes the results of surveys for physical barriers and more intensive investigations into land use and habitat descriptions. Phase 2 of the ERA did not include any additional biological sampling, so the initial supporting information based on benthic macroinvertebrate sampling remains valid for the ERA.

The preliminary remediation goals (i.e., PRGs or "cleanup levels") presented in the Phase 1 ERA are reviewed and refined based on Phase 2 TRVs and risk estimates. These final PRGs, presented in Section 9.3, are intended to provide risk managers with chemical concentrations in abiotic media that are adequately (but not overly) protective of ecological resources.

Section 9.4 summarizes the results of Phase 2 surveys and data compilations conducted to (1) more fully characterize land use and describe habitats within the study area, (2) identify potential barriers to fish migration, and (3) describe the potential for bats to be exposed to mining-related stressors. Section 9.5 presents a discussion of uncertainties within the various components of the ERA.

Section 7
Exposure Assessment

The Phase 2 Exposure Assessment is based on the same methods and assumptions as presented in the Phase I Exposure Assessment. Phase 2 data are evaluated independent of Phase 1 data because of temporal and spatial variability. For these reasons, the Phase 2 data are considered alone and associated risk estimates therefore are not based on any of the sampling supporting the Phase 1 ERA. The recently collected Phase 2 abiotic media quality data are discussed below.

The data on which the Phase 2 ERA is based resulted in additional COCs compared to those identified in Phase 1. The final COCs identified in the Phase 1 ERA include the following:

■ Surface Water COCs – copper, lead, and zinc (all dissolved)

■ Sediment COCs – arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc

■ Surface Soil/Spoils COCs – arsenic, cadmium, chromium, copper, lead, manganese, mercury, silver, and zinc

The Phase 2 ERA also evaluates these preliminarily identified COCs, but also screens all recently detected and potentially hazardous chemicals for inclusion in Phase 2 ERA. This process is based on comparing the overall (combined exposure areas or EAs) maximum detected concentrations of all recently detected and potentially hazardous chemicals (including both CDM and GSI data for surface water and sediment) against conservative ecological screening levels (ESLs). This process is performed for each media type, and the results are shown on Tables 7-1a (river and tributary surface water) and 7-1b (adits, springs, and miscellaneous surface water), 7-2 (sediment), and 7-3a (surface soil) and 7-3b (mine spoils). The final media-specific COCs are presented in Sections 7.1.3 (surface water), 7.2.3 (sediment), and 7.3.3 (soil and spoils).

Exposure areas (EAs) are defined as discreet locations where ecological receptors may be exposed to a specific set of conditions or chemical stressors. Designations of individual media-specific EAs are based primarily on available media quality data, presence of or relationship to known or suspected contaminant source areas, and unique features that can affect exposure (e.g., major tributaries, industrial sites, etc.). Each designated EA is considered to be sufficiently different from other EAs of the same media type to warrant independent evaluation. Media-specific EAs are described below.

7.1 Surface Water Data

Surface water data includes two major categories: 1) rivers and tributaries and (2) adits, springs, and miscellaneous surface waters. EAs are designated for the

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former, with each EA representing a reach of the Avoca River sufficiently different from adjacent reaches or a major tributary to the Avoca. The latter includes a large number and variety of smaller or more isolated water bodies, including mine adits, springs, small ponds, very small tributaries, or other waters that flow only intermittently (e.g., stormwater flows). Each of these surface water bodies is considered unique and is assessed independently as a potential source area for ecological receptors.

7.1.1 Surface Water Sampling Locations

These waters include the primary surface waters of interest relative to a diverse aquatic life community, potentially including salmonid fish. Because restoration and/or enhancement of salmonid fisheries is a major goal for most of these waters, the assessment of these waters is focused on the potential for supporting the survival, growth, and reproduction of salmonid fish.

SW Exposure Areas (EAs) – Rivers and Tributaries

- EA-1 – Avoca River from above Meeting of the Waters (Ballinacleish Bridge and Lions Bridge) downstream to above White's Bridge (primary REFERENCE). This includes stations at Ballinacleish Bridge, Lions Bridge and Transect 1. Vale View stream also enters in this reach.

- EA-2 – Avoca River above White's Bridge to just downstream of Transect 5. This includes all the mining area discharges (Deep and Road Adits and Ballygahan discharge) and the landfill. This includes stations at Transect 2 and Transect 5 and Drews Discharge (small tributary).

- EA-3 – Below Transect 5 to just downstream of Transect 4 (below Avoca Bridge). This reach is below the mining and landfill area and includes the following tributaries: Red Road, Sulfur Brook and unknown Tributary. This includes stations at Transect 3 (below transect 5) and Transect 4.

- EA-4 – Avoca River downstream of Avoca Bridge/Transect 4 to just upgradient of confluence with Aughrim River (along Woodenbridge Golf Course, SW only). This includes only one station: Avoca upstream of the Aughrim River.

- EA-5 – Confluence of Aughrim and Avoca Rivers downstream to just above Shelton Abbey Tailings. This includes two stations: Avoca Downstream of Aughrim and Shelton Abbey Upstream.

- EA-6 – Avoca River at upper boundary of Shelton Abbey tailings downstream to just above former Fertilizer Plant. This includes Downstream of Shelton Abbey.

- EA-7 – Avoca River at upper boundary of former Fertilizer Plant to downstream boundary of former Fertilizer Plant. This includes one station: Downstream of Fertilizer Plant.

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■ EA- 8 – Avoca River at downstream boundary of former Fertilizer Plant to Arklow. This includes several stations: Downstream of the Landfill, Arklow Bridge, and Arklow Left Bank and Arklow Right Bank. The Left and Right Bank samples were collected near the outlet of the Avoca River to the Irish Sea. As a result, the samples contained high total dissolved solids (TDS) and chloride due to tidal influence. These two samples also had a very high hardness. As a result, the average hardness for EA-8 was abnormally high and does not reflect conditions in the Avoca River. The hardness value and other concentrations dropped to typical values at the Arklow Bridge just upgradient of the locations of the Left and Right Bank samples.

Adit, Spring, and Miscellaneous Surface Water Exposure Areas

Although many of these surface water bodies comprising this category (see below) do not and are not expected to support aquatic life, they are assessed using toxicity data for aquatic life primarily to reveal the magnitude of contamination. A few are springs that represent groundwater discharging to the surface. In other cases, these waters are sufficiently large and persistent (vs. ephemeral waters) to potentially attract wildlife or support types of aquatic life that are tolerant of existing conditions. All of these waters are assessed as potential exposure media for sensitive aquatic invertebrates to help interpret the degree of contamination and to better understand existing water quality. Each is assigned a unique EA designation (EA-1 though EA-24). Exposures by fish are unlikely for nearly all of these EAs, and such exposures are not evaluated for these waters. Also, exposures by wildlife (e.g., drinking) are not expected to be critical based on the expectation of infrequent exposures of short duration. This expectation is based on the mostly unsuitable habitat provided by these waters and on the greater likelihood that birds and mammals will find much more suitable habitats (with cover and prey) elsewhere. The following comprise the water sampled and evaluated in this media quality category.

■ EA-1 - Ballygahan Adit
■ EA-2 - Cronebane Intermediate Adit
■ EA-3 - Cronebane Pit Lake
■ EA-4 - Cronebane Seeps
■ EA-5 - Cronebane Shallow Adit
■ EA-6 - Cronebane Small Seep
■ EA-7 - Deep Adit
■ EA-8 - Deep Adit Confluence
■ EA-9 - Deep Adit Runoff
■ EA-10 - Drews Discharge
■ EA-11 - East Avoca Pit Lake
■ EA-12 - Holy Well
■ EA-13 - Kilmacoo Adit
■ EA-14 - Mt Platt Seep East
■ EA-15 - Mt Platt Seep West
■ EA-16 - Mulcahy Ditch
■ EA-17 - Paddy's Spring
■ EA-18 - Radio Tower Spring

CDM

- EA-19 - Red Road Stream
- EA-20 - Road Adit
- EA-21 - Road Adit Confluence
- EA-22 - Shelton Abbey Base Pond
- EA-23 - Spa Adit
- EA-24 - Valve Box Seep

Finally, the ERA presents and evaluates the 2006 and 2007 surface water data collected by the GSI from the following miscellaneous sampling locations that are not within designated EAs:

- Vale View Stream (2006 and 2007)
- Red Road Stream (2006 and 2007)
- Sulphur Brook near discharge to Avoca River (2006 and 2007)
- Sulphur Brook midway (2006 and 2007)
- Spoil run-off – Avoca River mixing zone (2006 and 2007)
- East Avoca OP – Castlehoward area drainage ditch
- Avoca River below Shelton Abbey TMF (2006)
- Avoca River below Vale View stream (2006)

7.1.2 Surface Water Sampling Results

Table 7-1a presents the exposure data based on Phase 2 surface water sampling and analyses for Rivers and Tributaries. Part 1 of this table presents CDM data by EAs for those locations with multiple samples (statistics included). These data are the result of samples collected during the last week of July and the first week of August 2007. This time of year was selected as the historic low flow period (based on the previous 12 years of data at the Rathdrum flow gauge). A low flow time was selected because the impact (metal concentrations) at the Avoca River will be the greatest. However in 2007, rainfall had occurred for many days prior to this period and flows in the Avoca River and its tributaries were elevated. As a result of this high flow, measured metal concentrations were lower than anticipated. Part 2 presents GSI data by EA for 2006 and 2007 (statistics included). The GSI data were collected at lower flow conditions in the Avoca River. In particular, the June 2007 data were collected during a period of lower flow and metal concentrations measured in the Avoca River are higher than measured in July/August 2007. The data include the minimum, mean, and maximum concentrations, by EA, of potentially hazardous chemicals in rivers and tributaries, including ammonia (where data are available) and dissolved inorganic constituents. Total (vs. dissolved) concentrations are not included because the dissolved fraction is the primary bioavailable and potentially toxic fraction to aquatic life. Also include on this table is the frequency of detection for each constituent, by EA.

Table 7-1b presents similar exposure data based on surface water sampling and analyses for adits, springs, and miscellaneous surface waters. Part one presents CDM data by EA for sampling locations with multiple values (statistics included). Part 2 presents CDM data by EA for locations with single values (no statistics). Finally, Part 3 presents GSI data from 2006 and 2007 for miscellaneous surface water sampling locations.

CDM

Table 7.1a Exposure Data for Surface Water - Rivers and Tributaries
Part 1 - CDM High Flow Data

EA	Statistic	Ammonia mg/l as N	D Ag ug/l	D Al ug/l	D As ug/l	D Ba ug/l	D Cd ug/l	D Cr ug/l	D Co ug/l	D Cu ug/l	D Hg ug/l	D Pb ug/l	D Mn ug/l	D Ni ug/l	D Sb ug/l	D Se ug/l	D Sn ug/l	D Tl ug/l	D Ti ug/l	D U ug/l	D V ug/l	D Zn ug/l	Hardness	D Ca mg/L	D Mg mg/L
1	min	0.02	1.0	13	0.5	7	0.2	0.5	0.5	0.5	0.025	0.5	8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3			
1	mean	0.1175	1.0	60.75	0.5	8.75	0.2	0.5	0.5	3.625	0.025	2.125	9.75	1.125	0.5	0.625	0.5	0.5	0.625	0.5	1.375	17.75	mean	8.80	2.47
1	max	**0.15**	**1.0**	**100**	**0.5**	**12**	**0.2**	**0.5**	**0.5**	**8**	**0.025**	**3**	**14**	**2**	**0.5**	**1**	**0.5**	**0.5**	**1**	**0.5**	**2**	**29**	hardness	32	
1	frequency	25	0	100	0	100	0	0	0	75	0	75	100	75	0	25	0	0	25	0	75	100			
2	min	0.03	1.0	164	0.5	6	0.2	0.5	0.5	12	0.025	4	35	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	143			
2	mean	0.047	1.0	190	0.500	22.3	1.100	0.50	1.50	19.00	0.025	5.33	78.33	2.00	0.500	0.67	0.50	0.50	0.67	0.50	0.67	393	mean	5.10	2.83
2	max	**0.06**	**1.0**	**208**	**0.5**	**54**	**2.5**	**0.5**	**2**	**24**	**0.025**	**7**	**103**	**3**	**0.5**	**1**	**0.5**	**0.5**	**1**	**0.5**	**1**	**770**	hardness	24	
2	frequency	100	0	100	0	100	66.67	0	66.67	100	0	100	100	100	0	33.33	0	0	33.33	0	33.33	100			
3	min	0.01	1.0	1	0.5	0.5	0.2	0.5	0.5	0.5	0.025	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5			
3	mean	0.032	1.0	108.2	0.7	9.4	0.42	0.7	0.7	6.6	0.025	2.5	33.6	1	0.5	1.3	0.5	0.5	0.6	0.5	0.5	171.9	mean	4.20	2.27
3	max	**0.05**	**1.0**	**313**	**1**	**31**	**0.8**	**1**	**1**	**16**	**0.025**	**6**	**76**	**2**	**0.5**	**3**	**0.5**	**0.5**	**1**	**0.5**	**0.5**	**239**	hardness	20	
3	frequency	100	0	80	40	60	40	40	40	60	0	40	60	60	0	40	0	0	20	0	0	80			
4	min	0.15	1.0	69	0.5	7	0.6	0.5	1	10	0.025	1	78	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	219			
4	mean	0.15	1.0	69	0.5	7	0.6	0.5	1	10	0.025	1	78	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	219	mean	9.30	3.57
4	max	**0.15**	**1.0**	**69**	**0.5**	**7**	**0.6**	**0.5**	**1**	**10**	**0.025**	**1**	**78**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**219**	hardness	38	
4	frequency	0	0	100	0	100	100	0	100	100	0	100	100	100	0	0	0	0	0	0	0	100			
5	min	0.15	1.0	110	0.5	7	0.2	0.5	0.5	8	0.025	2	50	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	131			
5	mean	0.15	1.0	114.5	0.5	22.5	0.4	0.5	0.75	8.5	0.025	2	52	1.5	0.5	0.75	0.5	0.5	0.5	0.5	0.5	133.5	mean	6.90	3.21
5	max	**0.15**	**1.0**	**119**	**0.5**	**38**	**0.6**	**0.5**	**1**	**9**	**0.025**	**2**	**54**	**2**	**0.5**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**136**	hardness	30	
5	frequency	0	0	100	0	100	50	0	50	100	0	100	100	100	0	50	0	0	0	0	0	100			
6	min	1.3	1.0	133	0.5	37	0.5	0.5	1	10	0.025	2	82	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	146			
6	mean	1.3	1.0	133	0.5	37	0.5	0.5	1	10	0.025	2	82	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	146	mean	7.40	3.38
6	max	**1.3**	**1.0**	**133**	**0.5**	**37**	**0.5**	**0.5**	**1**	**10**	**0.025**	**2**	**82**	**2**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**146**	hardness	32	
6	frequency	100	0	100	0	100	100	0	100	100	0	100	100	100	0	0	0	0	0	0	0	100			
7	min	0.15	1.0	91	0.5	10	0.5	0.5	0.5	11	0.025	1	156	1	0.5	0.5	0.5	0.5	0.5	0.5	1	148			
7	mean	0.15	1.0	91	0.5	10	0.5	0.5	0.5	11	0.025	1	156	1	0.5	0.5	0.5	0.5	0.5	0.5	1	148	mean	8.60	3.73
7	max	**0.15**	**1.0**	**91**	**0.5**	**10**	**0.5**	**0.5**	**0.5**	**11**	**0.025**	**1**	**156**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**148**	hardness	37	
7	frequency	0	0	100	0	100	100	0	0	100	0	100	100	100	0	0	0	0	0	0	100	100			
8	min	0.15	1.0	59	0.5	7	0.2	0.5	0.5	2	0.025	0.5	93	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	103			
8	mean	0.15	1.0	86.5	2.875	15.5	0.275	0.5	0.75	4.5	0.025	1.125	95	2	0.5	7.25	0.5	0.5	0.5	0.5	1.125	123.5	mean	28.90	69.29
8	max	**0.15**	**1.0**	**124**	**6**	**41**	**0.5**	**0.5**	**1**	**7**	**0.025**	**2**	**101**	**2**	**0.5**	**17**	**0.5**	**0.5**	**0.5**	**0.5**	**3**	**152**	hardness	356	
8	frequency	0	0	100	75	100	25	0	50	100	0	75	100	100	0	50	0	0	0	0	25	100			
	SW MAX	**1.30**	**1.0**	**313**	**6.00**	**54.0**	**2.5**	**1.00**	**2.0**	**24.0**	**0.025**	**7.0**	**156**	**3.0**	**0.50**	**17.0**	**0.50**	**0.50**	**1.0**	**0.50**	**3.0**	**770**			

EA 1-7 mean   31
EA 8 mean   356

means based on half the detection limit for nondetect samples
FD - frequency of detection (percent)
D = dissolved concentration
Hardness (mg/L CaCO$_3$) = 2.5 (Ca, mg/L) + 4.1 (Mg, mg/L)

CDM

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Part 2 - GSI Low Flow Data

Nov 06																				D Ca	D Mg				
EA	Statistic	D Hg	D Al	D Sb	D As	D Ba	D Cd	D Cr	D Cu	D Fe	D Pb	D Mn	D Mo	D Ni	D Se	D Sn	D U	D V	D Zn	D Ca mg/L	D Mg mg/L		**Hardness Calculations**		
2	Min	0.03	268	0.50	0.50	9.00	0.50	2.00	34.00	76.00	5.00	54.00	0.50	3.00	0.50	0.50	0.50	0.50	102	3,850	1,792				
2	Mean	0.04	3,407	0.67	0.50	10.33	2.83	2.67	86.00	9,094	57.67	2,032	0.50	14.67	0.50	0.50	1.00	0.50	2,305	23,190	22,601	mean	23.2	22.6	
2	Max	0.08	8,982	1.00	0.50	12.00	5.00	3.00	184	27,060	143.00	5,925	0.50	37.00	0.50	0.50	2.00	0.50	5,904	61,640	62,890	hardness	**151**		
2	Frequency	33	100	67	0	100	67	100	100	100	100	100	0	100	0	0	67	0	100	1	1			EA-2	
3	Min	0.03	205	0.50	0.50	6.00	0.50	0.50	6.00	221	3.00	57.00	0.50	0.50	0.50	0.50	0.50	0.50	145	4,308	1,903				
3	Mean	0.04	206	0.50	0.50	7.00	0.50	1.75	11.50	234	4.00	60.00	0.50	1.75	0.50	5.25	0.50	0.75	164	4,428	2,088	mean	4.4	2.1	
3	Max	0.05	207	0.50	0.50	8.00	0.50	3.00	17.00	246	5.00	63.00	0.50	3.00	0.50	10.00	0.50	1.00	182	4,548	2,273	hardness	**20**		
3	Frequency	50	100	0	0	100	0	50	100	100	100	100	0	50	0	50	0	50	100	1	1			EA-3	
6	Min	0.03	130	0.50	0.50	6.00	0.50	0.50	0.50	80.00	2.00	2.00	0.50	1.00	0.50	0.50	0.50	0.50	49.00	4,537	1,928				
6	Mean	0.03	152	0.50	0.50	6.00	0.50	0.50	3.25	103	2.00	25.00	0.50	1.50	1.25	4.75	0.50	0.50	85.00	5,089	2,359	mean	5.1	2.4	
6	Max	0.03	173	0.50	0.50	6.00	0.50	0.50	6.00	126	2.00	48.00	0.50	2.00	2.00	9.00	0.50	0.50	121	5,640	2,789	hardness	**22**		
6	Frequency	0	100	0	0	100	0	0	50	100	100	100	0	100	50	50	0	0	100	1	1			EA-6	
June 07	Statistic	D Hg	D Al	D Sb	D As	D Ba	D Cd	D Cr	D Cu	D Fe	D Pb	D Mn	D Mo	D Ni	D Se	D Sn	D U	D V	D Zn						
2	Min	0.03	4,705	0.50	0.50	5.00	2.30	0.50	69.00	75.00	15.00	787	0.50	5.00	0.50	0.50	0.50	0.50	1,159	4,489	10,720				
2	Mean	0.03	11,043	0.50	0.50	6.00	13.15	0.50	184	198	127.00	793	0.50	7.00	0.75	0.50	1.25	0.50	5,163	10,565	14,985	mean	10.6	15.0	
2	Max	0.03	17,380	0.50	0.50	7.00	24.00	0.50	298	321	239.00	798	0.50	9.00	1.00	0.50	2.00	0.50	9,167	16,640	19,250	hardness	**88**		
2	Frequency	0	100	0	0	100	100	0	100	100	100	100	0	100	50	0	50	0	100	1	1			EA-2	
3	Min	0.03	129	0.50	0.50	6.00	0.90	0.50	11.00	127	0.50	130	0.50	3.00	0.50	0.50	0.50	0.50	378	4,824	3,130				
3	Mean	0.03	4,332	0.50	0.50	10.50	1.30	0.50	13.50	142	1.25	137	0.50	4.00	1.25	0.50	0.50	0.50	389	7,652	3,131	mean	7.7	3.1	
3	Max	0.03	8,535	0.50	0.50	15.00	1.70	0.50	16.00	156	2.00	143	0.50	5.00	2.00	0.50	0.50	0.50	399	10,480	3,132	hardness	**32**		
3	Frequency	0	100	0	0	100	100	0	100	100	50	100	0	100	50	0	0	0	100	1	1			EA-3	

means based on half the detection limit for nondetect samples
FD - frequency of detection (percent)
D = dissolved concentration
all values = ug/L

EA-2 mean	119
EA-3 mean	26
EA-6 mean	22

Table 7.1b Exposure Data for Surface Water - Adits, Springs, and Miscellaneous Surface Waters

Part 1 - CDM Exposure Data for EAs with Multiple Samples

EA	Statistic	Ammonia	D Hg	D Al	D Sb	D As	D Ba	D Cd	D Cr	D Co	D Cu	D Pb	D Mn	D Ni	D Se	D Ag	D Tl	D Sn	D Ti	D U	D V	D Zn
		mg/l as N	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
3	Min	0.11	0.025	13,780	0.5	0.5	11	14.1	0.5	23	4,188	475	558	4	0.5	1	0.5	0.5	0.5	2	0.5	5,015
3	Mean	0.21	0.025	66,140	0.5	0.75	11	14.8	0.5	25	18,474	609	3,104	4.5	0.5	1	0.5	0.5	1.3	2	0.5	5,114
3	Max	**0.31**	**0.025**	**118,500**	**0.5**	**1**	**11**	**15.5**	**0.5**	**27**	**32,760**	**742**	**5,650**	**5**	**0.5**	**1**	**0.5**	**0.5**	**2**	**2**	**0.5**	**5,213**
3	FD	100	0	100	0	0	100	100	0	100	100	100	100	100	0	0	0	0	0	100	0	100
5	Min	0.54	0.025	36,700	0.5	9	10	289	5	295	8,921	1,301	9,375	155	0.5	1	3	0.5	4	32	0.5	85,900
5	Mean	0.66	0.025	190,800	0.75	21.5	17	311	9	315	9,070	1,318	12,148	161	1.75	1	3.5	0.5	5	36	1.8	98,050
5	Max	**0.78**	**0.025**	**344,900**	**1**	**34**	**24**	**333**	**13**	**335**	**9,218**	**1,334**	**14,920**	**167**	**3**	**1**	**4**	**0.5**	**6**	**39**	**3**	**110,200**
5	FD	100	0	100	0	100	100	100	100	100	100	100	100	100	0	0	100	0	100	100	0	100
7	Min	0.27	0.025	84,020	0.5	0.5	7	91.4	0.5	105	845	1,339	4,100	39	0.5	1	2	0.5	4	9	0.5	47,620
7	Mean	0.27	0.025	93,310	0.5	1.25	7	104	0.5	109	989	1,528	4,190	39	0.5	1	2	0.5	5	9.5	1.3	48,125
7	Max	**0.27**	**0.025**	**102,600**	**0.5**	**2**	**7**	**116**	**0.5**	**113**	**1,133**	**1,717**	**4,280**	**39**	**0.5**	**1**	**2**	**0.5**	**6**	**10**	**2**	**48,630**
7	FD	100	0	100	0	0	100	100	0	100	100	100	100	100	0	0	100	0	100	100	0	100

Table 7.1b Exposure Data for Surface Water - Adits, Springs, and Miscellaneous Surface Waters

Part 2 - CDM Exposure Data for EAs with Single Samples

EA	Location	Ammonia	D Hg	D Al	D Sb	D As	D Ba	D Cd	D Cr	D Co	D Cu	D Pb	D Mn	D Ni	D Se	D Ag	D Tl	D Sn	D Ti	D U	D V	D Zn
		mg/l as N	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
1	Ballygahan Adit	9.04	0.05	99,110	1.00	22.0	15.0	51.0	3.0	200	5,237	237	17,050	92.0	5.0	2.0	5.0	1.0	4.0	11.0	1.0	21,680
2	Cronebane Intermediate Adit	0.33	0.05	71,360	1.00	10.00	11.0	127.0	2.0	101.0	3,198	1,352	3,132	53.0	2.0	2.0	4.0	1.0	3.0	10.0	3.0	33,030
3	Cronebane Pit Lake	0.11	0.05	13,780	1.00	1.00	11.0	15.5	1.0	27.0	4,188	475	558	4.0	1.0	2.0	1.0	1.0	2.0	2.0	1.0	5,213
3	Crone Lake	0.31	0.05	118,500	1.00	1.00	11.0	14.1	1.0	23.0	32,760	742	5,650	5.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	5,015
4	Cronebane Seeps	0.08	0.05	18,390	1.00	1.00	12.0	23.3	5.0	38.0	5,212	1,065	875	5.0	1.0	2.0	1.0	1.0	2.0	2.0	1.0	6,610
5	Cronebane Shallow Adit	0.78	0.05	36,700	1.00	34.0	24.0	289.3	13.0	295	8,921	1,334	9,375	155.0	3.0	2.0	3.0	1.0	6.0	32.0	1.0	85,900
5	Cronebane Shallow Adit	0.54	0.05	344,900	1.00	9.00	10.0	332.6	5.0	335	9,218	1,301	14,920	167	1.0	2.0	4.0	1.0	4.0	39.0	3.0	110,200
6	Cronebane Small Seep		0.05	34,660	1.00	4.00	7.0	69.4	1.0	94.0	14,800	1,339	1,670	6.0	2.0	2.0	1.0	1.0	3.0	6.0	1.0	19,640
7	Deep Adit		0.05	102,600	1.00	2.00	7.0	115.6	1.0	113	845	1,717	4,100	39.0	1.0	2.0	2.0	1.0	6.0	10.0	2.0	47,620
7	Deep Adit	0.27	0.05	84,020	1.00	1.00	7.0	91.4	1.0	105	1,133	1,339	4,280	39.0	1.0	2.0	2.0	1.0	4.0	9.0	1.0	48,630
8	Deep Adit Confluence	0.33	0.05	9.0	1.00	1.00	63.0	0.4	1.0	9.0	1.0	1.0	961	42.0	1.0	2.0	1.0	1.0	10.0	1.0	1.0	43,090
9	Deep Adit Runoff		0.05	22,980	1.00	3.00	134	7.7	4.0	21.0	4,549	108	654	9.0	1.0	2.0	1.0	1.0	6.0	1.0	1.0	2,806
10	Drews Discharge	3.70	0.05	20	1.00	1.00	17.0	15.0	1.0	45.0	26.0	1.0	1,501	39.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	5,046
11	East Avoca Pit Lake	0.30	0.05	6,752	1.00	6.00	11.0	125.9	1.0	92.0	2,822	1,226	2,905	51.0	3.0	2.0	4.0	1.0	4.0	9.0	1.0	31,810
12	Holy Well		0.05	8.0	1.00	1.00	41.0	0.4	1.0	1.0	2.0	1.0	6.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0	22
13	Killmacoo	0.03	0.05	4,017	1.00	1.00	37.0	11.0	1.0	7.0	311.0	2,176	347.0	8.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2,655
14	Mt Platt Seep East		0.05	1,032,000	1.00	1.00	66.0	518.5	102	495	88,760	9.0	14,860	329	3.0	2.0	1.0	1.0	11.0	61.0	2.0	132,900
15	Mt Platt Seep West		0.05	313,600	2.00	154.0	113	367.6	28.0	172	39,510	98.0	4,568	114	1.0	2.0	1.0	1.0	9.0	25.0	1.0	113,300
16	Mulcahy Ditch		0.05	1,188	1.00	1.00	25.0	1.1	1.0	1.0	28.0	4.0	35.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	192
17	Paddys Spring		0.05	56	1.00	1.00	4.0	0.4	1.0	1.0	14.0	1.0	69.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	71
18	Radio Tower Spring	0.30	0.05	10	1.00	1.00	11.0	0.4	1.0	1.0	46.0	1.0	32.0	4.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	117
19	Red Road	0.03	0.05	118,400	1.00	1.00	11.0	13.1	1.0	20.0	31,950	630	5,480	5.0	2.0	2.0	1.0	1.0	2.0	1.0	1.0	5,026
20	Road Adit		0.05	20,930	1.00	6.00	17.0	12.3	1.0	134	268	308	13,240	61.0	3.0	2.0	2.0	1.0	3.0	3.0	1.0	10,950
21	Road Adit Confluence	6.59	0.05	984	1.00	3.00	25.0	0.4	9.0	2.0	1.0	1.0	42.0	7.0	1.0	2.0	1.0	1.0	4.0	3.0	1.0	10,600
22	SA Base Pond	0.63	0.05	158	1.00	1.00	40.0	0.5	1.0	3.0	16.0	28.0	184.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	177
23	Spa Adit	1.22	0.05	21,730	1.00	1.00	7.0	54.8	6.0	299	8,390	102	10,410	89.0	1.0	2.0	2.0	1.0	6.0	11.0	1.0	14,300
24	Valve Box Seep		0.05	69	1.00	1.00	27.0	0.8	1.0	1.0	12.0	8.0	7.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	115
	Overall Maximum	**9.04**	**0.05**	**1,032,000**	**2.0**	**154**	**134**	**519**	**102**	**495**	**88,760**	**2,176**	**17,050**	**329**	**5.0**	**2.0**	**5.0**	**1.0**	**11.0**	**61.0**	**3.0**	**132,900**

means based on half the detection limit for nondetect samples

FD - frequency of detection (percent)

D = dissolved concentration

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Table 7.1b Exposure Data for Surface Water - Adits, Springs, and Miscellaneous Surface Waters

Part 3 - GSI Low Flow Exposure Data for Miscellaneous Surface Waters (2006-2007)

Sampling Location (2006)	D Hg	D Al	D Sb	D As	D Ba	D Cd	D Cr	D Cu	D Fe	D Pb	D Mn	D Mo	D Ni	D Se	D Sn	D U	D V	D Zn
Vale View Stream	0.03	11.0	4.0	0.50	12.0	0.50	2.00	8.0	33.0	0.5	4.0	0.50	3.0	0.50	0.5	0.5	0.5	30.0
Red Road stream	0.03	98.0	0.5	0.50	17.0	0.50	3.00	23.0	67.0	0.5	290	0.50	4.0	0.5	0.5	0.5	0.5	209
Sulphur Brook near discharge to Avoca River	0.08	33.0	0.5	0.50	7.0	0.50	0.50	9.0	1.0	2.0	16.0	0.50	0.5	0.5	10.0	0.5	0.5	68.0
Sulphur Brook midway	0.03	62.0	0.5	0.50	12.0	0.50	0.50	34.0	1.0	10.0	44.0	0.50	0.5	0.5	9.0	0.5	0.5	149
Spoil run-off - Avoca River mixing zone	0.03	214	10.0	0.50	7.0	0.50	3.00	19.0	138	6.0	26.0	0.50	2.0	0.5	0.5	0.5	0.5	104
East Avoca OP - Castlehoward area drainage ditch	0.03	79.0	0.5	0.50	13.0	0.50	0.50	0.5	1.0	0.5	18.0	0.50	0.5	0.5	9.0	0.5	0.5	63.0
Avoca River below Shelton Abbey TMF	0.29		24,970		0.5	U	U	11.0		4.0	274,600		0.5	U	227		3,102	
Avoca River below Vale View stream	0.03	110	0.5	0.50	6.0	0.20	0.50	8.0	14.0	0.5	5.0	0.50	1.0	0.5	0.5	0.5	0.5	64.0
Sampling Location (2007)	**D Hg**	**D Al**	**D Sb**	**D As**	**D Ba**	**D Cd**	**D Cr**	**D Cu**	**D Fe**	**D Pb**	**D Mn**	**D Mo**	**D Ni**	**D Se**	**D Sn**	**D U**	**D V**	**D Zn**
Vale View Stream	0.03	1,635	0.5	0.50	9.0	0.20	0.50	0.5	7.0	0.5	2.0	0.50	0.5	0.5	0.5	0.5	0.5	14.0
Red Road stream	0.03	63.0	0.5	0.50	17.0	1.60	0.50	7.0	20.0	0.5	625	0.50	4.0	2.0	0.5	0.5	0.5	479
Sulphur Brook near discharge to Avoca River	0.03	2,037	0.5	0.50	8.0	0.20	0.50	8.0	1.0	0.5	23.0	0.50	0.5	0.5	0.5	0.5	0.5	88.0
Sulphur Brook midway	0.03	716	0.5	0.50	15.0	1.20	0.50	46.0	1.0	8.0	79.0	0.50	2.0	0.5	0.5	0.5	0.5	315
Spoil run-off - Avoca River mixing zone	0.03	1,927	0.5	0.50	6.0	1.70	0.50	42.0	5.0	0.5	133	0.50	2.0	2.0	0.5	0.5	0.5	532

all concentrations = ug/L

U = not detected above detection limit

highlighted cells indicated outllier or suspect data (not selected as maximums due to low confidence in results)

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7.2 Sediment Data

Sediments were collected by CDM in 2007 from five different EAs, described below. Also, the GSI collected sediment data in 2007 from locations linked to EAs 1, 2, 3, 4, and 6. The sediment quality data associated with these samples are assessed using toxicity data based on exposures by sensitive benthic invertebrates. Sediment quality is important from the viewpoint of contributing to surface water and pore water contamination as well as potentially directly and indirectly affecting aquatic invertebrates and fish.

7.2.1 Sediment Sampling Locations

Exposure Areas (EAs)

Sediment sampling stations are assigned to the same EA designations as used for surface water sampling. In some cases, no sediment samples were collected from the EA as designated for surface water. Therefore, EAs 4, 5, and 7 apply only to surface water sampling and are not applicable for sediment sampling.

- EA-1 – Avoca River from above Meeting of the Waters (Ballinacleish Bridge and Lions Bridge) downstream to above White's Bridge (primary REFERENCE). This includes stations at Ballinacleish Bridge, Lions Bridge and Transect 1. Vale View stream also enters in this reach.

- EA-2 – Avoca River above White's Bridge to just downstream of Transect 5. This includes all the mining area discharges (Deep and Road Adits and Ballygahan discharge) and the landfill. This includes stations at Transect 2 and Transect 5 and Drews Discharge (small tributary).

- EA-3 – Below Transect 5 to just downstream of Transect 4 (below Avoca Bridge). This reach is below the mining and landfill area and includes the following tributarties: Red Road, Sulfur Brook and unknown Tributary. This includes stations at Transect 3 (below transect 5) and Transect 4.

- EA-6 – Avoca River at upper boundary of Shelton Abbey tailings downstream to just above former Fertilizer Plant. This includes one SW station and two SED locations: Downstream of Shelton Abbey (SW) and SAT1 and SAT2 (SED).

- EA-Unique – Aughrim River at Golf Course (Reference)

CDM

7.2.2 Sediment Sampling Results

Part 1 of Table 7-2 presents the exposure data based on CDM Phase 2 sediment sampling and analyses. Part 2 of this table presents the sediment data from the 2007 GSI data set collected from EAs 1, 2, 3, 4, and 6. GSI sediment data for cadmium and nickel are shown as zero on this table, indicating that these analytes were not included in the analyses. These two constituents are presented on this table only to indicate that they were initially considered for inclusion because of potential toxicity. Nontoxic chemicals, essential nutrients or electrolytes, and chemicals found at very high concentrations naturally in media of concern are not included on this table (e.g., aluminum, calcium, magnesium, iron, sodium, and sulfur). In addition, ecotoxicity data are unavailable for several chemicals detected in sediment and shown on Table 7-2 (barium, bismuth, thallium, tin, titanium, uranium, and vanadium). The lack of ecotoxicity data for these chemicals is based in part on the assumption that these are not highly toxic chemicals and therefore these have not been subject to ecotoxicity testing. The concentrations of these non-tested chemicals in EAs 2, 3, 6, and Unique are compared to concentrations in sediments from the reference location (EA 1). The results of this comparison support the decision to eliminate these chemicals from further assessment because the concentrations downgradient of the reference location are not substantially different from those of the reference.

7.3 Soil and Spoils Data

These media together comprise the terrestrial solids media. Surface soils were collected from several agricultural fields, while mine spoils were collected from mining-impacted locations (spoil piles).

7.3.1 Soil and Spoils Sampling Locations

Exposure Areas (EAs)

The following main sampling locations are identified as surface soil EAs, and each is a unique sampling location (identified by the owner of the fields from which the samples were collected).

- Gerald Murphy's Field (GMF)
- Ivor Fitzpatrick's Field (IFF)
- Kavanagh's Field #1 (KF1)
- Kavanagh's Field #2 (KF2)
- Paddy Hogan's Field (PHF)
- Tom Merrigan's Field #1 (TMF1)
- Tom Merrigan's Field #2 (TMF2)

Table 7-2 Exposure Data for Sediment

Part 1 - CDM Phase 2 Sediment Data

EA	Statistic	Ag	As	Ba	Bi	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Th	Ti	U	V	Zn
1	Min	1.05	27.79	59.85	0.30	1.84	20.20	29.02	34.91	0.08	5,016	0.99	23.84	259.31	0.10	1.28	0.87	8.02	262.85	1.78	26.27	267.95
1	Mean	1.05	27.79	59.85	0.30	1.84	20.20	29.02	34.91	0.08	5,016	0.99	23.84	259.31	0.10	1.28	0.87	8.02	262.85	1.78	26.27	267.95
1	Max	**1.05**	**27.79**	**59.85**	**0.30**	**1.84**	**20.20**	**29.02**	**34.91**	**0.08**	**5,016**	**0.99**	**23.84**	**259.31**	**0.10**	**1.28**	**0.87**	**8.02**	**262.85**	**1.78**	**26.27**	**267.95**
1	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Min	0.02	30.25	4.57	0.04	0.17	1.77	4.00	133.60	0.01	77.53	0.94	3.62	229.33	0.10	0.40	0.40	2.00	45.05	0.49	4.00	141.63
2	Mean	0.19	202.86	19.98	0.75	0.48	7.79	14.76	265.92	0.10	2,852	1.40	10.76	400.25	0.95	0.40	0.76	4.21	129.48	1.65	14.03	193.83
2	Max	**0.35**	**481.25**	**40.34**	**1.84**	**0.98**	**17.92**	**30.59**	**503.46**	**0.16**	**8,070**	**2.00**	**20.79**	**704.21**	**1.68**	**0.40**	**1.49**	**6.66**	**263.75**	**3.84**	**24.63**	**238.17**
2	FD	0.33	1	1	0.33	1	1	33.33	1	0.33	1	1	1	1	0.33	0	0.66	1	1	1	0.66	1
3	Min	0.10	27.53	49.85	0.35	0.52	15.70	30.68	85.61	0.01	2,286	0.86	23.12	144.06	0.10	0.40	0.40	5.65	207.97	1.32	24.98	192.98
3	Mean	0.13	32.87	51.90	0.66	0.71	16.76	32.28	155.79	0.01	2,397	1.00	23.56	148.34	0.10	0.40	0.40	5.84	222.29	1.36	25.38	218.51
3	Max	**0.17**	**38.21**	**53.96**	**0.97**	**0.90**	**17.82**	**33.87**	**225.97**	**0.01**	**2,507**	**1.14**	**24.00**	**152.62**	**0.10**	**0.40**	**0.40**	**6.02**	**236.62**	**1.41**	**25.79**	**244.03**
3	FD	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1
6	Min	0.04	27.73	53.67	0.64	0.20	15.42	29.13	68.88	0.01	1,717	0.94	24.49	69.06	0.10	0.40	0.40	6.65	216.70	1.51	27.50	138.30
6	Mean	0.07	29.77	57.87	0.90	0.40	17.53	29.78	72.64	0.01	1,925	1.02	25.48	80.40	0.10	0.40	0.40	6.86	236.91	1.64	29.06	163.54
6	Max	**0.11**	**31.66**	**60.45**	**1.20**	**0.70**	**18.70**	**30.71**	**78.13**	**0.01**	**2,055**	**1.14**	**25.83**	**93.50**	**0.10**	**0.40**	**0.40**	**7.41**	**249.28**	**1.85**	**30.21**	**200.91**
6	FD	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1
unique	Min	0.02	21.58	70.55	0.29	0.26	18.23	24.43	21.83	0.01	2,066	0.57	21.95	21.36	0.10	0.40	0.40	6.21	291.46	1.89	28.81	102.86
unique	Mean	0.02	21.58	70.55	0.29	0.26	18.23	24.43	21.83	0.01	2,066	0.57	21.95	21.36	0.10	0.40	0.40	6.21	291.46	1.89	28.81	102.86
unique	Max	**0.02**	**21.58**	**70.55**	**0.29**	**0.26**	**18.23**	**24.43**	**21.83**	**0.01**	**2,066**	**0.57**	**21.95**	**21.36**	**0.10**	**0.40**	**0.40**	**6.21**	**291.46**	**1.89**	**28.81**	**102.86**
unique	FD	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1
	SED MAX	1.05	481.25	70.55	1.84	1.84	20.20	33.87	503.46	0.16	8,070	2.00	25.83	704.21	1.68	1.28	1.49	8.02	291.46	3.84	30.21	267.95

means based on half the detection limit for nondetect samples

FD - frequency of detection (fraction)

units - mg/kg

EA 1 - upstream reference

EA Unique - Aughrim River (secondary reference)

COC - COCs with substantially different concentrations is one or more reference locations relative to mining-impacted areas of the Avoca River

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Table 7-2 Exposure Data for Sediment

Part 2 - GSI Sediment Data (2007)

EA	Site	Cd	Pb	As	Zn	Cu	Ni	Mn
1	Meetings Avonmore River	0	594	33.8	433	34.5	0	5,397
1	Avonmore, up/s of Meetings of the Waters	0	640	34.6	755	60.8	0	6,959
2	Whitesbridge d/s	0	181	47.7	267	443	0	1,717
2	Deep Adit	0	314	53.0	151	280	0	2,283
3	Avoca Village	0	546	73.1	587	381	0	4,933
3	up/s Sulphur Brook	0	134	33.0	193	57.3	0	1,969
4	Woodenbridge	0	412	60.2	573	257	0	3,665
6	Shelton Abbey	0	257	47.3	784	224	57.9	3,861

"0" indicates chemical not analyzed in these samples
units - mg/kg

CDM

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The following main sampling locations are identified as spoils EAs. Surface spoil samples for EAs 1-4 and 6-7 were collected in 2007 as part of the Phase 2 sampling. Data associated with the Deep Adit location (EA-5) were collected by the GSI and used in this Phase 2 assessment to the extent possible.

- EA-1 – Connary
- EA-2 - Mount Platt
- EA-3 - East Avoca/Tigroney West
- EA-4 – Ore Bins areas at Tigroney West
- EA-5 – Deep Adit Area
- EA-6 – West Avoca
- EA-7 – Shelton Abbey

7.3.2 Soil and Spoils Sampling Results

Table 7-3a and 7-3b presents the exposure data based on Phase 2 surface soils and mine spoils sampling and analyses, respectively. Not included on these tables are essential nutrients or electrolytes (e.g., Ca, Mg, P, Na, K), minimally toxic or nontoxic chemicals in solid surface media (e.g., Al and Fe), and chemicals for which soil-based ecotoxicity data are lacking. As for sediments, lack of ecotoxicity data is assumed to be based in part on the expectation that these chemicals are not a major ecotoxicity concern in terrestrial solids media.

7.4 Selection of Phase 2 COCs

Many of the same conservative COC- and media-specific ecological screening levels (ESLs) used in the Phase 1 ERA are used here in Phase 2 to screen COCs for inclusion in the Phase 2 ERA. Where chemicals were detected in Phase 2 samples but not in Phase 1 sampling, additional ESLs are included. Also, new ESLs are used in the Phase 2 screening if more recent and/or higher quality ESLs were found to be available since completion of Phase 1. For surface water and sediment, maximum concentrations used for screening COCs include both CDM and GSI data with the following exception.

- The maximum detected concentrations of antimony, manganese, tin, and vanadium in miscellaneous surface waters based on 2006 GSI data from the Avoca River below the Shelton Abbey TMF are *not* selected as the overall maximums for miscellaneous surface waters. This is based on the extraordinarily high values for these four chemicals, suggesting that these may be outliers or at least suspect with regard to data quality.

The ESLs and chemicals detected in Phase 2 sampling for all media are shown on Table 7-4. Also shown on Table 7-4 are the screening level HQs, which are used to eliminate (HQ<1) or retain (HQ>1) chemicals as final COCs for the Phase 2 ERA. All chemicals for which the screening HQ equals or exceeds 1.0 are retained as final media-specific COCs for the ERA.

CDM

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Table 7-3a. Exposure Data for Phase 2 Surface Soil

EA	Statistic	Ag	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Th	Ti	U	V	Zn
GMF	Min	1.02	53.8	23.7	0.35	1.30	9.52	192.2	0.09	185	5.05	3.19	346	0.41	0.40	1.43	4.12	100.6	1.56	15.7	89.5
GMF	Mean	2.75	84.0	35.5	0.49	2.04	13.07	283.0	0.22	295	6.32	4.77	568	0.64	0.46	1.76	5.40	134.8	1.81	22.2	134.7
GMF	Max	**6.01**	**106.1**	**49.4**	**0.68**	**2.86**	**17.56**	**359.9**	**0.35**	**469**	**7.09**	**7.42**	**818**	**0.96**	**0.81**	**2.02**	**6.30**	**178.9**	**2.00**	**32.9**	**168.6**
GMF	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.14	1	1	1	1	1	1
IFF	Min	0.16	15.7	12.1	0.15	0.20	4.00	26.7	0.01	23	1.04	0.40	39	0.10	0.40	0.40	2.62	20.0	0.81	4.00	17.3
IFF	Mean	0.26	22.8	15.1	0.25	0.62	5.13	42.8	0.03	88	2.52	1.36	62	0.16	0.40	0.47	3.94	54.8	1.12	9.65	33.6
IFF	Max	**0.48**	**28.3**	**24.9**	**0.44**	**1.31**	**11.90**	**73.9**	**0.07**	**215**	**4.65**	**3.11**	**117**	**0.39**	**0.40**	**0.87**	**6.28**	**112.1**	**1.54**	**26.9**	**56.5**
IFF	FD	1	1	1	1	0.86	0.14	1	0.71	1	1	0.71	1	0.29	0.00	0.14	1	0.86	1	0.43	1
KF1	Min	0.42	32.7	19.4	0.27	0.60	4.00	29.8	0.02	91	1.78	1.85	100	0.10	0.40	0.40	3.44	81.2	1.31	4.00	35.8
KF1	Mean	1.15	59.8	24.4	0.44	0.93	8.37	50.5	0.11	146	4.02	2.89	142	0.25	0.53	0.89	4.77	100.8	1.35	17.9	48.0
KF1	Max	**2.43**	**144.4**	**28.8**	**0.72**	**1.39**	**12.06**	**83.9**	**0.18**	**187**	**7.16**	**3.50**	**219**	**0.45**	**1.06**	**1.27**	**5.97**	**143.0**	**1.38**	**24.8**	**68.6**
KF1	FD	1	1	1	1	1	0.60	1	1	1	1	1	1	0.60	0.20	0.80	1	1	1	0.80	1
KF2	Min	0.38	40.6	36.5	0.22	1.41	10.68	81.0	0.11	180	3.21	3.37	143	0.10	0.40	0.40	4.12	78.1	1.73	19.6	59.5
KF2	Mean	0.48	47.3	73.9	0.33	2.67	18.25	110.7	0.13	289	4.22	6.84	195	0.16	0.51	0.40	5.19	114.8	1.87	26.8	78.5
KF2	Max	0.71	60.7	166.7	0.48	3.81	23.72	177.3	0.17	412	5.83	10.06	346	0.30	0.94	0.40	6.13	132.8	2.16	34.3	114.9
KF2	FD	1	1	1	1	1	1	1	1	1	1	1	1	0.40	0.20	0.00	1	1	1	1	1
PHF	Min	1.19	70.2	126.1	1.08	18.63	26.78	358.8	0.34	2,204	4.43	21.05	659	0.38	0.40	2.53	5.42	175.6	2.06	33.8	344.3
PHF	Mean	1.41	73.1	135.3	1.67	19.42	29.05	428.9	0.46	2,296	4.60	21.81	728	0.47	0.40	2.90	5.90	196.0	2.29	35.9	541.6
PHF	Max	**1.57**	**74.7**	**147.2**	**2.11**	**20.67**	**31.20**	**515.6**	**0.56**	**2,345**	**4.76**	**22.25**	**766**	**0.54**	**0.40**	**3.52**	**6.52**	**215.1**	**2.57**	**38.0**	**647.2**
PHF	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	1.00	1	1	1	1	1	1
TMF1	Min	0.72	114.8	44.4	0.15	4.00	12.64	158.5	0.13	405	5.65	5.17	227	0.43	0.40	1.15	5.50	69.6	2.05	19.6	118.7
TMF1	Mean	1.83	184.3	65.6	0.34	5.84	16.43	313.0	0.25	565	8.18	9.40	379	0.85	0.78	1.69	6.57	97.8	2.62	26.9	162.0
TMF1	Max	**2.63**	**275.5**	**89.2**	**0.48**	**9.80**	**29.78**	**574.7**	**0.65**	**861**	**12.39**	**13.11**	**643**	**1.87**	**1.30**	**2.69**	**7.83**	**137.4**	**3.76**	**57.2**	**227.4**
TMF1	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.57	1	1	1	1	1	1
TMF2	Min	0.30	47.6	43.6	0.13	2.62	9.48	94.0	0.09	271	2.33	3.42	145	0.21	0.40	0.40	4.13	54.2	1.77	19.9	69.7
TMF2	Mean	1.30	106.1	77.4	0.35	8.98	27.10	124.4	0.17	715	7.66	11.34	190	0.40	0.80	1.04	5.40	132.6	2.25	49.0	146.4
TMF2	Max	**4.12**	**227.9**	**111.7**	**0.58**	**31.95**	**73.94**	**163.8**	**0.33**	**1,381**	**18.56**	**41.11**	**225**	**0.75**	**1.43**	**2.67**	**8.97**	**387.3**	**2.77**	**128.3**	**335.7**
TMF2	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.43	0.71	1	1	1	1	1
	SS MAX	**6.01**	**275.5**	**166.7**	**2.11**	**32.0**	**73.9**	**574.7**	**0.65**	**2,345**	**18.56**	**41.11**	**818**	**1.87**	**1.43**	**3.52**	**8.97**	**387.3**	**3.76**	**128.3**	**647.2**

means based on half the detection limit for nondetect samples
FD - frequency of detection (fraction)
units - mg/kg

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Table 7-3b. Exposure Data for Phase 2 Spoils

EA	Statistic	Ag	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Tl	Ti	U	V	Zn
1	Min	2.50	73.17	60.41	0.13	0.20	4.00	81.20	0.36	85.07	3.80	0.40	1,112	0.75	0.40	0.40	2.74	20.00	0.63	4.00	86.69
1	Mean	29.23	1,076	346	0.66	0.62	4.00	2,016	5.90	259	47.67	2.44	23,812	13.28	1.25	1.58	12.99	45.51	3.05	6.59	485
1	Max	**82.56**	**3,509**	**1,384**	**1.57**	**1.37**	**4.00**	**7,078**	**16.68**	**861**	**108**	**5.47**	**78,441**	**39.42**	**2.79**	**6.07**	**29.48**	**73.11**	**4.88**	**14.28**	**1,313**
1	FD	1	1	1	1	0.72	0	1	1	1	1	0.89	1	1	0.61	0.44	1	0.72	1	0.39	1
2	Min	1.35	263	24.76	0.13	0.20	4.00	150	0.57	20.00	2.14	0.40	1,506	1.29	0.40	0.40	8.85	20.00	1.35	4.00	47.29
2	Mean	8.93	571	101	0.52	1.43	5.95	612	2.61	116	25.35	2.39	5,192	3.54	1.37	1.01	13.18	55.02	2.77	6.28	203
2	Max	**19.05**	**1,046**	**343**	**1.21**	**3.68**	**37.58**	**1,337**	**17.48**	**417**	**53.82**	**11.52**	**24,266**	**7.45**	**3.94**	**5.25**	**26.24**	**209**	**12.82**	**15.54**	**376**
2	FD	1	1	1	1	0.92	0.08	1	1	1	1	0.83	1	1	0.75	0.17	1	0.63	1	0.29	1
3	Min	1	8	5	0	0.58	4.00	73.95	0.17	44.67	1.31	0.40	111.81	0.89	0.40	0.40	0.40	20.00	0.40	4.00	49.01
3	Mean	9.83	457	27.36	0.31	2.39	6.62	1,490	0.94	499	45.62	3.16	5,360	2.04	1.31	5.51	7.50	130	1.52	9.95	199
3	Max	**31.38**	**942**	**93.23**	**0.53**	**5.92**	**13.33**	**2,912**	**3.76**	**1,043**	**88.34**	**8.16**	**21,753**	**4.62**	**3.06**	**24.59**	**9.46**	**259**	**2.36**	**22.96**	**415**
3	FD	1	1	1	1	1	0.33	1	1	1	1	0.92	1	1	0.67	0.92	1	0.92	1	0.50	1
4	Min	1.67	216	20.85	0.33	0.47	4.00	466	0.23	97.60	11.79	1.01	1,091	0.87	0.40	0.40	6.69	20.00	1.12	4.00	181
4	Mean	20.18	1,084	31.23	1.94	3.37	4.88	2,895	5.73	365	88.34	4.28	21,932	11.42	1.82	6.58	9.81	185.80	2.63	11.02	1,037
4	Max	**44.62**	**2,893**	**70.97**	**6.30**	**8.54**	**11.03**	**11,116**	**20.87**	**471**	**186**	**11.44**	**74,877**	**44.01**	**6.17**	**13.75**	**14.14**	**849**	**4.80**	**26.28**	**2,628**
4	FD	1	1	1	1	1	0.13	1	1	1	1	1	1	1	0.75	0.88	1	0.88	1	0.63	1
5	Min	35.00	371.91	10.00	50.00	30.00	75.00	410.12	15.00	35.00	NA	25.00	1,128	20.00	20.00	30.00	10.00	601	0.00	25.00	25.00
5	Mean	35.00	982	421	50.00	411	75.00	1,210	15.00	669	NA	25.00	7,846	79.72	20.00	30.00	280	1,287	0.00	25.00	285
5	Max	**35.00**	**2,940**	**1,549**	**50.00**	**1,774**	**75.00**	**3,404**	**15.00**	**957**	NA	**25.00**	**22,877**	**228.89**	**20.00**	**30.00**	**949**	**2,299**	**0.00**	**25.00**	**796**
5	FD	0	1	0.38	0	0.31	0	1	0	0.94	NA	0	1	0.38	0	0	0.81	1	0	0	0.75
6	Min	0.02	67.46	13.27	0.02	0.20	4.00	57.11	0.16	89.33	1.20	1.24	106.77	0.10	0.40	0.40	5.59	72.77	1.18	4.00	65.96
6	Mean	7.39	1,150	42.76	0.23	3.95	14.02	719	1.21	610	61.50	7.77	3,759	4.09	3.02	4.95	10.90	193	2.44	27.62	167
6	Max	**55.35**	**3,903**	**92.40**	**1.32**	**17.64**	**90.21**	**2,822**	**8.20**	**1,777**	**188**	**31.33**	**28,363**	**19.93**	**9.76**	**26.67**	**16.55**	**779**	**5.32**	**180**	**733**
6	FD	0.96	1	1	0.85	0.96	0.31	1	1	1	1	1	1	0.96	0.88	0.85	1	1	1	0.88	1
7	Min	ND	24.0	0.24	ND	59.7	35.2	31.1	4.2	112	NA	24.3	29.4	ND	ND	ND	NA	NA	NA	NA	4.9
7	Mean	ND	62.3	1.2	ND	59.7	118	44.0	4.4	297	NA	45.5	274	ND	ND	ND	NA	NA	NA	NA	22.2
7	Max	ND	184	2.2	ND	59.7	243	59.9	4.6	791	NA	79.9	960	ND	ND	ND	NA	NA	NA	NA	41.3
7	FD	ND	1	1	ND	1	1	1	1	1	NA	1	1	ND	ND	ND	NA	NA	NA	NA	1
	Spoils MAX	**82.56**	**3,903**	**1,549**	**6.30**	**1,774**	**243**	**11,116**	**20.87**	**1,777**	**188**	**79.9**	**78,441**	**229**	**9.76**	**26.67**	**949**	**2,299**	**12.82**	**180**	**2,628**

means based on half the detection limit for nondetect samples

overall maximums do not include EA maximums where constituent was not detected (i.e., where maximums are based only on half the detection limit)

FD - frequency of detection (fraction)

units - mg/kg

Data for EA-5 are from GSI, and values associated with non-detect data (where FD=0) are invalid for comparison or risk estimation

ND = constituent not detected above detection limit in any sample (FD=0)

NA = not analyzed for this constituent

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Table 7-4. Phase 2 Selection of Ecological COCs

Surface Water	Max Conc		Ecological Screening Level		Screening HQ	
COPC	Rivers	Adits/Misc.	ESL	ESL Source	River HQ	Adit/Misc. HQ
Ammonia (total, mg/L)	1.3	9.04	0.0017	4	**765**	**5,318**
Aluminum (D)	24,970	1,032,000	87	2	**287**	**11,862**
Antimony (D)	10	2.0	30	3	0.33	0.1
Arsenic (D)	6.0	154	190	2.0	0.03	0.8
Barium (D)	54	134	4	3	**14**	**34**
Cadmium (D)	24	519	1.1	2	**21.8**	**472**
Chromium (D)	1.0	102	210	2	0.005	0.5
Cobalt (D)	2.0	495	23	3	0.1	**22**
Copper (D)	298	88,760	5	1	**59.6**	**17,752**
Lead (D)	239	2,176	5	1	**47.8**	**435**
Manganese (D)	15,840	17,050	120	3	**132.0**	**142**
Mercury (D)	0.03	0.05	0.0028	3	**8.9**	**18**
Nickel (D)	124	329	160	2	0.78	**2.1**
Selenium (D)	17	5.0	5	2	**3.4**	**1.0**
Silver (D)	1.0	2.0	0.36	3	**2.8**	**5.6**
Thallium (D)	0.5	5.0	12	3	0.04	0.4
Tin (D)	10	1.0	73	3	0.14	0.01
Titanium (D)	1.0	11	No Value	NA	NA	NA
Uranium (D)	2	61	2.6	3	0.8	**23**
Vanadium (D)	3.0	3.0	20	3	0.2	0.2
Zinc (D)	9,167	132,900	50	1	**183**	**2,658**

Notes:
Maximum concentrations for rivers and tributaries (rivers) are from CDM high flow and GSI low flow data sets (2006-2007)
Maximum concentrations for adits/misc. surface waters are from CDM high flow and GSI low flow data sets (2006-2007)
Outlier or suspect data not included (e.g., Sb, Mn, Sn, and V data for Avoca River below Shelton Abbey TMF (GSI)
Units are µg/L except for ammonia
D = dissolved concentration
ESL Source:
1 - Ireland EPA Dangerous Substances Regulations Limit for surface water
2 - USEPA chronic criterion to protect aquatic life (@ hardness = 100 mg/L where applicable)
3 - Secondary chronic value, ORNL (Suter and Tsao 1997)
4 - Lowest chronic value for fish, ORNL (Suter and Tsao 1997)

Sediment (mg/kg)				
COPC	Max Conc	ESL	ESL Source	Screening HQ
Antimony	1.68	12	5	0.14
Arsenic	481	9.79	1	**49.1**
Cadmium	1.84	0.99	1	**1.9**
Chromium	33.9	43.4	1	0.78
Cobalt	20.2	50	1	0.40
Copper	503	31.6	1	**15.9**
Lead	704	35.8	1	**19.7**
Manganese	8,070	630	2	**12.8**
Mercury	0.16	0.174	1	0.92
Molybdenum	2.00	10	3	0.20
Nickel	25.8	22.7	1	**1.1**
Selenium	1.28	2	4	0.64
Silver	1.05	2	5	0.53
Zinc	268	121	1	**2.2**

Table 7-4. Phase 2 Selection of Ecological COCs
ESL Source:
1 - USEPA Region 5 Ecological Screening Level
2 - Lowest Assessment and Remediation of Contaminated Sediments (ARCS) Program Threshold
   Effects Level (*Hyalella azteca*), in Buchman 1999 (NOAA SQuiRTS Table)
3 - Dutch Ministry of Standards Target Value (MHSPE 1994)
4 - USEPA Region 3 Ecological Screening Level
5 - USEPA Region 4 Ecological Screening Level

Surface Soil Exposure (mg/kg)				
COPC	Max Conc	ESL	ESL Source	Screening HQ
Antimony	1.87	5	3	0.37
Arsenic	276	5.7	1	**48.4**
Barium	167	440	4	0.38
Cadmium	2.11	2.22	1	0.95
Chromium	73.9	0.4	1	**185**
Cobalt	32	200	4	0.16
Copper	575	5.4	1	**106**
Lead	818	0.0537	1	**15,233**
Manganese	2,345	100	2	**23.5**
Mercury	0.65	0.1	1	**6.5**
Molybdenum	18.6	10	5	**1.9**
Nickel	41.1	13.6	3	**3.0**
Selenium	1.43	1.8	4	0.8
Silver	6.01	4.04	1	**1.5**
Thallium	8.97	1.0	3	**9.0**
Tin	3.52	NV	-	-
Titanium	387	1,000	6	0.39
Uranium	3.76	NV	-	-
Vanadium	128	58	4	**2.2**
Zinc	647	6.62	1	**97.7**

ESL Source:
1 - USEPA Region 5 RCRA ESL for surface soil
2 - ORNL Screening Benchmark for soil microorganisms and microbial processes
3 - ORNL Screening Benchmark for phytotoxicity
4 - USEPA Region 3 BTAG Ecological Screening Level
5 - Threshold for molybdenosis in cattle (USEPA Region 6-approved ESL for Molycorp MIning Site, NM, 2006)
6 - USEPA Region 4 Ecological Screening Value

Mine Spoils Exposure (mg/kg)				
COPC	Max Conc	ESL	ESL Source	Screening HQ
Antimony	229	5	3	**45.8**
Arsenic	3,903	5.7	1	**685**
Barium	1,549	440	4	**3.5**
Cadmium	6.3	2.22	1	**2.8**
Chromium	243	0.4	1	**608**
Cobalt	1,774	200	4	**8.9**
Copper	11,116	5.4	1	**2,059**
Lead	78,441	0.0537	1	**1,460,726**
Manganese	1,777	100	2	**17.8**
Mercury	20.9	0.1	1	**209**
Molybdenum	188	10	5	**18.8**
Nickel	79.9	13.6	3	**5.9**
Selenium	9.8	1.8	4	**5.4**
Silver	82.6	4.04	1	**20.4**
Thallium	949	1.0	3	**949**
Tin	26.7	NV	-	-

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Table 7-4. Phase 2 Selection of Ecological COCs

Titanium	2,299	1,000	6	**2.3**
Uranium	12.8	NV	-	-
Vanadium	180	58	4	**3.1**
Zinc	2,628	6.62	1	**397**

ESL Source:

1 - USEPA Region 5 RCRA ESL for surface soil

2 - ORNL Screening Benchmark for soil microorganisms and microbial processes

3 - ORNL Screening Benchmark for phytotoxicity

4 - USEPA Region 3 BTAG Ecological Screening Level

5 - Threshold for molybdenosis in cattle (USEPA Region 6-approved ESL for Molycorp MIning Site, NM, 2006)

6 - USEPA Region 4 Ecological Screening Value

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Section 8
Effects Assessment

The Effects Assessment step of the ERA replaces the conservative and relatively general ESLs used for screening COCs with more receptor-specific toxicity data. This results in risk estimates that are more realistic and more applicable to specific receptors or receptor groups. The Phase 2 Effects Assessment is based on the same methods and assumptions presented in the Phase 1 ERA. In addition, some of the effects values selected for use in the Phase 1 ERA as toxicity reference values (TRVs) are retained for use in the Phase 2 ERA. The primary difference between the Phase 1 and Phase 2 Effects Assessments is the addition of Phase 2 TRVs for COCs not evaluated in the Phase 1 ERA. For all media, TRVs are selected based on the receptors or receptor groups of most interest.

8.1 Surface Water Effects Data

Surface water TRVs for surface water are divided into two categories, reflecting the two categories of surface waters: (1) rivers and tributaries and (2) adits, springs, and miscellaneous surface waters.

TRVs for the former are based on toxicity data for salmonid fish where such data are available. For hardness-dependent inorganic COCs, the hardness-adjusted equations are based on studies in which salmonid fish were exposed to dissolved inorganic COCs at varying hardness. From these studies a relationship was established between hardness and toxicity, and the equations depicting these relationships are presented in Table 8-1. Hardness values used to modify the salmonid-based TRVs were calculated using the average dissolved calcium and magnesium concentrations for each EA based on CDM 2007 data. For all EAs except EA-8, the average hardness was calculated as approximately 31 mg/L $CaCO_3$. For EA-8, the average hardness was considerably higher at 356 mg/L. As previously discussed, this high hardness value result from two samples (Left and Right Bank) that had tidal (sea water) influence. The high hardness is not representative of the Avoca River. Salmonid-specific TRVs for hardness-dependent metals were adjusted for each of these two hardness values, and both sets of TRVs are shown on Table 8-1. In a few cases, TRVs for rivers and tributaries are not salmonid specific because data were lacking. TRVs for rivers and tributaries, in order of preference, are based on the following test organisms: salmonid fish>freshwater non-salmonid fish>freshwater invertebrate.

For comparison purposes, the average hardness was also calculated for EAs 2, 3, and 6 based on lower flow GSI surface water data for rivers and tributaries. The average hardness values thus calculated equal 119 mg/L (EA-2), 26 mg/L (EA-3), and 22 mg/L (EA-6). These data were not used to modify the hardness-dependent TRVs because they included multiple sampling years (2006 and 2007) and because the data set included considerably fewer values than the more extensive 2007 CDM data set. However, it should be noted that the hardness values based on the GSI data for EAs 3 and 6 are very similar to those calculated from the CDM data set. The major difference

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in average hardness values between the two data sets (GSI and CDM) is noted for EA-2, where the average is 119 mg/L for the GSI 2006 and 2007 data, and 24 mg/L for the 2007 CDM data. This substantial difference is likely attributable to the much higher flows under which the CDM data were collected (providing dilution of dissolved Ca and Mg). For retaining a conservative approach, the mean hardness calculated for EAs 1-7 based on CDM data (31 mg/L) is used to modify hardness-dependent TRVs. Using the GSI-based hardness of 119 mg/L for EA-2 would result in substantially higher (less stringent or conservative) TRVs.

TRVs for adits, springs, and miscellaneous surface waters are based primarily on toxicity data for aquatic invertebrates, in recognition that these waters are unlikely to support fish. In many cases, these waters are also unlikely to support aquatic invertebrates. However, using toxicity data based on aquatic invertebrates for adits, springs, etc. reveals the relative aquatic toxicity of these waters.

For both major categories of surface water, selected COC-specific TRVs are based on chronic (as opposed to shorter term acute) exposures. This approach ensures protection against long term exposures that can result in sublethal as well as lethal effects. Effect endpoints of concern include survival, growth, and reproduction.

Table 8-1. Surface Water Ecological Toxicity Reference Values (TRVs)

Chronic TRVs for Salmonid Fish (Rivers and Tributaries)							
Hardness-dependent Metals (Hardness = 356 mg/L)							
SW COC	Dissolved	T/R	mc	hard	ln hard	bc	CF
Al	**1,777**	1,777	0.8327	356	5.8749	2.5905	1
Cd	**7.97**	9.31	0.7061	356	5.8749	-1.9172	0.856
Cr III	**503**	585	0.8190	356	5.8749	1.5603	0.86
Cu	**46**	48	0.5897	356	5.8749	0.3979	0.96
Pb	**650**	1,073	1.2730	356	5.8749	-0.5004	0.606
Mn	**15,732**	15,732	0.9237	356	5.8749	4.2368	1
Ni	**470**	471	0.8460	356	5.8749	1.1851	0.997
Zn	**2,302**	2,334	0.8806	356	5.8749	2.582	0.986

Hardness Equations
[1] Total Al chronic = $e^{0.8327[\ln(\text{hardness})]+2.5905}$
[2] Dissolved Cd chronic = $(1.101672-[(\ln \text{hardness})(0.041838)])*e^{0.7061[\ln(\text{hardness})]-1.9172}$
[3] Dissolved Cr III chronic = $0.962*e^{0.8190[\ln(\text{hardness})]+1.5603}$
[4] Dissolved Cu chronic = $0.960*e^{0.5897[\ln(\text{hardness})]+0.3979}$
[5] Dissolved Pb chronic = $(1.46203-[(\ln \text{hardness})(0.145712)])*e^{1.2730[\ln(\text{hardness})]-0.5004}$
[6] Total Mn chronic = $e^{0.9237[\ln(\text{hardness})]+4.2368}$
[7] Dissolved Ni chronic = $0.997*e^{0.8460[\ln(\text{hardness})]+1.1851}$
[8] Dissolved Zn chronic = $0.986*e^{0.8806[\ln(\text{hardness})]+2.5820}$

Chronic TRVs for Salmonid Fish (Rivers and Tributaries)							
Hardness-dependent Metals (Hardness = 31 mg/L)							
SW COC	Dissolved	T/R	mc	hard	ln hard	bc	CF
Al	**233**	233	0.8327	31	3.434	2.5905	1
Cd	**1.59**	1.66	0.7061	31	3.434	-1.9172	0.958
Cr III	**68**	79	0.8190	31	3.434	1.5603	0.86
Cu	**11**	11	0.5897	31	3.434	0.3979	0.96
Pb	**46**	48	1.2730	31	3.434	-0.5004	0.962
Mn	**1,650**	1,650	0.9237	31	3.434	4.2368	1
Ni	**60**	60	0.8460	31	3.434	1.1851	0.997
Zn	**268**	272	0.8806	31	3.434	2.582	0.986

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Table 8-1. Surface Water Ecological Toxicity Reference Values (TRVs)

Hardness Equations

[1] Total Al chronic = $e^{0.8327[\ln(hardness)]+2.5905}$

[2] Dissolved Cd chronic = $(1.101672-[(\ln hardness)(0.041838)])*e^{0.7061[\ln(hardness)]-1.9172}$

[3] Dissolved Cr III chronic = $0.962*e^{0.8190[\ln(hardness)]+1.5603}$

[4] Dissolved Cu chronic = $0.960*e^{0.5897[\ln(hardness)]+0.3979}$

[5] Dissolved Pb chronic = $(1.46203-[(\ln hardness)(0.145712)])*e^{1.2730[\ln(hardness)]-0.5004}$

[6] Total Mn chronic = $e^{0.9237[\ln(hardness)]+4.2368}$

[7] Dissolved Ni chronic = $0.997*e^{0.8460[\ln(hardness)]+1.1851}$

[8] Dissolved Zn chronic = $0.986*e^{0.8806[\ln(hardness)]+2.5820}$

TRV Source:

1 - USEPA chronic ambient water quality criterion (AWQC), hardness adjusted (Salmonid-specific data based on multiple evaluations by Chadwick Ecological Consultants 2007)

Hardness slope and toxicity database are freshwater salmonid-specific

General equation from USEPA for chronic AWQC (2006) is:

$AWQC_{chronic} = \exp\{mc[\ln(hardness)]+bc\}(CF)$

mc and bc are model inputs from USEPA adjusted for salmonid fish only

CF is the total recoverable to dissolved converstion factor

ln hardness is the normal log of the site water hardness

Chronic TRVs for Surface Water (Other)				
COC	**River**	**Source**	**Adit**	**Source**
Ammonia (mg/L)	**2.6**	1	**3.5**	1
Aluminum (D)	see above		**1900**	3
Antimony (D)	**1600**	2	**5400**	3
Arsenic (D)	**2,962**	2	**914**	3
Barium (D)	**4**	4	**4**	4
Cadmium (D)	see above		**0.15**	3
Chromium (D)	see above		**44**	3
Cobalt (D)	**290**	2	**5.1**	3
Copper (D)	see above		**0.23**	3
Lead (D)	see above		**12.3**	3
Manganese (D)	see above		**1,100**	3
Mercury (D)	**0.23**	2	**0.96**	3
Nickel (D)	see above		**5**	3
Selenium (D)	**88.3**	2	**91.7**	3
Silver (D)	**0.12**	2	**2.6**	3
Thallium (D)	**57**	2	**130**	3
Tin (D)	**73**	4	**350**	3
Titanium (D)	no available data			
Uranium (D)	**142**	2	**2.6**	4
Vanadium (D)	**80**	2	**1,900**	3
Zinc (D)	see above		**46.7**	3

Notes:

TR = Total Recoverable

Units are µg/L except for ammonia

Ammonia TRVs assume pH = and temp(C) = (averages)

River - applicable to rivers and tributaries (mostly based on protection of fish)

Adit - applicable to adits, springs, and misc. SW (non-fish based)

TRV Source:

1 - USEPA Ammonia Criteria, All rivers and tributaries = pH=6.4, T=15 C.

2 - Lowest chronic value for fish, ORNL (Suter and Tsao 1997)

3 - Lowest chronic value for daphnids, ORNL (Suter and Tsao 1997)

4 - ORNL Tier II Secondary Chronic Value

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8.2 Sediment Effects Data

As discussed previously, TRVs for sediment are based primarily on potential toxicity to freshwater benthic invertebrates. For most sediment COCs, these are Consensus Based Threshold Effects Concentrations (MacDonald et al. 2000). For manganese, the selected TRV is the lowest effect concentration associated with adverse effects in the benthic amphipod *Hyalella azteca* (Buchman 1999). Maintaining sediment concentrations below the selected TRV levels is assumed to prevent adverse effects in the benthic community based on survival, growth, and reproduction.

Table 8-2 Sediment Ecological Toxicity Reference Values (TRVs)

Sediment TRVs (mg/kg)			
COC	**TRV**	**Receptor Group**	**Source**
arsenic	9.79	benthic macroinvertebrates	1
cadmium	0.99	benthic macroinvertebrates	1
copper	31.6	benthic macroinvertebrates	1
lead	35.8	benthic macroinvertebrates	1
manganese	630	benthic macroinvertebrates	2
nickel	22.7	benthic macroinvertebrates	1
zinc	121	benthic macroinvertebrates	1

TRV Source:

1 - Consensus based threshold effect concentration (MacDonald et al. 2000)

2 - Lowest Assessment and Remediation of Contaminated Sediments
    (ARCS) Program Threshold Effects Level (*Hyalella azteca*), in Buchman
    1999 (NOAA SQuIRTS Table)

8.3 Soil and Spoils Effects Data

Ecotoxicity data for terrestrial media (defined here as soils and spoils) are sparse compared to data for water and sediment. For some of the less-studied soil and spoils COCs, there is greater uncertainty in selected TRVs. Where data allow, TRVs for both soils and spoils are based on toxicity to terrestrial plants (phytotoxicity) or terrestrial invertebrates (represented by earthworm). Because of special concerns with molybdenosis in livestock (which manifests as a copper deficiency), the TRV for molybdenum in soils and spoils is based on the threshold for molybdenosis in cattle. Cattle have been shown to be among the most sensitive domestic animals to molybdenum exposures.

Table 8-3 Surface Soil and Spoils Ecological Toxicity Reference Values (TRVs)

Surface Soil TRVs (mg/kg)			
COC	**TRV**	**Receptor Group**	**Source**
antimony	5	terrestrial plants	1
arsenic	10	terrestrial plants	1
barium	500	terrestrial plants	1
cadmium	4	terrestrial plants	1
chromium	0.4	earthworm	2
cobalt	20	terrestrial plants	1
copper	50	earthworm	2
lead	50	terrestrial plants	1
manganese	500	terrestrial plants	1
mercury	0.1	earthworm	2
molybdenum	10	cattle	3
nickel	30	terrestrial plants	1
selenium	1	terrestrial plants	1

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Table 8-3 Surface Soil and Spoils Ecological Toxicity Reference Values (TRVs)

silver	2.0	terrestrial plants	1
thallium	1.0	terrestrial plants	1
titanium	1,000	soil microbes	4
vanadium	2.0	terrestrial plants	1
zinc	50	terrestrial plants	1

Notes:
Soil TRVs are lowest of relevant and available values for phytotoxicity and soil invertebrate toxicity
TRVs are unavailble for Tin and Uranium (detected in spoils)

TRV Source:
1 - ORNL phytotoxicity benchmark (Efroymson, Will, Suter II, and Wooten 1997)
2 - ORNL soil invertebrate benchmark (Efroymson, Will, and Suter II 1997)
3 - Threshold for molybdenosis in cattle (USEPA Region 6-approved ESL for Molycorp MIning Site, NM)
4 - ORNL benchmark for soil microbes and microbial processes (Efroymson, Will, and Suter II 1997)

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Section 9
Risk Characterization

The Risk Characterization approach used in Phase 2 is similar to that used in Phase 1 – the Hazard Quotient or HQ approach. As discussed in the Phase 1 ERA, HQs are derived by dividing exposure point concentrations by effects data concentrations. Because data for most COCs and EAs were relatively few in the Phase 1 ERA, exposure concentrations in Phase 1 were based on both mean and maximum concentrations for surface water and on single values for sediment and soils and spoils. Exposure concentrations for Phase 2 are based on average (arithmetic mean) values, which are assumed to best represent the COC concentration to which ecological receptors could be exposed.

9.1 Hazard Quotients

Hazard quotients or HQs are used to quantify risks to ecological receptors, based on comparisons of exposure concentrations (e.g., mean concentrations) to effects concentrations (i.e., TRVs).

$$HQ = \frac{Exposure\ Concentration\ of\ COC}{Effects\ Concentration\ of\ COC}$$

As described in detail in the Phase 1 ERA, HQs greater than 1.0 suggest potential for adverse effects (risk), while HQs below 1.0 suggest little or no significant risk. Higher HQs don't necessarily indicate more severe effects, but can be related to greater likelihood that adverse effects will occur or be observed. Phase 2 HQs are presented in the following tables:

- Table 9-1: Surface Water HQs
  - Part 1: Rivers and Tributaries - CDM data
  - Part 2: Rivers and Tributaries - GSI data
  - Part 3: Adits, Springs, and Miscellaneous Surface Waters – CDM data
  - Part 4: Adits, Springs, and Miscellaneous Surface Waters – GIS data
- Table 9-2: Sediment HQs
  - Part 1: CDM data
  - Part 2: GSI data
- Table 9-3a: Surface Soils HQs
- Table 9-3b: Mine Spoils HQs

These are presented and discussed below.

9.1.1 Surface Water HQs

Table 9-1 includes four parts. These are (1) HQs for Rivers and Tributaries – CDM data, (2) HQs for Rivers and Tributaries – GSI data, (3) HQs for Miscellaneous Surface Waters – CDM data, and (4) Miscellaneous Surface Waters – GSI data.

CDM

Table 9-1. Surface Water Hazard Quotients (HQs)
Part 1 - Rivers and Tributaries - CDM Data

Rivers and Tributaries	Fish-based TRV (H=31)	Fish-based TRV (H=356)	EA1 REF		EA2		EA3		EA4		EA5		EA6		EA7		EA8	
COPC			EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
Ammonia (total, mg/L)	2.6	2.6	0.118	0.05	0.047	0.02	0.032	0.01	0.15	0.06	0.15	0.06	1.3	0.50	0.15	0.06	0.15	0.06
Aluminum (D)	233	1,777	61	0.26	190	0.82	108	0.46	69	0.30	115	0.49	133	0.57	91	0.39	87	0.05
Barium (D)	4.0	4.0	8.8	**2.2**	22.3	**5.6**	9.4	**2.4**	7.0	**1.8**	22.5	**5.6**	37	**9.3**	10	**2.5**	15.5	**3.9**
Cadmium (D)	1.59	7.97	0.2	0.13	1.1	0.69	0.42	0.26	0.6	0.38	0.4	0.25	0.5	0.31	0.5	0.31	0.28	0.04
Copper (D)	11	46	3.63	0.33	19	**1.7**	6.6	0.60	10	0.91	8.5	0.77	10	0.91	11	**1.0**	4.5	0.10
Lead (D)	46	650	2.13	0.05	5.33	0.12	2.5	0.05	1.0	0.02	2.0	0.04	2.0	0.04	1.0	0.02	1.13	0.002
Manganese (D)	1,650	15,732	10	0.006	78.3	0.05	33.6	0.02	78	0.05	52	0.03	82	0.05	156	0.09	95	0.01
Mercury (D)	0.23	0.23	0.025	0.11	0.025	0.11	0.025	0.11	0.025	0.11	0.025	0.11	0.025	0.11	0.025	0.11	0.025	0.11
Selenium (D)	88.3	88.3	0.625	0.01	0.67	0.01	1.3	0.01	0.5	0.01	0.75	0.01	0.5	0.01	0.5	0.01	7.25	0.08
Silver (D)	0.12	0.12	1.0	**8.3**	1.0	**8.3**	1.0	**8.3**	1.0	**8.3**	1.0	**8.3**	1.0	**8.3**	1.0	**8.3**	1.0	**8.3**
Zinc (D)	268	2,302	17.75	0.07	393	1.47	171.9	0.64	219	0.82	133.5	0.50	146	0.54	148	0.55	123.5	0.05

EPCs are EA-specific average COC concentrations (ug/L except ammonia)
H = average EA-specific hardness (mg/L CaCO$_3$): 31 mg/L for EA1-EA7, and 356 mg/L for EA8
D = dissolved

Part 2 - Rivers and Tributaries - GSI Data

Rivers and Tributaries	Fish-based TRV (H=31)	EA2		EA3		EA6	
COPC		EPC	HQ	EPC	HQ	EPC	HQ
Aluminum (D)	233	11,043	**47.4**	4,332	**18.6**	152	0.65
Barium (D)	4.0	10.3	**2.6**	10.5	**2.6**	6	**1.5**
Cadmium (D)	1.59	13.2	**8.3**	1.3	0.82	0.5	0.31
Copper (D)	11	184	**16.7**	13.5	**1.23**	3.3	0.30
Lead (D)	46	127	**2.8**	4.0	0.09	2.0	0.04
Manganese (D)	1,650	2,032	**1.2**	143	0.09	25	0.02
Mercury (D)	0.23	0.03	0.13	0.03	0.13	0.03	0.13
Selenium (D)	88.3	0.75	0.01	2.0	0.02	1.3	0.01
Zinc (D)	268	5,163	**19.3**	389	**1.5**	85	0.32

EPCs are highest of 2006 or 2007 GSI data for EAs 2 and 3 (single sampling event in 2006 for EA6)
Units = mg/L
D = dissolved

Part 3 - Miscellaneous Surface Waters - CDM Data

Adits, Springs, Misc. Surface Waters	Aq. Invert-based TRV	EA1		EA2		EA3		EA4		EA5		EA6		EA7		EA8		EA9		EA10		EA11		EA12	
COPC		EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
Ammonia (total, mg/L)	3.5	9.04	**2.6**	0.33	0.1	0.21	0.06	0.08	0.02	0.66	0.2	NV	NA	0.27	0.1	0.33	0.09	NV	NA	3.7	**1.1**	0.3	0.09	NV	NA
Aluminum (D)	1,900	99,110	**52**	71,360	**38**	66,140	**35**	18,390	**9.7**	190,800	**100**	34,660	**18**	93,310	**49**	9	0.005	22,980	**12**	20	0.01	6,752	**4**	8	0.004
Barium (D)	4.0	15	**3.8**	11	**2.8**	11	**2.8**	12	**3.0**	17	**4.3**	7	**1.8**	7	**1.8**	63	**16**	134	**34**	17	**4.3**	11	**2.8**	41	**10.3**
Cadmium (D)	0.15	51	**340**	127	**847**	15	**99**	23.3	**155**	311	**2,073**	69.4	**463**	103.5	**690**	0.4	**2.7**	7.7	**51**	15	**100**	126	**840**	0.4	**2.7**
Cobalt (D)	5.1	200	**39**	101	**20**	25	**4.9**	38	**7.5**	315	**62**	94	**18**	109	**21**	9	**1.8**	21	**4.1**	45	**8.8**	92	**18**	1	0.2
Copper (D)	0.23	5.2	**22.6**	3198	**13,904**	18,474	**80,322**	5212	**22,661**	9070	**39,435**	14800	**64,348**	989	**4,300**	1	**4.3**	4549	**19,778**	26	**113**	2822	**12,270**	2	**8.7**
Lead (D)	12.3	237	**19**	1352	**110**	609	**50**	1065	**87**	1318	**107**	1339	**109**	1528	**124**	1	0.1	108	**8.8**	1	0.08	1266	**103**	1	0.08
Manganese (D)	1,100	17,050	**16**	3,132	**2.8**	3,104	**2.8**	875	0.8	12,148	**11**	1,670	**1.5**	4,190	**3.8**	961	0.9	654	0.6	1,501	**1.4**	2,905	**2.6**	6	0.01
Mercury (D)	0.96	0.05	0.1	0.05	0.1	0.03	0.03	0.05	0.1	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nickel (D)	5.0	92	**18**	53	**11**	4.50	0.9	5	**1.0**	161	**32**	6	**1.2**	39	**7.8**	42	**8.4**	9	**1.8**	39	**7.8**	51	**10.2**	1	0.2
Selenium (D)	91.7	5	0.1	2	0.02	0.50	0.01	1	0.01	1.75	0.02	2	0.02	0.5	0.01	1	0.01	1	0.01	1	0.01	3	0.03	1	0.01
Silver (D)	2.6	2	0.8	2	0.8	1.0	0.4	2	0.8	1	0.4	2	0.8	1	0.4	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8
Uranium (D)	2.6	11	**4.2**	10	**3.8**	2.0	0.8	2	0.8	35.5	**14**	6	**2.3**	9.5	**3.7**	1	0.4	1	0.4	1	0.4	9	**3.5**	1	0.4
Zinc (D)	46.7	21,680	**464**	33,030	**707**	5,114	**110**	6,610	**142**	98,050	**2,100**	19,640	**421**	48,125	**1,031**	43,090	**923**	2,806	**60**	5,046	**108**	31,810	**681**	22	0.5

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Table 9-1. Surface Water Hazard Quotients (HQs)

Adits, Springs, Misc. Surface Waters COPC	Aq. Invert-based TRV	EA13 EPC	HQ	EA14 EPC	HQ	EA15 EPC	HQ	EA16 EPC	HQ	EA17 EPC	HQ	EA18 EPC	HQ	EA19 EPC	HQ	EA20 EPC	HQ	EA21 EPC	HQ	EA22 EPC	HQ	EA23 EPC	HQ	EA24 EPC	HQ
Ammonia (total, mg/L)	3.5	0.03	0.01	NV	NA	NV	NA	NV	NA	NV	NA	0.3	0.09	0.03	0.01	NV	NA	6.59	1.9	0.63	0.2	1.22	0.3	NV	NA
Aluminum (D)	1,900	4,017	2.1	1,032,000	543	313,600	165	1,188	0.6	56	0.03	10	0.01	118,400	62	20,930	11	984	0.5	158	0.08	21,730	11	69	0.04
Barium (D)	4.0	37	9.3	66	17	113	28	25	6.3	4	1.0	11	2.8	11	2.8	17	4.3	25	6.3	40	10	7	1.8	27	6.8
Cadmium (D)	0.15	11	73	519	3,460	368	2,453	1.1	7.3	1	6.7	0.4	2.7	13.1	87	12.3	82	0.4	2.7	0.5	3.3	54.8	365	0.8	5.3
Cobalt (D)	5.1	7	1.4	495	97	172	34	1	0.2	1	0.2	1	0.2	20	3.9	134	26	1	0.2	3	0.6	299	59	1	0.2
Copper (D)	0.23	311	1,352	88,760	385,913	39,510	171,783	28	122	14	61	46	200	31,950	138,913	268	1,165	2	8.7	16	70	8,390	36,478	12	52
Lead (D)	12.3	2,176	177	9	0.7	98	8.0	4	0.3	1	0.08	1	0.08	630	51	308	25	1	0.08	28	2.3	102	8.3	8	0.7
Manganese (D)	1,100	347	0.3	14,860	14	4,568	4.2	35	0.03	69	0.06	32	0.03	5,480	5.0	13,240	12	42	0.04	184	0.2	10,410	9.5	7	0.01
Mercury (D)	0.96	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nickel (D)	5.0	8	1.6	329	66	114	23	1	0.2	2	0.4	4	0.8	5	1.0	61	12	7	1.4	2	0.4	89	18	2	0.4
Selenium (D)	91.7	2	0.02	3	0.03	1	0.01	1	0.01	1	0.01	1	0.01	2	0.02	3	0.03	1	0.01	1	0.01	1	0.01	1	0.01
Silver (D)	2.6	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8	2	0.8
Uranium (D)	2.6	1	0.4	61	23	25	9.6	1	0.4	1	0.4	1	0.4	1	0.4	3	1.2	3	1.2	1	0.4	11	4.2	1	0.4
Zinc (D)	46.7	2,655	57	132,900	2,846	113,300	2,426	192	4.1	71	1.5	117	2.5	5,026	108	10,950	234	10,600	227	177	3.8	14,300	306	115	2.5

EPCs are EA-specific average COC concentrations (EAs 3, 5, and 7) or single available concentrations (all other EAs)
D = dissolved concentration
units are µg/L except for ammonia
NV = no value for this COC at this location
NA = not applicable (no EPC)

Part 4 - Miscellaneous Surface Waters - GSI Data

Adits, Springs, Misc. Surface Waters COPC	Aq. Invert-based TRV	Vale View Stream EPC	HQ	Red Road Stream EPC	HQ	Sulphur Brook near discharge to Avoca River EPC	HQ	Sulphur Brook midway EPC	HQ	Spoil run-off - Avoca River mixing zone EPC	HQ	East Avoca OP - Castlehoward Area ditch EPC	HQ	Avoca River below Shelton Abbey TMF EPC	HQ	Avoca River below Vale View stream EPC	HQ
Aluminum (D)	1,900	1,635	0.9	98	0.1	2,037	1.1	716	0.4	1,927	1.0	79	0.0	no data	NA	110	0.1
Barium (D)	4.0	12	3.0	17	4.3	8.0	2.0	15	3.8	7.0	1.8	13	3.3	0.5	0.1	6.0	1.5
Cadmium (D)	0.15	0.5	3.3	1.6	10.7	0.5	3.3	1.2	8.0	1.7	11.3	0.5	3.3	ND	NA	0.2	1.3
Copper (D)	0.23	8.0	34.8	23	100	34	147.8	46	200	42	183	0.5	2.2	11	47.8	8.0	34.8
Lead (D)	12.3	0.5	0.04	0.5	0.04	2.0	0.2	10	0.8	6.0	0.5	0.5	0.04	4.0	0.3	0.5	0.04
Manganese (D)	1,100	4.0	0.004	625	0.6	23	0.02	79	0.1	133	0.1	18	0.02	274,600	250	5.0	0.005
Mercury (D)	0.96	0.03	0.0	0.03	0.0	0.08	0.1	0.03	0.0	0.03	0.0	0.03	0.0	0.29	0.3	0.03	0.0
Nickel (D)	5.0	3.0	0.6	4.0	0.8	0.50	0.1	0.5	0.1	2.0	0.4	0.5	0.1	0.5	0.1	1.0	0.2
Selenium (D)	91.7	0.5	0.01	2.0	0.02	0.50	0.01	2.0	0.02	2.0	0.02	0.5	0.01	ND	NA	0.5	0.01
Uranium (D)	2.6	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.2
Zinc (D)	46.7	30	0.6	479	10.3	88	1.9	315	6.7	532	11.4	63	1.3	no data	NA	64	1.4

EPCs are highest of 2006 or 2007 GSI data
units - µg/L
ND - not detected (U qualified value)
NA - not applicable
highlighted EPCs appear to be outliers or suspect values
D = dissolved

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All River and Tributary HQs are based on salmonid fish TRVs. For River and Tributary data based on CDM high flow sampling, HQs generally remain below 1.0 for most dissolved inorganic COCs except for Cu and Zn in EA-2 (mining area). Low but elevated HQs are noted for barium and silver, but these HQs are not based on extensive toxicity data and are therefore associated with some uncertainty. Based on GSI lower flow data, HQs are elevated for aluminum, barium, cadmium, copper, lead, manganese, and zinc. These surface water data and associated HQs are applicable only to EAs 2, 3, and 6; 2007 GSI data are lacking for the other designated EAs. HQs were significantly higher using the GSI data at lower flows (especially in EA-2 for Cu, Zn, and Al).

Many of the miscellaneous surface waters sampled by both CDM and the GSI are associated with elevated HQs based on the selected TRVs for aquatic invertebrates. These include aluminum, barium, cadmium, cobalt, copper, lead, manganese, nickel, uranium, and zinc (CDM data, all dissolved concentrations). Dissolved constituents with elevated HQs are also noted for aluminum, barium, cadmium, copper, manganese, and zinc based on the GSI data set.

9.1.2 Sediment HQs

As can be seen on Table 9-2, sediment HQs based on average concentrations (EPCs) within the CDM data set are most elevated for arsenic, copper, and lead in EA-2. Compared to the upstream reference location (EA-1), the HQs for these COCs are substantially higher at EA-2 and lower but still elevated at EA-3 and EA-4 (arsenic and copper). Interestingly, HQs for zinc are below 1.0 only for EA-Unique, which represents the lower Aughrim River just upstream of its confluence with the Avoca. This observation indicates that EA-1 (Reference) probably has elevated metal concentrations from upgradient sources. Nickel is slightly elevated in sediments collected from EA-1, 3, 6, and Unique. Figure 9-1 presents the mean and maximum concentrations of arsenic, copper, lead, and zinc in sediments for EAs 1, 2, 3, 4, 6, and Unique. This figure clearly shows that most mean and most maximum concentrations of these COCs in sediment are associated with EA-2.

For the 2007 GSI data set, elevated HQs are noted for arsenic, copper, lead, manganese, nickel, and zinc at one or more EAs. Note that this data set is more limited in the EAs sampled (EAs 1, 2, 3, 4, and 6) and in the number of constituents. HQs are higher for EAs downgradient of the reference EA (EA-1) for arsenic, copper, and to minimal degree, zinc (EA-6 only). Data from EA-1 (Reference) probably have elevated metal concentrations due to upgradient metal sources.

Table 9-2. Sediment Hazard Quotients (HQs)
Part 1 - CDM Data (2007)

Sediment HQs		EA-1 (REF)		EA-2		EA-3		EA-6		EA-Unique	
COC	TRV	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
arsenic	9.79	27.8	**2.8**	203	**20.7**	32.9	**3.4**	29.8	**3.0**	21.6	**2.2**
cadmium	0.99	1.84	**1.9**	0.48	0.5	0.71	0.7	0.40	0.4	0.26	0.3
copper	31.6	34.9	**1.1**	266	**8.4**	156	**4.9**	72.6	**2.3**	21.8	0.7
lead	35.8	259	**7.2**	400	**11.2**	148	**4.1**	80.4	**2.2**	21.4	0.6
manganese	630	5,016	**8.0**	2,852	**4.5**	2,397	**3.8**	1,925	**3.1**	2,066	**3.3**
nickel	22.7	23.8	**1.0**	10.8	0.5	23.6	**1.0**	25.5	**1.1**	22.0	**1.0**
zinc	121	268	**2.2**	194	**1.6**	219	**1.8**	164	**1.4**	103	0.9

all units are mg/kg
EPCs are based on mean concentrations
HQs > 1 shown in **bold** type
HQs>REF are shown in highlight

Part 2 - GSI Data (2007)

Sediment HQs		EA-1 (REF)		EA-2		EA-3		EA-4		EA-6	
COC	TRV	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
arsenic	9.79	34.6	**3.5**	53	**5.4**	73.1	**7.5**	60.2	**6.1**	47.3	**4.8**
copper	31.6	60.8	**1.9**	443	**14.0**	381	**12.1**	257	**8.1**	224	**7.1**
lead	35.8	640	**17.9**	314	**8.8**	546	**15.3**	412	**11.5**	257	**7.2**
manganese	630	6,959	**11.0**	2,283	**3.6**	4,933	**7.8**	3,665	**5.8**	3,861	**6.1**
nickel	22.7	no data	NA	no data	NA	no data	NA	no data	NA	57.9	**2.6**
zinc	121	755	**6.2**	267	**2.2**	587	**4.9**	573	**4.7**	784	**6.5**

all units are mg/kg
EPCs are highest of two values for EAs 1, 2, and 3 (single values for EAs 4 and 6)
HQs > 1 shown in **bold** type
HQs>REF are shown in highlight

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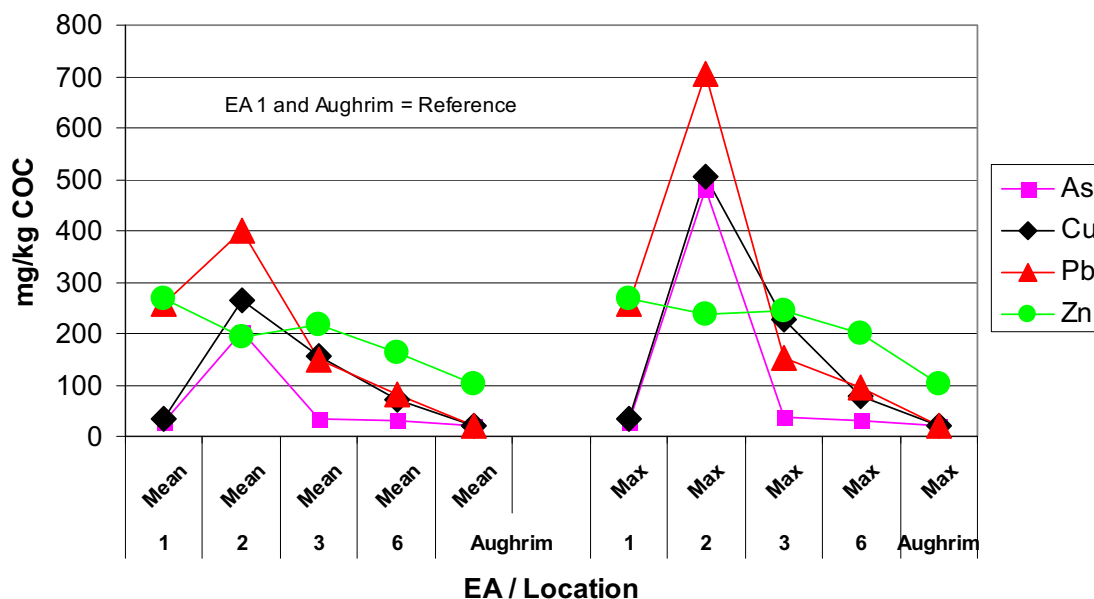
Figure 9-1. Mean and Maximum Concentrations of Selected COCs in Sediment (2007 CDM Data)

9.1.3 Surface Soils/Spoils HQs

Table 9-3a provides the surface soil risk estimates for locations identified as farmer's agricultural fields. These results are shown as HQs based on measured concentrations of metals in agricultural fields divided by conservative soil-based TRVs. The resulting HQs are quite conservative because the TRVs are stringent values based on protection of sensitive plants or soil-dwelling organisms. Because of the inherent conservatism, exceedance of TRVs (i.e., HQ>1) is not unexpected in some cases. This is especially true for chemicals for which toxicity data are sparse, such as molybdenum, thallium, and vanadium and for chemicals for which the toxicity data are extremely conservative (e.g., Cr). HQs for these COCs probably overestimate risk to some degree. HQs for metals in agricultural fields are generally below 1.0 (no unacceptable risk) for molybdenum, nickel, and silver. HQs are highest for chromium, but again these risk estimates are likely not indicative of a strong likelihood of adverse effects. HQs are also elevated for arsenic, copper, lead, manganese, thallium, vanadium, zinc, and, in a few cases, mercury. Many of these HQs are near the 1.0 threshold and adverse effects are unexpected.

Table 9-3b presents similar data for mine spoils based on EAs 1 through 7, and these locations are identified in previous sections. The same TRVs as described for agricultural fields are used to generate HQs for the mine spoils data. Again, some of these TRVs are overly conservative, and others are based on limited toxicity data. In general, HQs are low (below or not substantially exceeding 1.0) for antimony, barium, cadmium, cobalt, manganese, nickel, selenium (except EA-5), and titanium. HQs are quite elevated for arsenic, chromium (again, these risk estimates are probably overly conservative), copper, lead, mercury, silver, thallium, vanadium, and zinc. HQs are moderately elevated for molybdenum, and these HQs are based on potential for molybdenosis in livestock. The highest HQs are for EAs 5 (generally the highest), 4, and 1.

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Table 9-3a. Surface Soil Hazard Quotients (HQs)

Surface Soil HQs		EA-PHF		EA-GMF		EA-IFF		EA-KF1		EA-KF2		EA-TMF1		EA-TMF2	
COC	TRV	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
arsenic	10.0	73	**7.3**	84	**8.4**	22.8	**2.3**	59.8	**6.0**	47.3	**4.7**	184	**18.4**	106	**10.6**
chromium	0.4	29.1	**72.8**	13.1	**32.8**	5.13	**12.8**	8.4	**21.0**	18.3	**45.8**	16.4	**41.0**	27.1	**67.8**
copper	50	429	**8.6**	283	**5.7**	42.8	0.9	50.5	**1.0**	111	**2.2**	313	**6.3**	124	**2.5**
lead	50	728	**14.6**	568	**11.4**	62	**1.2**	142	**2.8**	195	**3.9**	379	**7.6**	190	**3.8**
manganese	500	2,296	**4.6**	295	0.6	88	0.2	146	0.3	289	0.6	565	**1.1**	715	**1.4**
mercury	0.1	0.46	**4.6**	0.22	**2.2**	0.03	0.3	0.11	**1.1**	0.13	**1.3**	0.25	**2.5**	0.17	**1.7**
molybdenum	10	4.6	0.5	6.3	0.6	2.5	0.3	4.0	0.4	4.2	0.4	8.2	0.8	7.7	0.8
nickel	30	21.8	0.7	4.8	0.2	1.4	0.0	2.9	0.1	6.8	0.2	9.4	0.3	11.3	0.4
silver	2.0	1.4	0.7	2.8	**1.4**	0.26	0.1	1.2	0.6	0.48	0.2	1.8	0.9	1.3	0.7
thallium	1.0	5.9	**5.9**	5.4	**5.4**	3.9	**3.9**	4.8	**4.8**	5.2	**5.2**	6.6	**6.6**	5.4	**5.4**
vanadium	2.0	35.9	**18.0**	22.2	**11.1**	9.7	**4.9**	17.9	**9.0**	26.8	**13.4**	26.9	**13.5**	49.0	**24.5**
zinc	50	542	**10.8**	135	**2.7**	33.6	0.7	48	**1.0**	78.5	**1.6**	162	**3.2**	146	**2.9**

all units are mg/kg
EPCs are based on mean concentrations
HQs > 1 shown in **bold** type

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Table 9-3b. Mine Spoils Hazard Quotients (HQs)

Spoils HQs		EA-1		EA-2		EA-3		EA-4		EA-5*		EA-6		EA-7	
COC	TRV	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ	EPC	HQ
antimony	5	1.3	0.3	1.4	0.3	1.3	0.3	1.8	0.4	80	**16.0**	3.0	0.6	ND	NA
arsenic	10	1,076	**108**	571	**57.1**	457	**45.7**	1,084	**108**	982	**98.2**	1,150	**115**	62.3	**6.2**
barium	500	346	0.7	101	0.2	27.4	0.1	31.2	0.1	421	0.8	42.8	0.1	1.2	0.002
cadmium	4	0.66	0.2	0.52	0.1	0.31	0.1	1.9	0.5	50	**12.5**	0.23	0.1	ND	NA
chromium	0.4	4.0	**10.0**	6.0	**14.9**	6.6	**16.6**	4.9	**12.2**	75	**188**	14.0	**35.0**	118	**295**
cobalt	20	0.62	0.03	1.43	0.1	2.39	0.1	3.37	0.2	411	**20.6**	3.95	0.2	59.7	**3.0**
copper	50	2,016	**40.3**	612	**12.2**	1,490	**29.8**	2,895	**57.9**	1,210	**24.2**	719	**14.4**	44	0.9
lead	50	23,812	**476**	5,192	**104**	5,360	**107**	21,932	**439**	7,846	**157**	3,759	**75.2**	274	**5.5**
manganese	500	259	0.5	116	0.2	499	**1.0**	365	0.7	669	**1.3**	610	**1.2**	297	0.6
mercury	0.1	5.9	**59.0**	2.6	**26.0**	0.94	**9.4**	5.7	**57.0**	15.0	**150**	1.2	**12.0**	4.4	**44.0**
molybdenum	10	47.7	**4.8**	25.4	**2.5**	45.6	**4.6**	88.3	**8.8**	NA	NA	61.5	**6.2**	NA	NA
nickel	30	2.4	0.1	2.4	0.1	3.2	0.1	4.3	0.1	25	0.8	7.8	0.3	45.5	**1.5**
selenium	1	1.3	**1.3**	1.4	**1.4**	1.3	**1.3**	1.8	**1.8**	20	**20**	3	**3.0**	ND	NA
silver	2	29.2	**14.6**	8.9	**4.5**	9.8	**4.9**	20.2	**10.1**	35	**17.5**	7.4	**3.7**	ND	NA
thallium	1	13.0	**13.0**	13.2	**13.2**	7.5	**7.5**	9.8	**9.8**	280	**280**	10.9	**10.9**	NA	NA
titanium	1,000	45.5	0.05	55.0	0.1	130	0.1	186	0.2	1,287	**1.3**	193	0.2	NA	NA
vanadium	2	6.6	**3.3**	6.3	**3.2**	10.0	**5.0**	11.0	**5.5**	25	**12.5**	27.6	**13.8**	NA	NA
zinc	50	485	**9.7**	203	**4.1**	199	**4.0**	1,037	**20.7**	285	**5.7**	167	**3.3**	41.3	0.8

all units are mg/kg

EPC = 0 indicates not detected (below unavailable detection limit)

NA - Not analyzed for this constituent, or Not Applicable for HQ associated with ND EPC

ND - All samples below detection limit (Non Detect)

HQs > 1 shown in **bold** type

* GSI Data - See Note Below:

Note: Mean values (EPCs) for Ag, Cd, Cr, Hg, Ni, Se, and V are all based on half the detection limit--all samples were not detected above detection limit

EPCs and associated HQs for these constituents in this EA are therefore substantially overestimated

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9.2 Phase 2 Risk Summary

This section summarizes the Phase 2 risk estimates. In most cases, there is greater confidence in the Phase 2 risk estimates and conclusions than the Phase 1 estimates because the underlying data are more extensive, which allow for a better characterization of the nature and extent of contamination. The risk hypotheses developed in the Phase 1 ERA are repeated below, with responses based on the Phase 2 analyses used to summarize risks.

9.2.1 Risk Questions

The risk questions introduced in Section 2.3 are revised as appropriate and presented below. Also, the results of the Phase 2 analyses are used to provide responses to these questions. These responses provide a summary of the ecological risks identified in this final phase of the ERA.

Are the average levels of contaminants in soils from the soils exposure areas greater than the soil TRVs for the survival and growth of terrestrial plants?

YES – Phytotoxicity TRVs for soils COCs (applicable to As, Pb, Mn, Ag, Tl, V, and Zn) are exceeded by (or equal) the average COC concentration as follows:

- All soil EAs (As, Pb, Tl, and V)
- Soil EA PHF, TMF1, and TMF2 (Mn)
- Soil EA GMF (Ag)
- Soil EA PHF, GMF, KF1, KF2, TMF1, and TMF2 (Zn)

NO – Phytotoxicity TRVs are **not** exceeded by the average COC concentration as follows:

- All soil EAs (Ni)

Are the average levels of contaminants in spoils from the spoils exposure areas greater than the soil TRVs for the survival and growth of terrestrial plants?

YES – Phytotoxicity TRVs for spoils COCs (applicable to Sb, As, Cd, Co, Pb, Mn, Ni, Se, Ag, Tl, V, and Zn) are exceeded by (or equal) the average COC concentration as follows:

- All spoil EAs (As, Pb, Se, Ag, Tl, and V)
- Spoil EA 1-6 (Zn)
- Spoil EA 5 (Sb, Cd, and Co)
- Spoil EA 3, 5, and 6 (Mn)
- Spoil EA 7 (Ni)

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NO – Phytotoxicity TRVs are **not** exceeded by the average COC concentration as follows:

- All spoil EAs (Ba)

Are the average levels of contaminants in soils from the soil exposure areas greater than the soil TRVs for protection of other soil-based receptors or receptor groups?

YES – Toxicity based on exceedance of other TRVs for soil EAs (applicable Cr , Cu and Hg (invertebrates) and Mo (cattle)).

- All soil EAs (Cr)
- Soil EA PHF, GMF, KF1, KF2, TMF1 and TMF2 (Cu and Hg)
  – Soil EA IFF (HQ for Cu approaches but does not exceed 1.0 (HQ=0.9)

NO – Toxicity based on exceedance of other TRVs for soil EAs (applicable Cr , Cu and Hg (invertebrates) and Mo (cattle)).

- All soil EAs (Mo)

Are the average levels of contaminants in spoils from the spoils exposure areas greater than the spoil TRVs for protection of other soil-based receptors or receptor groups?

YES – Toxicity based on exceedance of other TRVs for spoil EAs (applicable Cr , Cu and Hg (invertebrates); and Mo (cattle); and Ti (soil microbes and microbial processes.

- All spoil EAs (Cr, Hg, Mo)
- Spoil EAs 1-6 (Cu)
- Spoil EA 5 (Ti)

Are the levels of contaminants in soils and/or spoils from the terrestrial exposure areas sufficiently elevated to contribute to adverse effects in consumers of terrestrial plants, invertebrates, birds, and/or small mammals?

Spoils - VARIBLE – Mo concentrations in spoils exceed thresholds for molybdenosis in cattle, and therefore adverse effects in cattle may be experienced if cattle have access to and consume sufficient amounts of plants growing in Mo-contaminated spoils. This exposure is expected to be unlikely or limited in most cases. In general, spoils areas provide mostly unsuitable conditions for vegetative cover and also provide little suitable habitat for most terrestrial invertebrates (based in part on expectations of low moisture and nutrient content and in part on particle size). The conditions limiting survival, growth, and reproduction of soil dwelling invertebrates and terrestrial plants also precludes significant exposure by upper trophic level vertebrates. Birds and mammals are unlikely to find sufficient cover or food (plants or prey) in most of the spoils areas. Based on measured concentrations of highly toxic and bioaccumulative Cd and Hg in spoils, potential exposure to these areas is a

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concern for upper trophic level receptors. However, as discussed previously, the lack of suitable habitat, limited cover, and likely scenario of limited foraging in spoils areas suggests that such exposures would be minimal at best. Food web modeling is not performed to address these issues because of the habitat limitations that are expected to preclude exposures of sufficient frequency and duration to result in adverse effects to individuals, populations, or communities. Because Hg does not accumulate in the aboveground portion of plants, even risk to sheep grazing on spoils (Connary) would be minimal.

Soils - VARIBLE – Some metals in farmer's fields exceed conservative thresholds for direct toxicity to plants and soil invertebrates. However, the most bioaccumulative COCs (e.g., Hg) that would be of most concern for upper trophic level consumers (e.g., birds and mammals) are only slightly elevated above very conservative thresholds. The expectation of infrequent and short duration foraging on these fields, along with the minimally elevated concentrations of bioaccumulative COCs, suggests that risks to birds and mammals would be insignificant. This conclusion also applies to grazing cattle and sheep.

Are the average levels of contaminants in whole sediments from the river and tributary exposure areas (EAs 1, 2, 3, 6, and Unique for sediments) greater than the sediment TRVs for the survival, growth, or reproduction of benthic invertebrates?

YES – Average concentrations of one or more COCs in sediments, based on CDM 2007 sampling, exceed threshold TRVs (applicable to As, Cd, Cu, Pb, Mn, Ni, and Zn) for adverse effects in benthic invertebrates at all five of the sediment EAs sampled in the Phase 2 sampling.

- EA 1, 2, 3, and 6 and EA Unique (As and Mn)
- EA 1, 2, 3, and 6 (Cu, Pb, and Zn)
- EA 1, 3, 6 and Unique (Ni)
- EA 1 (Cd)

The following risk question is repeated from the Phase 1 ERA because it is an important summary conclusion and similar data were not collected during the Phase 2 sampling:

Is the structure of benthic macroinvertebrate communities in Avoca River sediments significantly different than that from reference locations?

YES – Screening level benthic invertebrate community surveys (April 2007) indicate that the communities in the upper Avoca River below the mining-impacted areas are impaired relative to the reference stations (probably due to mining related contaminants). In addition, it appears that lower Avoca River benthic communities are also impaired relative to the reference stations, but more likely due to a different suite of stressors (assumed to include both mining-related metals and excessive levels of one or more nutrients).

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Are the average concentrations of contaminants in water from the rivers and tributaries greater than the surface water TRVs for the survival, growth, and reproduction of fish?

YES – Based on exceedance of hardness-adjusted salmonid-specific chronic TRVs and other chronic TRVs intended to protect the survival, growth, and reproduction of salmonid fish. These are applicable to ammonia and dissolved inorganic COCs: Al, Ba, Cd, Cu, Pb, Mn, Hg, Se, Ag, and Zn. Two sets of hardness-adjusted salmonid-specific TRVs are used—one set based on hardness of 31 mg/L (applicable to EAs 1-7) and the other based on hardness of 356 mg/L (EA 8). Conclusions are based on both CDM and GSI data. HQs were significantly higher for the GSI data at lower flows.

- All EAs (Ba and Ag)
- EA 2 and 7 (Cu)
- Higher flow (CDM data)
  - All EAs (Ba and Ag)
  - EA 2 and 7 (Cu)
  - EA 2 (Zn)
- Lower flow (GSI data)
  - All EAs (Ba)
  - EA 2 and 3 (Al, Cu, Zn)
  - EA 2 (Cd, Pb, and Mn)

NO – Based on average COC concentrations remaining below all chronic TRVs intended to protect the survival, growth, and reproduction of salmonid fish. These are applicable to ammonia, Al, Ba, Cd, Cu, Pb, Mn, Hg, Se, Ag, and Zn.

- All EAs (ammonia, Hg, and Se)

Are the concentrations of contaminants in water from the adits, springs, and miscellaneous surface waters greater than the surface water TRVs for the survival, growth, and reproduction of aquatic invertebrates?

YES – Based on multiple combinations of COCs (dissolved metals) and unique sampling locations. Conclusions are based on 2007 CDM data. Mostly similar conclusions would be assigned to the results of more limited 2007 GSI surface water data.

- Most EAs (Al, Ba, Cd, Co, Cu, Pb, Mn, Ni, U, and Zn)
- Only EA-1 (ammonia)
- Highest HQs for dissolved Cu, Cd, and Zn

NO – Based on HQs <1.0 for all EAs (dissolved Hg, Se, and Ag) and on HQs <1.0 for most COCs in certain springs and other unique sampling locations.

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Are the concentrations of contaminants in water from the rivers, tributaries, adits, springs, and miscellaneous surface waters sufficiently elevated to contribute to adverse effects in upper trophic level (ecological) consumers of fish and adult life stages of aquatic invertebrates?

VARIABLE – Rivers and Tributaries – This exposure route is most applicable (and most likely) for the rivers and tributaries. However, the concentrations of COCs for these media suggest that such exposures would be of minimal concern. None of the most bioaccumulative and toxic COCs (e.g., Cd and Hg) exceed conservative thresholds for the protection of salmonid fish. Salmonid-based TRVs do not, however, address potential effects due to bioaccumulation and effects related to ingestion of COC-contaminated fish by upper trophic level consumers (e.g., piscivorous birds and mammals). This exposure scenario was not assessed quantitatively because at this time there are insufficient numbers of fish in the sampled rivers and tributaries to support such an assessment. However, if there is a significant improvement in the numbers of fish in these waters following successful remediation, then the fish-ingestion pathway should be quantitatively assessed using site-specific fish tissue data.

Another approach for answering this particular risk question is the comparison of metals concentrations in recently collected surface water samples from the Avoca River to various regulatory limits. Such limits include the Water Quality (Dangerous Substances) Regulations, SI No. 12 of 2001 and the European Communities (Quality of Salmonid Waters) Regulation, 1988 SI No. 293 of 1988. These are referred to as SI 12 and SI 293 in the table below (Table 9-3c). Also included on this table are the average concentrations of relevant metals (dissolved) from samples collected in 2006 and 2007.

The comparisons of the average concentrations of metals from recently collected Avoca River samples to the (hardness-adjusted) regulatory limits reveals multiple exceedances for copper and zinc at nearly all EAs except EA-1, the upstream reference reach. Also, the mean measured concentrations of dissolved lead at EU-2 exceed regulatory limits established by Ireland.

CDM

Table 9-3c Comparison of Surface Water Data for Avoca River to Regulatory Limits

EA	Statistic	Mean Hard.	Dissolved Copper			Dissolved Lead			Dissolved Zinc		
			Measured	SI No. 12	SI No. 293	Measured	SI No. 12	SI No. 293	Measured	SI No. 12	SI No. 293
		mg/L	ug/l			μg/L			Ug/l		
1	mean	31	3.6	5.0	22	2.1	5.0	NA	17.8	50	200
2a	mean	31	**19.0**	5.0	22	**5.3**	5.0	NA	**393**	50	200
2b	Mean	151	**86.0**	30	112	**57.7**	30	NA	**2,305**	100	500
2c	Mean	88	**184**	5.0	40	**127**	5.0	NA	**5,163**	50	300
3a	mean	31	**6.6**	5.0	22	2.5	5.0	NA	**172**	50	200
3b	Mean	20	**11.5**	5.0	22	4.0	5.0	NA	**164**	50	200
3c	Mean	32	**13.5**	5.0	22	1.3	5.0	NA	**389**	50	200
4	mean	31	**10.0**	5.0	22	1.0	5.0	NA	**219**	50	200
5	mean	31	**8.5**	5.0	22	2.0	5.0	NA	**134**	50	200
6a	mean	22	**10.0**	5.0	22	2.0	5.0	NA	**146**	50	200
6b	Mean	22	3.3	5.0	22	2.0	5.0	NA	**85.0**	50	200
7	mean	31	**11.0**	5.0	22	1.0	5.0	NA	**148**	50	200
8	mean	356	4.5	30	112	1.1	30	NA	**124**	100	500

means based on half the detection limit for nondetect samples
D = dissolved concentration
Hardness (mg/L CaCO$_3$) = 2.5 (Ca, mg/L) + 4.1 (Mg, mg/L)
Data for EA 1, 4, 5, 7, 8 = CDM high flow data (2007)
EA(x)a = CDM high flow data (2007)
EA(x)b = GSI low flow data (Nov 2006)
EA(x)c = GSI low flow data (June 2007)
Regulatory limits are based on measured or calculated hardness values, and assume annual mean concentrations
NA - not applicable, no standard for this COC/agency
bold = measured value exceeds one or more standards

> **CONDITIONAL – Adits, Springs, and Miscellaneous Surface Waters** – Although the concentrations of COCs in these waters are highly elevated in many cases, this exposure pathway is of less concern for the following reasons. First is the expectation that most of these waters do not support sufficient numbers of aquatic invertebrates (and probably no fish) to provide successful foraging by insectivorous (or piscivorous) predators. Second, most of these waters are not associated with habitat suitable for most ecological receptors. The elevated concentrations of COCs in these waters would be a serious concern for wildlife exposed via prolonged direct contact and ingestion of water (drinking) or ingestion of prey that may have accumulated COCs in their tissues. However, the poor habitat associated with most of these waters probably precludes them from being an attractant to most wildlife regardless of prey availability. Clearly, remediation of those waters that are associated with decent quality habitat would reduce the hazards to wildlife that may be initially attracted, such as waterfowl to larger pit lakes. Finally, certain springs and other unique surface waters exhibit especially good water quality relative to the others, based on low concentrations of dissolved metals. These include EA-12, 21, 22, and 24.

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9.3 Preliminary Remediation Goals (PRGs)

The PRGs presented below in Table 9-4 are the COC-specific and media-specific values to be considered as numeric remediation goals (cleanup values) for those COCs associated with (1) elevated (>1.0) HQs in surface water, (2) elevated HQs and site concentrations greater than reference concentrations for sediment, and (3) elevated HQs and site concentrations greater than local background for surface soil. For the most part, all Phase 1 COCs are included in Phase 2. Copper, lead, and zinc are included as surface water COCs from Phase 1.

- **Surface Water PRGs** – For surface water, PRGs include both toxicity-based values as well as regulatory limits for those surface water COCs for which limits are available. Note that regulatory limits shown as PRGs are hardness-specific for some surface water COCs, so the PRG varies with hardness.

- **Sediment PRGs** – The two sets of PRGs for sediment are based on (1) toxicity-based threshold concentrations (e.g., CB TECs) and (2) the mean COC concentration in sediment from the reference area upgradient of the site. The mean value for the reference area is the highest of either the CDM 2007 mean or the GSI 2007 mean. The PRG selected (and shown in bold type) is the highest of either the mean reference area concentration or the toxicity-based value, based on the assumption that numeric remediation goals (i.e., cleanup values) below local background are inappropriate.

- **Surface Soil/Spoils PRGs** – Values selected to serve as PRGs for surface soils are commonly based on toxicity reference values (TRVs, see Table 8-3) which, for most contaminants, are typically based on sparse information resulting in very conservative values. These conservative values are in many cases lower than background concentrations. Therefore, selected PRGs for most surface soil/spoils COCs identified in this investigation are instead based on local background concentrations assumed to represent non-impacted soils. Two sources of background values are included; the first is the measured concentration from the agricultural field associated with the lowest soils metals concentrations (EA-IFF) and the second is the median metal concentration in soil for Counties Wicklow and North Wexford, based on 55 independent samples from a variety of habitats and soil types. These County soil data are available for all soil COCs except silver. The toxicity-based soil TRVs for copper (50 mg/kg), molybdenum (10 mg/kg), nickel (30 mg/kg) and silver (2 mg/kg) are higher than the background concentrations and are therefore used as the PRGs for these four COCs.

The list of applicable PRGs may vary over time if conditions change such that concentrations of chemicals currently identified as COCs decrease or those not currently identified as COCs increase within the medium of concern.

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Table 9-4. Ecological PRGs for COCs with HQ>1

COC	PRG	Description / Comment
Surface Water PRGs (ug/L, salmonids present, based on average hardness of EAs 1-7)		
Barium (D)	4	survival, growth, reproduction (salmonid fish), Oak Ridge National Laboratory (ORNL) Tier 2
Copper (D)	5	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness < 100 mg/L
	5	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness <10 mg/L
	11	survival, growth, reproduction (salmonid fish) – calculated based on average hardness of 31 mg/L in Avoca River
	22	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness 10-50 mg/L
	30	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness >100 mg/L
	40	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness 50-100 mg/L
Lead (D)	5	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness < 100 mg/L
	10	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness >100 mg/L
	13	Survival, growth, reproduction (salmonid fish) – calculated based on average hardness of 31 mg/L in Avoca River
Silver (D)	0.12	survival, growth, reproduction (salmonid fish), ORNL Lowest Chronic Value for Fish
Zinc (D) (total for EU standards)	8	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness < 10 mg/L
	30	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness <10 mg/L
	50	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness 10 - 100 mg/L
	100	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness >100 mg/L
	268	Survival, growth, reproduction (salmonid fish) – calculated based on average hardness of 31 mg/L in Avoca River
	200	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness 10-50 mg/L
	300	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness 50-100 mg/L
	500	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness >100 mg/L
Surface Water PRGs (ug/L, aquatic invertebrates (fish absent), variable hardness but not <25 or >200 mg/L) – ORNL Lowest Chronic Value for Daphnids		
Ammonia (mg/L)	3.5	Lowest EC_{20} for aquatic invertebrates or surrogate
Aluminum (D)	1,900	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Barium (D)	4	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Cadmium (D)	0.15	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Cobalt (D)	5.1	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Copper (D)	0.23	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Lead (D)	12.3	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Manganese (D)	1,100	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Nickel (D)	5	Lowest chronic value for daphnid or secondary chronic value for aquatic life

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Table 9-4. Ecological PRGs for COCs with HQ>1

COC	PRG	Description / Comment
Uranium (D)	2.6	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Zinc (D)	46.7	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Sediment PRGs (mg/kg, benthic macroinvertebrates and reference area)		
Arsenic	9.79	CB TEC (Consensus Based Threshold Effects Concentrations)
	34.6	Mean concentration from EA-1 (reference)
Copper	31.6	CB TEC
	60.8	Mean concentration from EA-1 (reference)
Lead	35.8	CB TEC
	640	Mean concentration from EA-1 (reference)
Manganese	630	Lowest ARCS TEL
	5,016	Mean concentration from EA-1 (reference)
Nickel	22.7	CB TEC
	23.8	Mean concentration from EA-1 (reference)
Zinc	121	CB TEC
	755	Mean concentration from EA-1 (reference)
Mean reference concentration = highest of CDM 2007 and GSI 2007 mean values		
Highest of either mean reference or toxicity-based value selected as PRG (shown in bold type)		
Surface Soil - Spoils PRGs (mg/kg, EA-IFF and County Wicklow and Wexford median)		
Arsenic	17.2	Median concentration, County Wicklow and Wexford, background
	22.8	Measured concentration, soil EA-IFF
Chromium	**61.1**	Median concentration, County Wicklow and Wexford, background
	5.13	Measured concentration, soil EA-IFF
Copper[1]	18.5	Median concentration, County Wicklow and Wexford, background
	42.8	Measured concentration, soil EA-IFF
Lead	39.4	Median concentration, County Wicklow and Wexford, background
	62	Measured concentration, soil EA-IFF
Manganese	**1,175**	Median concentration, County Wicklow and Wexford, background
	88	Measured concentration, soil EA-IFF
Mercury	**0.14**	Median concentration, County Wicklow and Wexford, background
	0.03	Measured concentration, soil EA-IFF
Molybdenum[1]	1.05	Median concentration, County Wicklow and Wexford, background
	2.5	Measured concentration, soil EA-IFF
Nickel[1]	18.5	Median concentration, County Wicklow and Wexford, background
	1.4	Measured concentration, soil EA-IFF
Silver[1]	NA	Median concentration, County Wicklow and Wexford, background
	0.26	Measured concentration, soil EA-IFF
Thallium	0.64	Median concentration, County Wicklow and Wexford, background
	3.9	Measured concentration, soil EA-IFF
Vanadium	**83.9**	Median concentration, County Wicklow and Wexford, background
	9.7	Measured concentration, soil EA-IFF
Zinc	**83.3**	Median concentration, County Wicklow and Wexford, background
	33.6	Measured concentration, soil EA-IFF

(1) PRGs based on toxicity references values (TRVs) that are higher than background level: copper = **50** mg/kg, molybdenum = **10** mg/kg, nickel = **30** mg/kg and silver = **2** mg/kg. Other values based on the highest of either median county background or EA-IFF value (shown in bold type).

 ND – no data for this chemical

Again, an important underlying assumption regarding the use of the PRGs presented in Table 9-4 is that final numeric remediation goals (i.e., potential "cleanup" concentrations) would not be set at values below the PRGs. Where there is more than one value for a given element for sediment or surface soil/spoils COCs, the higher PRG is selected. This approach ensures that local background metals concentrations are incorporated into any remediation decisions.

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9.4 Supporting Studies

Several supporting studies were undertaken to provide additional lines of evidence regarding protection of ecological resources. These include a survey and summary of land uses/habitats along the Avoca River; a survey to identify potential physical barriers to fish migration within the Avoca River; a compilation of information regarding use of the mining-impacted portions of the Avoca River corridor by bats; and uptake of metals by terrestrial plants in mining-impacted areas. Each of these studies is discussed below.

9.4.1 Habitat Descriptions / Land Use

The habitat assessment study area includes the West and East Avoca mining areas, as well as Shelton Abbey tailings. It also includes the Avoca River from Meetings of the Waters to Shelton Abbey.

The Avoca River Valley (site code 001748) is a proposed National Heritage Area. It is a large area of mixed woodland located in the valleys of the Avoca and Aughrim rivers. The best examples of relatively pure deciduous woods are found around Shelton Abbey. Oak is the dominant tree species with ash, beech and birch locally abundant.

9.4.1.1 Methodology

The habitat assessment was carried out on March 19 and 20 and April 9, 2008. It was conducted in accordance with The Heritage Council's Draft methodology, *A Standard Methodology for Habitat Survey and Mapping in Ireland* (Natura 2005) and habitats were classified according to The Heritage Council's *A Guide to Habitats in Ireland* (Fossitt 2000). The classification of habitats according to this Guide is primarily based on the combination of plant species that occur in a particular area. The Lidar survey (2007) was employed to aid delineation of habitat types for the mine sites and Shelton Abbey and aerial photography (2000) was used for the riparian corridor. Plant identification principally follows Webb *et al.* (1996).

9.4.1.2 Habitats

The main habitats of the Avoca mines, Shelton Abbey tailings and the Avoca riparian corridor are described below and are shown in Figures 9-2a, b, c, d, e, and f. Habitat codes given in parentheses are those given by Fossitt (2000). Table 9-5 lists the 23 habitats categories encountered.

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Figure 9-2a Habitat Survey - Study Area

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Boundary of Study Area

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Figure 9-2b Habitat Survey East Avoca

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**Figure 9-2c Habitat Survey
West Avoca**

Figure 9-2d Habitat Survey - Riparian Corridor 1

Legend:
- Spoil and bare ground
- Recolonising bare ground
- Refuse and other waste
- Dry siliceous heath
- Oak-birch-holly woodland
- Riparian woodland
- Broadleaf woodland
- Mixed broadleaf conifer woodland
- Conifer woodland
- Conifer plantation
- Scattered trees and parkland
- Scrub
- Recently-felled woodland
- Wet grassland
- Improved agricultural grassland
- Amenity grassland
- Arable crops
- Tilled land
- Buildings and artificial surfaces
- Other artificial lakes and ponds
- Depositing/ lowland rivers
- Hedgerow
- Treeline

1:10,000

Meters
0   125   250   500

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Figure 9-2e Habitat Survey - Riparian Corridor 2

Figure 9-2f Habitat Survey
Shelton Abbey

Table 9-5 List of Habitat Categories

Habitat Categories	EU Annex I habitats (Natura 2000 code)
Spoil and bare ground (ED2)	
Recolonising bare ground (ED3)	
Refuse and other waste (ED5)	
Dry siliceous heath (HH1)	European dry heaths (4030)
Oak-birch-holly woodland (WN1)	Old sessile oak woodlands with *Ilex* and *Blechum* in the British Isles (91A0)
Riparian woodland (WN2)	
Broadleaf woodland (WD1)	
Mixed broadleaf/ conifer woodland (WD2)	
Conifer woodland (WD3)	
Conifer plantation (WD4)	
Scattered trees and parkland (WD5)	
Scrub (WS1)	
Recently-felled woodland (WS5)	
Hedgerows (WL1)	
Treelines (WL2)	
Improved agricultural grassland (GA1)	
Amenity grassland (GA2)	
Wet grassland (GS4)	
Depositing/lowland rivers (FW2)	
Other artificial lakes and ponds (FL8)	
Arable crops (BC1)	
Tilled land (BC3)	
Buildings and artificial surfaces (BL3)	

9.4.1.2.1 Exposed Rock/ Disturbed Ground (E)

Spoil and Bare Ground (ED2)

There are three main areas of spoil associated with previous mining activities that have not been covered by vegetation. These areas are in West and East Avoca. The open pits of east Avoca and Mount Platt are virtually unvegetated. Vegetation has begun to recolonise around the edges of the bare ground and the bottom of some spoil heaps. Ling heather (*Calluna vulgaris*) and Bell heather (*Erica cinerea*) and gorse (*Ulex europaeus*) are dominant. Young trees such as Scotts pine (*Pinus sylvestris*) and silver birch (*Betula sylvestris*) are the commonest type of tree species.

Revegetation trials were conducted at West Avoca as part of the Life project in 1995. Silver birch (*Betula pendula*), lodgepole pine (*Pinus contorta*) and Scots pine (*Pinus sylvestris*) were planted. Grass (*Phleum pratense*) was also sown.

There are two areas of bare ground near Connary that have most likely been cleared for agriculture or construction. There are also some unpaved roads that are included in this category.

Recolonising Bare Ground (ED3)

Some of the older spoil heaps such as Connary, have recolonised so that greater than 50% of the area is covered with vegetation. Bell heather (*Erica cinerea*) and Ling heather (*Calluna vulgaris*) are dominant with Gorse (*Ulex europaeus*) common at the edges. There are also some grasses present.

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Refuse and Other Waste (ED5)

Ballymurtagh Landfill is located in West Avoca. It was an open pit called Pond Lode open pit. The landfill closed in 2002 and has since been capped and is covered in grass. There is a recycling centre just below the landfill.

9.4.1.2.2 Heath (H)
Dry Siliceous Heath (HH1)

The dry siliceous heath habitat is found sloping ground in upland areas. The soils are dry and acid and poor in nutrients. The dominant vegetation are dwarf shrubs such as bell heather (*Erica cinerea*), Ling heather (*Calluna vulgaris*) and western gorse (*Ulex gallii*). There is also Gorse (*Ulex europaeus*) present in areas, sometimes forming mosaics of **scrub (WS1)** with the heath. There is also dry-humid acid grasses present such as mat-grass (*Nardus stricta*) and bents (*Agrostis* spp.)

9.4.1.2.3 Woodland and Scrub (W)
Oak-Birch-Holly Woodland (WN1)

This is semi-natural woodland that occurs in three areas of the study area. It is dominated by Sessile oak (*Quercus petraea*). Other common trees are downy birch (*Betula pubescens*), silver birch (*Betula pendula*) and holly (*Ilex aquifolium*). Ivy (*Hedera helix*), brambles (*Rubus fruticosus* agg.) and ferns are present. Rhododendron (*Rhododendron ponticum*) is present at the edge of the woodland on the east side of the riparian corridor.

Riparian Woodland (WN2)

The margins of the river support areas of riparian woodland. These comprise of species such as willows (*Salix* spp.) and the occasional alder (*Alnus glutinosa*) and downy birch (*Betula pubescens*). The riparian woodland often grades into other broadleaf woodland categories.

Broadleaf Woodland (WD1)

There is a broadleaf woodland at Shelton Abbey that has been planted around the ridge of the tailings. Silver birch (*Betula pendula*) is the dominant species. Along the ridge the ground layer is dominated by moss, towards the river the ground layer thickens, with brambles (*Rubus fruticosus* agg.), moss and liverworts present.

Mixed Broadleaf/ Conifer Woodland (WD2)

This category includes mixed stands of broadleaf and conifer trees, which are predominantly located along the riparian corridor, often lining the main road the R752. There is also a stand beside East Avoca the Castlehoward estate. The percentage of broadleaf versus conifer varies but with a minimum of 25% each present. Common broadleaf trees are silver birch (*Betula pendula*), downy birch (*Betula pubescens*), Sessile oak (*Quercus petraea*) and common beech (*Fagus sylvatica*). The common coniferous tree is Scots pine (*Pinus sylvestris*). Holly (*Ilex aquifolium*), gorse (*Ulex europaeus*), brambles (*Rubus fruticosus* agg.), bilberry (*Vaccinium myrtillus*) and grass are often

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present in the understory. Cherry laurel (*Prunus laurocerasus*) is frequent along the edge of the woodland.

Conifer Woodland (WD3)

There are stands of conifer woodlands that are not aimed at commercial timber production and show a history of planting. Scots pine (*Pinus sylvestris*) is common in stands around the mine sites. It was originally native to Ireland but it died out around 2000 years ago. It was reintroduced to Wicklow in the 19th century. It was planted by the miners as a wood supply. Young Scots pines display the characteristically conical shape of conifers, but as the trees mature, this gives way to the round-topped shapes. The European larch (*Larix decidua*) is also present. It is an unusual conifer as it is deciduous and disposes of its soft needles before the winter frosts can damage them.

Conifer Plantation (WD4)

Young conifer plantations are located around Connary. Conifer plantations are usually for commercial timber production, characterised by even aged stands of trees that are planted in regular rows often in angular blocks. Species diversity is low and most plantations are non-native species, such as Lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudostuga menziesii*).

Scattered Trees and Parkland (WD5)

There is a cluster of trees with amenity grassland at Meetings of the Waters. There is a mixed of non-native broadleaf and conifer trees.

Scrub (WS1)

There are several large areas of scrub habitat in the study area. This habitat is dominated by shrubs, stunted trees and brambles. Common components are gorse (*Ulex europaeus*) and brambles (*Rubus fruticosus* agg.). On parts of the former mine sites where the land the land has completely recolonised with shrubs and dwarf trees, heather (*Erica* spp.) is also common and as well as young trees such as Scots pine (*Pinus sylvestris*) and silver birch (*Betula sylvestris*).

Recently-felled Woodland (WS5)

There is one small area of recently felled coniferous trees in West Avoca.

Hedgerows (WL1)

Hedgerows occur mainly as field boundaries in the improved agricultural grassland. They are largely dominated by gorse (*Ulex europaeus*) and brambles (*Rubus fruticosus* agg.).

Treelines (WL2)

There are several treelines in the study area. The first type are lines of **riparian woodland (WN2)** that occur along the Avoca River. The second are planted treelines common as boundaries to gardens, these are mainly coniferous trees.

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9.4.1.2.4 Freshwater (F)
Depositing/Lowland Rivers (FW2)

The study area of the Avoca River begins at Meetings of the Waters the river passes between the West and East Avoca mine sites, it joins with the Aughrim River at the Woodenbridge Golf course which is just upstream of the Shelton Abbey tailings. The river is bordered by riparian woodland, improved agricultural grassland, built up areas and mixed broadleaf/conifer woodland.

The study section of the Avoca River erodes its banks and meanders across floodplains. The substratum comprises of pebbles and boulders. There was no submerged or floating aquatic vegetation at the time of the survey. There are a few vegetated islands.

Other Artificial Lakes and Ponds (FL8)

A small man made lake occurs in the Woodenbridge golf course. It is linked to the Avoca River. Cronebane pit and East Avoca pit also contain water (denoted on maps with Target notes).

9.4.1.2.5 Grassland (G)
Improved Agricultural Grassland (GA1)

These are areas of highly modified grassland that is regularly fertilised that is now heavily grazed or used for making silage. It is typically species poor with rye-grasses (*Lolium* spp.) usually abundant and may entirely dominate the sward. The largest area of improved agricultural grassland is in West Avoca, yet it is common along the riparian corridor and in East Avoca also.

Amenity Grassland (GA2)

Amenity grassland occurs frequently in the area. Most areas have been reseeded and are frequently mown to maintain short swards. The habitat is associated with pitches, gardens and the golf course on the Avoca River.

Wet Grassland (GS4)

The wet grassland habitat occurs at Shelton Abbey tailings, which is farmland that has not recently been improved. It is a large flat area with wet soils. Rushes (*Juncus* spp.) are abundant. Broadleaved herbs that were common were creeping buttercup (*Ranunculus repens*) and clover (*Trifolium* spp.). There were patches with willow trees (*Salix* spp.) (*cinerea*) and gorse (*Ulex europaeus*).

9.4.1.2.6 Cultivated and Built Land (B)
Arable Crops (BC1)

There are a few fields in West Avoca where land is cultivated for wheat production.

Tilled Land (BC3)

Areas of land have been tilled and prepared for planting but the type of use is unknown.

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Buildings and Artificial Surfaces (BL3)

These areas include all buildings, car parks, tarmac roads, and the railway line. They are especially common along the riparian corridor.

9.4.1.3 Conclusion

The study area includes a large area of mixed woodland along the river valley. Around the mine area are pine and pine/birch woodland. There are also pine and larch woodland on both sides of the river. The steep slopes of the Tigroney hill and the Mottee Stone and a large area in West Avoca are covered in heather/ gorse heathland. Agricultural land is mainly for grazing. Spoil heaps are covered scarcely or not at all by vegetation.

Many of the vascular plant species occurred in more than one habitat. This is an illustration of how the process of colonization of disturbed land relies on the surrounding flora to provide 'volunteer' plants. *Erica* and *Ulex*, species belonging to the heathland vegetation, successfully establish themselves in the pine woods of the mine sites and in scrub vegetation. *Pinus* can invade the oak wood, and likewise *Quercus* is a common component of the pine woods. (Fay, 1996).

9.4.2 Fauna

Section 2.3.2.3 discusses species of special concern and other protected organisms. The common lizard (*Lacerta vivipara*, protected by the Wildlife Acts of 1976 and 2000) was observed at the golf course in Woodenbridge and at the East Avoca Pit in April 2007. Table 9-6 shows the fauna of the Avoca mine site. The observed are the fauna seen during the habitat survey, the recorded are the fauna that have been noted in the literature and the expected are based on the habitats present or the geographic range. See the sections below for summary of the different groups of fauna.

Table 9-6 Summary of Fauna

	Observed	Recorded	Expected
Mammals	Rabbit (*Oryctolagus cuniculus*)	Badger (*Meles meles*) Fox (*Vulpes vulpes*) Hare (*Lepus timidus hibernicus*) Brown rat (*Rattus norvegicus*) Stoat (*Mustela erminea hibernica*) Mink (*Mustela vison*)	Red squirrels (*Sciurus vulgaris*)
Bats		Pipistrelles (*Pipistrellus* spp.) Leisler's bat (*Nyctalus leisleri*) Daubenton's bat (*Myotis Daubentonii*) Natterer's bat (*Myotis nattereri*)	Brown long-eared bat (*Plecotus auritus*)
Birds	Pheasant (*Phasianus colchicus*)	Wren (*Troglodytes troglodytes*) Robin (*Erithacus rubecula*) Blackbird (*Turdus merula*) Rook (*Corvus frugilegus*) Jackdaw (*Corvus monedula*) Woodpigeon (*Columba palumbus*) Red kite (*Milvus milvus*) Falcon (*Falco peregrinus*)	Jay (*Garrulus glandarius*) Long-eared owl (*Asio otus*) Treecreeper (*Certhia familiaris*) Woodcock (*Scolopax rusticola*) Blackcap (*Sylvia atricapilla*) Buzzard (*Buteo buteo*)

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Table 9-6 Summary of Fauna

	Observed	Recorded	Expected
Fish		Salmon (*Salmo salar*) Sea trout (*Salmo trutta*) Eel (*Anguilla anguilla*) Brook lamprey (*Lampetra planeri*) River lamprey (*Lampetra fluviatilis*) Sea lamprey (*Petromyzon marinus*)	

9.4.2.1 Mammals

Mammals such as badger (*Meles meles*), fox (*Vulpes vulpes*), hare (*Lepus timidus hibernicus*), brown rat (*Rattus norvegicus*), stoat (*Mustela erminea hibernica*) and mink (*Mustela vison*) have been recorded in the study area (Wann, 2000). Rabbits (*Oryctolagus cuniculus*) have been observed on the mine area of West Avoca, and Shelton Abbey during the habitat assessment, as well as, burrows and faecal pellets were seen. Red squirrels (*Sciurus vulgaris*) are expected in the Scots pine forests as it is an important habitat for them as they feed on its cones and live high up in the trees. See Section 9.4.3 for the description of bats in the area.

9.4.2.2 Birds

The principal bird habitats within the study area are upland heath and the woodlands. The unvegetated parts of the mines are poor in bird life. Wren (*Troglodytes troglodytes*), robin (*Erithacus rubecula*), blackbird (*Turdus merula*), rook (*Corvus frugilegus*), jackdaw (*Corvus monedula*) and woodpigeon (*Columba palumbus*) are the most common bird species in Ireland and were recorded in the study area.

The woodlands contain a typical breeding bird community of old woodlands. This includes a number of less common species such as jay (*Garrulus glandarius*), treecreeper (*Certhia familiaris*), woodcock (*Scolopax rusticola*) and blackcap (*Sylvia atricapilla*). Ireland's most common owl, the long-eared owl (*Asio otus*) has taken very well to coniferous forests and is more prevalent in the east of the country.

The buzzard (*Buteo buteo*) is a bird of prey which has recently re-established breeding territories in Co. Wicklow. It is very likely to breed in some of the older, less disturbed woodlands. Thirty red kites (*Milvus milvus*) have been reintroduced to County Wicklow. The majority of the kites can still be located in and around one large farm. Kites that frequent the main roost have been seen up to 9 km away during the day. Steep cliffs offer suitable nesting sites for falcons. A pair of peregrine falcons (*Falco peregrinus*) have been reported (but were not observed) to utilise the walls of the open mine pits within the study area.

9.4.2.3 Fish

Species of fish in the Avoca River include salmon (*Salmo salar*), sea trout (*Salmo trutta*), eel (*Anguilla anguilla*) and three species of lamprey: brook (*Lampetra planeri*), river (*Lampetra fluviatilis*) and sea lamprey (*Petromyzon marinus*). Both salmon and all three species of lamprey are listed Annex II species under the EU Habitats Directive. Fish kills occur regularly during low flow periods and thirteen fish kills have been

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recorded on the Avoca River between approximately 2000 and 2003. Species killed included adult salmon, sea trout, and juvenile lamprey (Doyle *et al.* 2003). Most salmon (*Salmon salar*) and sea trout (*Salmon trutta*) were attempting to swim upstream to spawning grounds, while all lampreys found were metamorphosed juveniles. Even though migratory salmonids successfully spawn in the headwaters of the Avoca catchment there is a potentially significant mortality risk to salmon and sea trout smolts as they migrate downstream to the sea. Although the polluted section supports little by way of resident salmonids, other species including lamprey and eel were present. This suggests that these species may have some tolerance to this form of toxic pollution (Doyle *et al.* 2003).

During the habitat survey in April 2008 there were no obvious physical barriers observed in the Avoca River, that would hinder the migration of fish. Adult salmon have penetrated up into the upper reaches of the Avonmore, the middle reaches of the Avonbeg and the upper reaches of the Aughrim. Salmon continue to enter the Avoca to spawn despite the toxic nature of the water through which they must ascend to reach these spawning areas (Doyle *et al.*, 2003). If water and sediment quality were improved, fish should be able to complete their migration with no physical or chemical barriers.

9.4.3 Bat Survey Information

This section provides a summary of the information on the species of bat found around mines, Avoca area and nearby parts of Wicklow. Data were compiled from the Avoca Bat Watch (Fay, 1996) and records of detections of bats from Bat Conservation Ireland.

Bats are widespread in Ireland and can generally be found in areas where suitable roost sites (trees, disused buildings, old stone walls and bridges, or caves) occur in close proximity to areas of suitable foraging habitat (woodland, scrub, hedgerows, wetland areas and open water). Bats commonly feed and commute along linear habitats; such as hedgerows, treelines and watercourses, for cover and because of the high densities of insects that are usually present. Two species of bat would benefit greatly from underground sites associated with mines, the Daubenton's and Natterer's.

Bats in Ireland are protected under Irish and EU legislation (see Section 2.3.2.3). Under the Wildlife Act (1976) and Wildlife (Amendment) Act 2000, it is an offence to intentionally harm a bat or disturb its resting place. Bats constitute a large proportion of the mammalian biodiversity in Ireland. Ten species of bat are known to occur in Ireland and form almost one third of Ireland's land mammal fauna. (Aughney *et al.*, 2006).

In September to November of 1995, six evenings were spent monitoring bat activity at the Avoca mines. They monitored three sites: East Avoca open pit, West Avoca shaft and West Avoca closed adit. Four species of bat were identified. Pipistrelle (*Pipistrellus* spp.) and Leisler's bat (*Nyctalus leisleri*) were identified using a bat

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detector, emerging from East Avoca open pit. Daubenton's bat (*Myotis Daubentonii*) and Natterer's bat (*Myotis nattereri*) were on or by the river at Whitesbridge (Fay, 1996).

A search of the Bat Conservation of Ireland database was undertaken on February 9, 2008 by Dr. Tina Aughney. The grid reference (E319700 N182090) acts as the centre point of a square. Therefore for the 10 km search, the database search was undertaken 10 km north, south, east and west of the grid reference (Figure 9-3). An important point to note is that bat species, where records are not currently available, does not mean that this species is not present within the study area. Records are in the form of the following: roosts, transect records, and ad hoc observations.

There were a large number of records for the 10 km search for the years 1997 to 2007. Six species of bat have been recorded in the area: the common pipistrelle (*Pipistrellus pipistrellus*), soprano pipistrelle (*Pipistrellus pygmaeus*), brown long-eared bat (*Plecotus auritus*), Leisler's bat (*Nyctalus leisleri*), *Myotis* species and Daubenton's bat (*Myotis Daubentonii*). Pipistrelle's are noted as being the most abundant type of bat in the area.

9.4.3.1 Roosts

A bat roost is any structure or place which is used for shelter or protection, whether or not bats are present at the time. The database search found thirteen roost sites. Grid references were not available for the roosts as they are private residences. Three of these roosts had more than one species of bat roosting within. The thirteen roost sites consisted of the following species:

- Soprano pipistrelles (*Pipistrellus pygmaeus*) (5 roosts)
- Common pipistrelles (*Pipistrellus pipistrellus*) (3 roosts)
- Unidentified pipistrelle (1 roost)
- Leisler's bats (*Nyctalus leisleri*) (2 roosts)
- Brown long-eared bats (*Plecotus auritus*) (2 roosts)
- Daubenton's bats (*Myotis Daubentonii*) (2 roosts)
- Unidentified bat species (3 roosts)

9.4.3.2 Transect Records

All Ireland Daunbeton's Bat Waterway Survey
The Daubenton's Bat Waterway Survey focuses on Daubenton's (*Myotis Daubentonii*) bat activity along waterways such as rivers and streams (but excludes ponds and lakes) as this species is known to have a high dependency on such waterbodies for foraging. It is considered that the Daubenton's Bat Waterway Survey is an ideal method to introduce inexperienced volunteers to bat surveying (Aughney *et al.*, 2006).

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Two All Ireland Daunbeton's Bat Waterway Sites are located within 10 km of the Grid Reference (see Figure 9-3). Daubenton's bats were recorded at each of the sites:

- Roddenagh Bridge, River Ow, E311700 N179200 (2006 and 2007)
- Clara Vale, Avonmore River, E318455 N191104 (2007)

Car-Based Bat Monitoring Scheme
Car-Based Bat Monitoring Scheme is a method of monitoring bats while driving. Monitoring is carried out using a bat detector which picks up the ultrasonic (high pitched) echolocation calls made by bats and converts them to a frequency audible to the human ear. The monitoring is carried out along known routes, at a specific time of year, while driving at a prescribed speed (Roche *et al.*, 2006).

A 30 km² area where the car-based monitoring was carried out in County Wicklow was referenced "T05" (see Figure 9-3). The route for this car survey starts close to Hacketstown and zig-zags in a roughly south-easterly direction to Courtown. The closest the route comes to the Avoca Valley is at Ballinglen, approximately 13-15 km west of Woodenbridge. A number of transects within the "T05" recorded the following species:

- Common pipistrelle (*Pipistrellus pipistrellus*)
- Soprano pipistrelle (*Pipistrellus pygmaeus*)
- Pipistrelle unidentified
- Brown long-eared bat (Plecotus auritus)
- Leisler's bat (Nyctalus leisleri)
- *Myotis* species

In conclusion, these data indicate that six species of bats have been observed or recorded in or near the Avoca River mining area. Survey locations supporting this summary are shown on Figure 9-2. Data are lacking to identify the relationship between mining-related caves, adits, and other potential habitats and bat abundance or diversity. It is expected that bats consume large numbers of flying insects, including adult life stages of species with aquatic early life stages. However, the screening level benthic macroinvertebrate survey results presented in the Phase 1 ERA suggest that insect taxa with flying adult life stages (e.g., mayflies, caddisflies, and midges) are currently not abundant in the mining-affected portions of the Avoca River. Where such taxa are abundant for prey (e.g., the lower Avoca below the confluence with the Aughrim River), the bats should not contain elevated levels of potentially toxic mining-related metals. This expectation is based on the substantially lower levels of metals in riverine sediments outside the mining impacted areas.
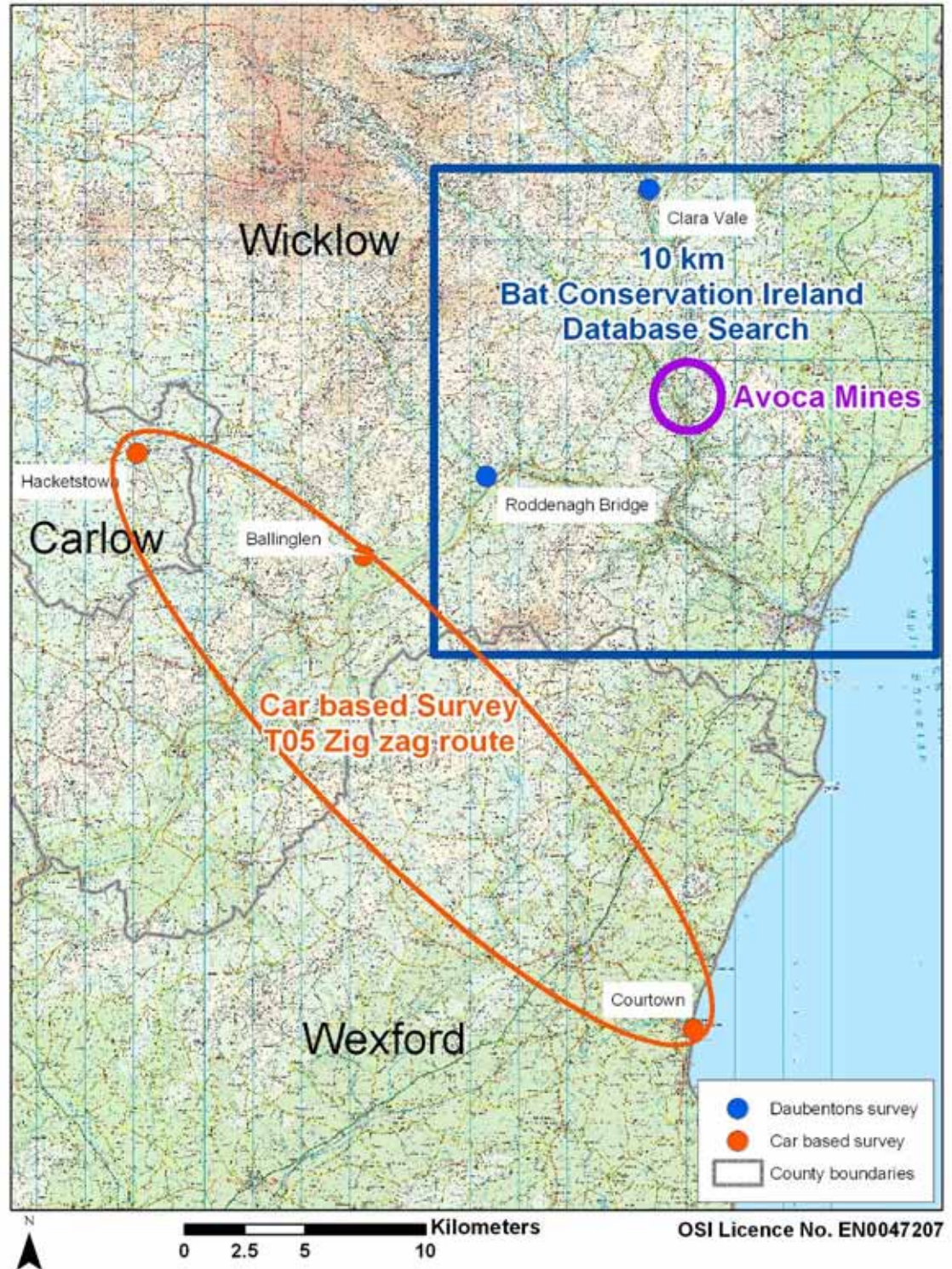
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Fig 9.3 Bat Record Locations

9.4.4 Metals Uptake in Terrestrial Plants

Many metals occur naturally in soil, and concentrations vary substantially from one area to another. Metals-related adverse effects on terrestrial plants can be influenced by metal form as well as concentration in soil. Site-specific soil characteristics such as pH, cation exchange capacity (CEC), and clay content affect metals bioavailability. For most metals except mercury, root uptake is probably the most important exposure route for terrestrial plants. Most mercury is acquired by terrestrial plants via foliar uptake. Another issue to be considered when evaluating metals concentrations in soils and plant tissues is essentiality. The following trace elements are essential for normal development of plants: cobalt, copper, iron, manganese, selenium, molybdenum, and zinc. In contrast, arsenic, cadmium, lead, and mercury have no known functions in plants (or animals).

Metals-related impacts on terrestrial plants can be evaluated with varying degrees of success using metals concentrations in soil, metals concentrations in plant tissues, or both using soil-to-biota uptake factors or bioaccumulation factors (BAFs). The rate of uptake is often more important than tissue concentrations because adverse effects will not occur as long as the uptake rate does not exceed the rate at which plants can bind the metal. BAFs for terrestrial plants most often remain below 1.0, but where BAFs exceed 1.0, risks to upper trophic level consumers of plants should be considered. Where BAFs remain much lower than 1.0, the role of soil ingestion by herbivores becomes more important than ingestion of plants.

Site-specific BAFs were determined for ten metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn) and locations in support of this ERA. Mercury was analyzed in soil and plants as well, but all plant concentrations remained below the detection limit of 0.02 mg/kg. BAFs are therefore not determined for mercury. These BAFs are based mostly on co-located soil and plant tissue samples (above ground unwashed plants). In a few cases the soil sample is near but not co-located with the associated plant sample. Table 9-7 presents the results of these soil and plant samples, and also reveals the site-specific soil-to-plant BAFs.

As can be seen on Table 9-7, nearly all BAFs are below 1.0. The single exception (BAF = 1.3) is for manganese at one location, and these results are based on soil and plant manganese concentrations in spoil sample SP25. Average BAFs by metal (average of all locations) range from 0.0095 (Fe) to 0.34 (Mn). The latter is influenced by the single high BAF of 1.3 discussed previously. These findings suggest that risks to local herbivores from consuming plants which have accumulated metals are likely low.

Table 9-7 Metals Uptake in Terrestrial Plants 2007 CDM Data

		Aluminium			Arsenic			Cadmium			Chromium			Copper		
Sample ID		Plant	Soil	BAF	Plant	Soil	BAF	Plant	Soil	BAF	Plant	Soil	BAF	Plant	Soil	BAF
Soil/Spoil ID	Plant ID	mg/kg	mg/kg		mg/kg	mg/kg		mg/kg	mg/kg		mg/kg	mg/kg		mg/kg	mg/kg	
SP25 (0,-1)	SP25 Extreme Vegetation	47.9	10,484	0.0046	0.4	1,309	0.00031	0.02	0.71	0.03	0.3	<8	>0.038	6.3	6,426	0.00098
TM1 - 40A	TM1 - 40A veg	100.2	18,539	0.0054	0.7	115	0.0061	0.02	0.31	0.06	0.3	14	0.021	4.5	222	0.020
TM1 - 80A	TM1 - 80A veg	71.2	21,523	0.0033	0.5	133	0.0038	0.03	0.48	0.06	0.4	13	0.031	5.9	159	0.037
TM1-80A	TM1- Berries	12.1	21,523	0.00056	<0.1	133	<0.00075	0.06	0.48	0.13	0.2	13	0.015	3.8	159	0.024
TM2 - 40B	TM2 - 40B veg	45.5	31,030	0.0015	0.4	228	0.0018	<0.02	0.13	<0.15	0.2	11	0.018	6.7	143	0.047
TM2-40B	TM2 - Corn	316.5	31,030	0.010	1.1	228	0.0048	0.02	0.13	0.15	1.3	11	0.12	4	143	0.028
K-1-40B	K-1-40B Veg Sample	26	8,123	0.0032	<0.1	32.7	<0.0031	0.03	0.72	0.04	0.2	<8	>0.025	5.3	71.9	0.074
IF1-80B	IF1-80B Veg	36.1	8,074	0.0045	<0.1	20.4	<0.0049	0.02	0.26	0.08	5.3	<8	>0.66	6.5	26.7	0.24
K2-1-40A	K2-1-40A Veg	788.1	14,460	0.055	4.1	60.7	0.068	0.08	0.48	0.17	1.1	16	0.069	19.4	177.3	0.11
			Min BAF	0.00056		Min BAF	0.00031		Min BAF	0.028		Min BAF	0.015		Min BAF	0.00098
			Mean	0.010		Mean	0.014		Mean	0.090		Mean	0.045		Mean	0.065
			Max BAF	0.055		Max BAF	0.068		Max BAF	0.17		Max BAF	0.12		Max BAF	0.24

		Iron			Lead			Manganese			Nickel			Zinc		
Sample ID		Plant	Soil	BAF	Plant	Soil	BAF	Plant	Soil	BAF	Plant	Soil	BAF	Plant	Soil	BAF
Soil/Spoil ID	Plant ID	mg/kg	mg/kg		mg/kg	mg/kg		mg/kg	mg/kg		mg/kg	mg/kg		mg/kg	mg/kg	
SP25 (0,-1)	SP25 Extreme Vegetation	107.1	90,753	0.0012	16.5	56,523	0.00029	115.4	89	1.30	0.2	1.6	0.13	26	706	0.037
TM1 - 40A	TM1 - 40A veg	165.3	33,120	0.0050	1	256	0.0039	29.3	514	0.057	<0.2	7.5	<0.027	17	119	0.14
TM1 - 80A	TM1 - 80A veg	137	37,654	0.0036	1.4	464	0.0030	28.1	861	0.033	<0.2	5.2	<0.038	20	159	0.13
TM1-80A	TM1- Berries	20.3	37,654	0.00054	0.1	464	0.00022	66.9	861	0.078	<0.2	5.2	<0.038	10	159	0.063
TM2 - 40B	TM2 - 40B veg	146	110,583	0.0013	2.1	217	0.0097	84.7	618	0.14	<0.2	5.4	<0.037	21	110	0.19
TM2-40B	TM2 - Corn	468.3	110,583	0.0042	1.9	217	0.0088	19	618	0.031	0.3	5.4	0.056	18	110	0.16
K-1-40B	K-1-40B Veg Sample	58.1	10,020	0.0058	0.6	219	0.0027	40	159	0.25	0.3	3.3	0.091	24	68.6	0.35
IF1-80B	IF1-80B Veg	94.7	7,847	0.012	0.7	53.1	0.013	67.6	77	0.88	2.2	<0.8	>2.8	20	26.8	0.75
K2-1-40A	K2-1-40A Veg	1437.3	27,880	0.052	19.4	347	0.056	108.1	330	0.33	0.2	5.3	0.038	34	115	0.30
			Min BAF	0.00054		Min BAF	0.00022		Min BAF	0.031		Min BAF	0.038		Min BAF	0.037
			Mean	0.0095		Mean	0.011		Mean	0.34		Mean	0.077		Mean	0.23
			Max BAF	0.052		Max BAF	0.056		Max BAF	1.30		Max BAF	0.13		Max BAF	0.75

Soil and spoil data from samples taken nearest sampled plants
Vegetation samples are grasses unless indicated otherwise (corn, berries)
Mercury not included - all vegetation samples <0.02 mg/kg (non detect)
"<" and ">" values not included in calculation of min, mean, or maximum BAFs

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Another approach for assessing risks to terrestrial receptors is to compare soil metals concentrations to concentrations that may be associated with adverse effects in representative terrestrial receptors. U.S. EPA has derived ecological soil screening levels (ECO-SSLs) that can be used to screen soil metals concentrations. Exceedance of ECO-SSLs does not necessarily suggest that adverse effects are imminent, but instead indicate the need for further investigation. These values are therefore often used as very conservative thresholds indicating that adverse effects could occur. With a few exceptions, ECO-SSLs have been derived for terrestrial plants, terrestrial invertebrates (primarily represented by earthworm), birds, and mammals. ECO-SSLs for birds and mammals consider bioaccumulation potential, and therefore are often quite low to allow for uptake and food web transfer.

Table 9-8 provides the results of the comparisons of ECO-SSLs and metals concentrations in soils collected in support of the soil/plant uptake study. This table consists of two parts. The first presents the soil metals concentrations by location, with the ECO-SSLs shown below, by receptor group. The second portion reveals the HQs for the four receptor groups for those metals with elevated concentrations and for which ECO-SSLs are available (As, Cd, Cu, Pb, Mn, and Zn).

Table 9-8 shows HQs greater than 1.0 for at least one metal at all sampling locations shown. The highest HQs by far are associated with the spoils sample shown as SP25. For this sample, HQs range from less than 1 for Cd to over 5,000 for lead (based on plant receptors). HQs for most other locations are substantially lower. Most HQs for other locations remain near or below 12 except for Pb. Bird and/or mammal-based HQs for lead are elevated at all locations (HQs for Pb for birds and mammals range from 0.9 to 42 at all locations except SP25). These apparently elevated HQs are offset by two considerations. First, all the ECO-SSLs are very conservative nature with substantial margins of safety. Second, lead in soils is often not highly bioavailable, and the underlying toxicity data upon which the Pb ECO-SSL is derived is based on laboratory studies using more soluble forms of lead. These considerations suggest that the HQs for Pb may overestimate potential for adverse effects.

In summary, the information shown on Table 9-8 suggests that the *spoils* with metals concentrations similar to SP25 have substantial potential to cause adverse effects in terrestrial receptors (plants, invertebrates, birds, and mammals). *Soils* with metals concentrations similar to those presented on this table have a much lower but still potentially significant possibility of contributing to adverse effects in one or more of these receptor groups. Risks to birds and mammals would require an assumption of significant exposure, which will vary with habitat quality. Where cover is available and foraging potential is suitable, exposure will be greater. However, if metals-contaminated soils are in locations without suitable cover or foraging potential, then birds and mammals are more unlikely to be significantly exposed. Risks to plants and soil invertebrates (and birds and mammals as well) will be highly dependent of the chemical form of the metals in soil and on site-specific soil characteristics.

Table 9-8 ECO-SSL-based Soil HQs 2007 CDM Data

		Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
	Sample ID	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Soil/Spoil ID	**Plant ID**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
SP25 (0,-1)	SP25 Extreme Vegetation	10,484	**1,309**	**0.71**	<8	**6,426**	90,753	**56,523**	89	1.6	**706**
TM1 - 40A	TM1 - 40A veg	18,539	**115**	0.31	14	**222**	33,120	**256**	**514**	7.5	**119**
TM1 - 80A	TM1 - 80A veg	21,523	**133**	0.48	13	**159**	37,654	**464**	**861**	5.2	**159**
TM1-80A	TM1- Berries	21,523	**133**	0.48	13	**159**	37,654	**464**	**861**	5.2	**159**
TM2 - 40B	TM2 - 40B veg	31,030	**228**	0.13	11	**143**	110,583	**217**	**618**	5.4	**110**
TM2-40B	TM2 - Corn	31,030	**228**	0.13	11	**143**	110,583	**217**	**618**	5.4	**110**
K-1-40B	K-1-40B Veg Sample	8,123	**32.7**	**0.72**	<8	**71.9**	10,020	**219**	159	3.3	**68.6**
IF1-80B	IF1-80B Veg	8,074	**20.4**	0.26	<8	26.7	7,847	**53.1**	77	<0.8	26.8
K2-1-40A	K2-1-40A Veg	14,460	**60.7**	**0.48**	16	**177.3**	27,880	**347**	**330**	5.3	**115**
	ECO-SSL	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Ni**	**Zn**
	plants	Nv	18	32	nv	70	nv[1]	120	220	38	160
	soil invertebrates	Nv	nv	140	nv	80	nv	1,700	450	280	120
	birds	Nv	43	0.77	26	28	nv	11	4,300	210	46
	mammals	Nv	46	0.36	34	49	nv	56	4,000	130	79

nv - no value derived (for Al, adverse effects are not expected if soil greater than pH.5.5)

ECO-SSL for Cr based on Cr III

[1]Fe is not expected to be toxic to plants because of uptake enhancement (USEPA 2003)

		As					Cd					Cu				
	Sample ID	Soil	HQ				Soil	HQ				Soil	HQ			
Soil/Spoil ID	**Plant ID**	**mg/kg**	**1**	**2**	**3**	**4**	**mg/kg**	**1**	**2**	**3**	**4**	**mg/kg**	**1**	**2**	**3**	**4**
SP25 (0,-1)	SP25 Extreme Vegetation	**1,309**	**72.7**	na	**30.4**	**28.5**	**0.71**	0.022	0.005	0.9	**2.0**	**6,426**	**91.8**	**80.3**	**230**	**131**
TM1 - 40A	TM1 - 40A veg	**115**	**6.4**	na	**2.7**	**2.5**	0.31	0.010	0.002	0.4	0.9	**222**	**3.2**	**2.8**	**7.9**	**4.5**
TM1 - 80A	TM1 - 80A veg	**133**	**7.4**	na	**3.1**	**2.9**	0.48	0.015	0.003	0.6	**1.3**	**159**	**2.3**	**2.0**	**5.7**	**3.2**
TM1-80A	TM1- Berries	**133**	**7.4**	na	**3.1**	**2.9**	0.48	0.015	0.003	0.6	**1.3**	**159**	**2.3**	**2.0**	**5.7**	**3.2**
TM2 - 40B	TM2 - 40B veg	**228**	**12.7**	na	**5.3**	**5.0**	0.13	0.004	0.001	0.2	0.4	**143**	**2.0**	**1.8**	**5.1**	**2.9**
TM2-40B	TM2 - Corn	**228**	**12.7**	na	**5.3**	**5.0**	0.13	0.004	0.001	0.2	0.4	**143**	**2.0**	**1.8**	**5.1**	**2.9**
K-1-40B	K-1-40B Veg Sample	**32.7**	**1.8**	na	0.8	0.7	**0.72**	0.023	0.005	0.9	**2.0**	**71.9**	**1.0**	0.9	**2.6**	**1.5**
IF1-80B	IF1-80B Veg	**20.4**	**1.1**	na	0.5	0.4	0.26	0.008	0.002	0.3	0.7	26.7	0.4	0.3	**1.0**	0.5
K2-1-40A	K2-1-40A Veg	**60.7**	**3.4**	na	**1.4**	**1.3**	**0.48**	0.015	0.003	0.6	**1.3**	**177.3**	**2.5**	**2.2**	**6.3**	**3.6**

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Table 9-8 ECO-SSL-based Soil HQs 2007 CDM Data

Sample ID		Pb					Mn					Zn				
		Soil	HQ				Soil	HQ				Soil	HQ			
Soil/Spoil ID	Plant ID	mg/kg	1	2	3	4	mg/kg	1	2	3	4	mg/kg	1	2	3	4
SP25 (0,-1)	SP25 Extreme Vegetation	**56,523**	**471**	**33.2**	**5,138**	**1,009**	89	0.4	0.2	0.02	0.02	**706**	**4.4**	**5.9**	**15.3**	**8.9**
TM1 - 40A	TM1 - 40A veg	**256**	**2.1**	0.2	**23.3**	**4.6**	**514**	**2.3**	**1.1**	0.1	0.1	**119**	0.7	**1.0**	**2.6**	**1.5**
TM1 - 80A	TM1 - 80A veg	**464**	**3.9**	0.3	**42.2**	**8.3**	**861**	**3.9**	**1.9**	0.2	0.2	**159**	1.0	**1.3**	**3.5**	**2.0**
TM1-80A	TM1- Berries	**464**	**3.9**	0.3	**42.2**	**8.3**	**861**	**3.9**	**1.9**	0.2	0.2	**159**	1.0	**1.3**	**3.5**	**2.0**
TM2 - 40B	TM2 - 40B veg	**217**	**1.8**	0.1	**19.7**	**3.9**	**618**	**2.8**	**1.4**	0.1	0.2	**110**	0.7	0.9	**2.4**	**1.4**
TM2-40B	TM2 - Corn	**217**	**1.8**	0.1	**19.7**	**3.9**	**618**	**2.8**	**1.4**	0.1	0.2	**110**	0.7	0.9	**2.4**	**1.4**
K-1-40B	K-1-40B Veg Sample	**219**	**1.8**	0.1	**19.9**	**3.9**	159	0.7	0.4	0.04	0.04	**68.6**	0.4	0.6	**1.5**	0.9
IF1-80B	IF1-80B Veg	**53.1**	0.4	0.0	**4.8**	0.9	77	0.4	0.2	0.02	0.02	26.8	0.2	0.2	0.6	0.3
K2-1-40A	K2-1-40A Veg	**347**	**2.9**	0.2	**31.5**	**6.2**	**330**	**1.5**	0.7	0.1	0.1	**115**	0.7	**1.0**	**2.5**	**1.5**

HQ 1 = plants
HQ 2 = invertebrates
HQ 3 = birds
HQ 4 = mammals
bold indicates HQ>1

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9.5 Uncertainty Analysis

This section discusses the uncertainties in the ERA that may influence the confidence in the results and conclusions. In addition, this section provides information that may help interpret the results in a manner most appropriate for making remedial and related decisions. Uncertainties are discussed for each major section of the ERA.

9.5.1 Uncertainty Analysis – Exposure Assessment

Sources of uncertainty in the exposure assessment include the values used to represent the magnitude and distribution of ecological COCs in various media. Obviously, all media cannot be sampled at all locations, so some degree of uncertainty is inherent in COC concentration data. The large amount of surface water, sediment, and surface soil/spoils samples taken from within the study area, including reference locations, reduces uncertainty to an acceptable level in most cases.

The abiotic samples collected have been appropriately analyzed to adequately describe the nature and extent of site-related contamination within the area of investigation. Sampling and analyses of surface water, sediment, and surface soil/spoils for certain COCs were limited in a few cases, and in others a COC was only infrequently detected. In such cases it was determined to be inappropriate to calculate EPCs based on mean values and instead either all data (e.g., two sample results) or the highest value from two sampling dates were used to represent exposure concentrations.

The median concentrations of soil COCs from 55 soil samples from Counties Wicklow and Wexford are used to represent non-impacted soils. Also, soil samples from the agricultural field EA-IFF is assumed to represent non-site-impacted conditions, based on comparatively low metals concentrations. In both cases, the assumption that these soils represent non-impacted conditions cannot be confirmed. This uncertainty is most applicable to the county soil data, which may include some samples that have been impacted by one or more sources. The use of the median concentration rather than the arithmetic mean reduces the influence of very high values that may represent contamination from unknown sources.

9.5.2 Uncertainty Analysis – Effects Assessment

In this section, the major sources of uncertainty in the effects assessment are identified and their potential impact on the ERA is evaluated. Concentrations of COCs associated with observed or predicted harmful effects on ecological receptors are the primary source of uncertainty in the effects assessment. These concentrations are used to calculate risk and are described as TRVs. TRVs used for risk estimation are taken from a longer list of potential TRVs and other types of concentration data (e.g., screening values) for each medium type and COC. In general, uncertainties are greatest for surface soil TRVs, followed by sediment TRVs, and finally, surface water TRVs. The degree of confidence is linked primarily to data availability and differs for each medium-specific.

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Preferred surface water TRVs (i.e., acute and chronic effects data for salmonid fish) are assumed to be associated with low uncertainty because these concentrations are based on experimentally derived values from a large database. Trout and salmon are among the well-studied receptors with regard to metals toxicity in surface water, and there is considerable agreement in the scientific community on effects data for salmonid fish exposed to metals. Some uncertainty may stem from using data for trout species other than those known to occur at the Site. For example, toxicity data for brook trout may not be fully applicable to brown trout. However, the differences in the responses of various salmonid species to exposure to COCs of interest to this site are expected to be small.

There is considerable confidence in (and relatively low uncertainty with) some of the more well-studied sediment COCs, such as cadmium, copper, lead, mercury, and zinc. For well-studied COCs such as these, sediment TRVs are assumed representative of concentrations that, if not exceeded, provide adequate protection of benthic biota. Most of the selected sediment TRVs are taken from a large group of values from several sources. For some of the COCs identified for this site, there is considerable agreement among the various concentrations proposed for use as thresholds by multiple agencies or sources. This agreement results in greater confidence in the threshold concentrations selected as sediment TRVs. For other sediment COCs, such as magnesium, few toxicity data are available. In these cases the limited data increases uncertainties with risk estimates based on these data.

In several cases, surface soil TRVs are associated with greater uncertainty than sediment and especially surface water TRVs. Surface soil TRVs often differ substantially for any given COC depending on the source. Even greater differences are noted between receptor groups (e.g., plants and soil invertebrates) for most COCs.

In summary, uncertainties related to effects assessment are considered relatively low, primarily because most of the important COCs identified for this ERA are well-studied with regard to ecotoxicity. This conclusion is most applicable to surface water- and sediment-based effects data. There is lower confidence in the effects data for soil-associated biota because exposure-response data are sparse for soil receptors exposed to site-related COCs.

9.5.3 Uncertainty Analysis – Risk Characterization

Uncertainties at any point in the ERA can affect confidence in the acceptance or rejection of hypotheses and overall conclusions reached in the ERA. Important areas of potential uncertainty related to exposure assessment and effects assessment are discussed above. Important components of these presentations are summarized here, along with uncertainties specifically related to risk characterization.

By definition, uncertainties in risk characterization are influenced by uncertainties in exposure assessment and effects assessment. The extensive sampling and analysis of surface water, sediment, surface soil, and spoils minimize uncertainties in exposure assessment related to abiotic media. Descriptions of the magnitude and distribution of

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COCs within the site and the reference areas are considered to be generally representative of current conditions within those areas. This is especially true for those media sampled multiple times over the past two years. In spite of the overall confidence in exposure data, some data are clearly biased towards times of the year when sampling is easiest or most desirable. For example, data collected during storm events are limited and may not represent the wide range of conditions that may be seen during such events. CDM surface water data are probably biased towards higher flow conditions and lower metal concentrations compared to the GSI surface water data, which are based on lower flow conditions and higher metal concentrations. Surface soil and other solids media data are also probably biased towards sampling areas with a higher probability of contamination (e.g., depositional areas or focus on analyses of only fine grained materials). This suggests that COC concentrations taken to be representative of certain media may be biased upwards, resulting in over-estimation of risks, except for surface water from the Avoca River during higher flow.

Effects data can also contribute to overall uncertainty in risk characterization. Science and scientific investigations can not prove any hypothesis beyond doubt. The scientific method is instead based on stating hypotheses, testing the hypotheses, and either accepting or rejecting the hypotheses based on one or more lines of evidence. Cause and effect relationships can be inferred, and evidence can support hypotheses, but cause and effect relationships can rarely be proven. Because no data are conclusive, site-specific biological and chemical data are subject to concerns of representativeness and the sensitivity of sampled species used to derive such data. Toxicity data that are not site-specific may not be totally applicable to the site being investigated.

There are also concerns about laboratory-to-field extrapolation of effects data and also concerns with taxa-to-taxa extrapolations. All effects data are, therefore, subject to some degree of uncertainty. Confidence in the ability of selected effects data for use as TRVs to assess potential for ecological risks varies for each data value selected. While each and every effects data value used in this and every other ERA is associated with some degree of uncertainty, it is the general trend described by the comparisons between exposure concentrations and effects concentrations, and the overall confidence in such comparisons, that are most important. For the most part, there is high confidence in effects data for the major surface water COCs. In decreasing order of confidence, these are followed by effects data for major COCs in sediment and in surface soil/spoils.

The risk characterization method itself can contribute to uncertainty. Careful calculation of EPCs, with special attention given to handling non-detect data and infrequently detected values, along with careful review of multiple sources of effects data minimizes this type of uncertainty. Incorporating general site observations and several other lines of evidence (e.g., benthic community structure, habitat quality) into risk characterization reduces the dependence on strict quantitative risk estimates that in some cases can be uncertain.

Finally, confidence in risk estimates varies among the COCs. There is generally high confidence in the risk estimates for well-studied COCs such as cadmium, copper, lead, zinc, and, where sufficient data exist, mercury. Risk estimates are probably less certain for chromium, nickel, selenium, manganese, thallium, vanadium and, depending on media type, a few others. Risk estimates are even more uncertain for molybdenum because little or no suitable ecotoxicity data are available for certain media types.

In summary, the degree of uncertainty in exposure estimation, effects data, and risk characterization are minimized by the extensive data collection and careful attention to detail where uncertainties are likely to be highest (e.g., calculation of EPCs for small data sets).

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Section 10
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The Department of Communications, Marine and Natural Resources

Feasibility Study for Management and Remediation of the Avoca Mining Site

Preliminary (Phase 1) Conceptual Site Model

May 23, 2007

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Executive Summary

ES1 Introduction

ES1.1 Purpose of the CSM

The purpose of the Phase 1 preliminary Conceptual Site Model (CSM) is to use the existing site data and the results of a limited site investigation to make an evaluation of the geochemical and hydrological processes that result in acid rock drainage (ARD) input to the Avoca River. The development of the preliminary CSM will help to identify any additional information needs (data gaps) that would need to be filled in order to prepare a Final CSM and focus additional field investigations (Phase 2). The results of the CSM will be used to help select appropriate remedial and management alternatives at the site.

ES1.2 Previous Investigations

CDM relied on a number of previous investigations to prepare the CSM, including the following:

- Biorehabilitation of the Acid Mine Drainage Phenomenon by Accelerated Bioleaching of Mine Waste (1993)

- Avoca/Avonmore Catchment Conversion Life Project (1995-96)

- Published Papers

ES1.3 Site Visit and Screening-Level Evaluation

CDM, GWP Consultants, and GSI personnel visited the site on April 2-4, 2007. The purpose of the visit was to become acquainted with the site, to test field procedures to be used for the July-August sampling effort, to perform a safety audit (GWP Consultants), and to provide preliminary data to be used in the CSM, risk assessments, and preliminary remedial alternatives reports.

At the adit sites, pH and electrical conductivity measurements were measured using field portable instruments. In addition, analyses of spoil heap materials were performed using a field portable X-ray fluorescence (XRF) instrument.

ES2 Potential ARD Sources

Potential sources of ARD include the following:

- Pit Walls
- Spoil Heaps
- Tailings
- Adits
- Underground Workings

ES2.1 Pit Walls

The pits located at the Avoca site consist of the following:

- Cronebane (open)
- East Avoca (open)
- Pond Lode (filled with municipal waste)
- North Lode (filled with tailings and spoils)
- Weaver's Lode (partially filled with debris and spoils)

The pits likely contribute to the loading of ARD to the Avoca River in a number of ways, including the following:

1. ARD is generated directly as precipitation flows along the pit walls and through spoil heaps located within the pits.

2. The pits can collect ARD from overland flow or interflow from surrounding areas or from direct adit discharge (in the cases of the Cronebane and East Avoca Pits).

3. All of the pits are in contact with the underground workings to one degree or another and provide a pathway to transport ARD to adit discharges and diffuse flow to the Avoca River.

ES2.2 Spoil Heaps

Spoils at the Avoca site were generated both during the historical (1720-1888) and modern (1947-1982) periods. In general, the spoils consist of sand to pebble-sized material contained in a fine-grained matrix. The older spoils are generally oxidized to a red-brown color, but still contain unreacted pyrite. The volumes of spoils located in each area of the site are shown in Table ES2-1.

Table ES2-1 Summary of Spoil Heap Volumes at the Avoca Site[1]

Area	Spoil Heaps	Total Volume (m^3)
Connary	SP22-SP25, SP29-SP32	165,156
Cronebane/Mount Platt	SP19, SP20, SP20A, SP21, SP26-SP28	721,372
East Avoca	SP5, SP6, SP7i, SP7ii, SP8, SP10, SP11, SP12i, SP12ii, SP12iii, SP12iv, SP13-SP18	92,226
Tigroney West	SP1, SP2, SP2A, SP3,SP4	57,055
West Avoca	SP33, SP34, SP34A, SP34B, SP35-SP39	422,278
TOTAL		**1,458,087**

[1] Volume estimates and "SP" classifications from Gallagher and O'Connor, 1997

Based on the XRF analyses performed by CDM, the spoils contain significant concentrations of copper (<100-5,500 mg/kg), zinc (<100-1,000 mg/kg), lead (400-24,000 mg/kg), and arsenic (25-1,500 mg/kg). Analyses of seepage from the Mount Platt spoils collected by GSI in 1993, indicate that the pH was low and metals concentrations were very high, as shown in Table ES2-2.

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Table ES2-2 Water Quality Data for Seepage from Mount Platt (November 1993 Data)[1]

Parameter[2]	Concentration (mg/L)
Iron	1,698
Aluminum	938
Copper	251
Zinc	373
Lead	26
Sulfate	12,100
pH (su)	2

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

ES2.3 Tailings

Tailings are known to be present at the following locations:

- Shelton Abbey Impoundment
- North Lode Pit
- Along the West bank of the Avoca near the Road Adit

Shelton Abbey is by far the most important tailings deposit at the site, with an estimated volume of 7,000,000 m³.

In general, the Shelton Abbey Tailings had lower concentrations of copper (30-400 mg/kg), zinc (<100 mg/kg), lead (30-1,000 mg/kg), and arsenic (30-800 mg/kg) than the spoils. The metals concentrations within leachate from the tailings were not measured, but the pH of a pond at the base of the impoundment had a pH of 3.7 su in April 2007.

ES2.4 Adit Discharges

The adits which have active discharge for at least a portion of the year include the following:

- Kilmacoo Adit (seasonal flow)
- Madam Butler's Adit
- Wood Adit (seasonal flow)
- Intermediate Adit
- Cronebane Shallow Adit
- Deep Adit
- Road Adit
- Ballygahan Adit
- Spa Adit

A summary of the water quality for the adit discharges which have been analyzed and the estimated or measured flows are presented in Table ES2-3.

Table ES2-3 Summary of Adit Water Quality (mg/L)

Parameter	Intermediate[1]	Cronebane Shallow[1]	Deep[2]	Road[2]	Spa[3]
Average Flow (l/s)	~2	~2	17.7	17.1	~0.15
Iron	2,311	410	33	115	-
Aluminum	2,153	493	104	28	-
Copper	53	45	2.3	0.4	-
Zinc	440	182	52	14	-
Lead	0.8	5.1	-	-	-
Sulfate	22,000	6,350	1136	1366	-
pH (su)	2.2	2.3	2.7	3.3	2.68

[1] 1993 Data (Flynn, 1994)
[2] 2006 Data (Unipure, 2006)
[3] 2007 Data Collected by CDM during site visit

The Intermediate and Cronebane Shallow adits have by far the worst water quality, if the 1993 conditions are still valid today. However, based on pH measurements collected during the April 2007 site visit, the Cronebane Shallow adit is now above 3 su.

ES2.5 Underground Workings

The underground workings at the Avoca mine site are extensive, with an aggregate of 30 km of shafts, adits, and levels in East Avoca, and 16-21 km in West Avoca. The total does not include stopes, the extent of which is unknown. The flooded portions of the workings, while in contact with large quantities of sulfide minerals, probably do not produce as much ARD as the workings that receive only periodic flow from infiltration water.

ES3 Hydrogeology

Pathways of water to and from the mined areas are complex. The discharges from adits reflect both direct and indirect groundwater recharge, and groundwater flow is strongly influenced by the underground drainage system. Insufficient groundwater data exist to precisely delineate the zones of contribution (ZOCs) of the mine system; however, reasonable estimates of the sizes of respective ZOCs in East and West Avoca can be made on the basis of water balance considerations and geological interpretations. The ZOC for East Avoca is estimated to cover an area of 1.23 km², not including the open pits, and is elongated along the axis of the mined ore bodies. The ZOC for West Avoca is estimated to cover an area of 1.50 km², not including the open pits. Hydrogeological heterogeneities and faults that cut through the ore deposits may influence shape of ZOCs further.

Hydraulic characteristics of the bedrock in the mined areas have been partly quantified from drilling and basic hydraulic testing. Past studies indicate that the top 20-30 meters of bedrock are of variable quality, with rock quality designation values <30 percent, and with derived transmissivity values of 0.04-11.5 m²/day.

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Most of the groundwater discharging from the adits originates as direct or indirect recharge in areas near and adjacent to the open pits. Whether or not all of the hydrochemically impacted groundwater is 'captured' and discharged by the underground drainage is not known. Water balance evaluation and geological interpretations would suggest that only small quantities of impacted groundwater would escape capture by the mine system.

Water level data from wells downstream of West Avoca indicates that the Avoca River is a gaining river, although flow paths and head gradients may change over short distances as a result of heterogeneities in the bedrock and alluvium. Using the reported range of transmissivity values and hydraulic gradients in poorly productive bedrock, diffuse discharges from the top 30 meters of bedrock would be expected to be on the order of 100-500 m^3/day (0.003-0.015 l/s) per kilometer of river length.

O'Suilleabhain (1996) has estimated ARD contaminated groundwater baseflow of 3 l/s to 6 l/s to the Avoca River on the basis of hydrochemical data over a 2.5 km stretch or river. This is approximately 10 to 20 percent of the average discharge from the Deep and Road Adits (35 l/s). Because of the difference in the various estimates of diffuse flow and the importance of the diffuse flow (contribution to metal concentrations in the Avoca River are difficult to treat), additional evaluations are recommended.

ES4 Geochemistry

ES4.1 ARD Production

ARD is produced mainly by the oxidation of pyrite within the ore and host rock materials. Pyrite oxidizes from exposure to oxygen, producing dissolved sulfate (SO_4^{-2}), ferrous iron (Fe^{+2}), and hydrogen ions (H^+). The hydrogen ions result in low pH waters. The ferrous iron can be oxidized to ferric iron (Fe^{+3}) by additional oxygen, but the reaction is very slow at low pH. However, bacteria typically drastically increase the reaction rate. The ferric iron produced then aggressively reacts with more pyrite to produce more acidity, resulting in a vicious cycle. Propagation of the cycle can be stopped or dramatically decreased by removing one or more of the elements within the cycle, including oxygen (by flooding or encapsulation of the pyrite), the bacteria (using bactericides), or ferric iron (by increasing the pH or adding phosphate). Other sulfide minerals which are present in the deposit, such as chalcopyrite, sphalerite, galena, and arsenopyrite, oxidize to produce dissolved copper, zinc, lead, and arsenic, respectively.

ARD can also result from the dissolution of secondary minerals (formed since the deposit was emplaced), such as jarosite and metal sulfates. Secondary minerals can store acidity and metals until conditions change at which point the metals and acidity are released into solution. In the case of metal sulfate, which is an evaporative crust, release of metals and acidity can occur as the result of a rain event as the material is very soluble. Jarosite can be dissolved as a result of an increase in the pH of the water

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in which it is in contact. Dissolution of secondary phases often results in slugs of metals and acidity following rain or storm events.

ES4.2 Attenuation Processes

Neutralization

ARD is neutralized by the dissolution of minerals from down-gradient bedrock or soil/sediments within the drainage basin. However, the ability of these materials to have an impact on the generation and persistence of ARD depends on the rate of dissolution of the neutralizing minerals compared to the rate of pyrite oxidation. The neutralizing mineral dissolution rate depends on the following factors:

- The grain size of the minerals (the smaller the grains the faster)

- The mineral type (carbonates are the fastest followed by ferromagnesium minerals and felsic minerals)

- The pH of the ARD (the lower the pH the faster)

In general, unless the ore deposited is hosted by carbonate rocks, silicate minerals dissolve in the presence of ARD. However, because the rate of pyrite oxidation is faster than the rate of neutralization reactions (silicate mineral dissolution), low pH water results. Once the ARD leaves the sulfide-bearing materials, the neutralization reactions become more effective and the pH can increase.

The effect of the pH buffering has several effects on the fate and transport of metals and the quality of the ARD, including:

- The concentrations of ferric iron in solution and the rate of pyrite oxidation (as discussed previously)

- The degree of adsorption

- Precipitation/coprecipitation reactions

The neutralization of the ARD ultimately attenuates most of the metals, although zinc tends to persist at pH values up to 7 or 8 su.

At the Avoca site, neutralization by chlorite, plagioclase, and to a lesser extent sericite, appears to be occurring within the mine workings. The Avoca River also appears to have the capacity to neutralize ARD, as the pH of the water in the river very quickly recovers a short distance down-stream from the adit discharges.

Adsorption

The adsorption of metals is enhanced at high pH due to the positive charge of the metals in solution and the negative surface charge of clay minerals and manganese dioxide. However, if the pH becomes too high, then neutral or negative aqueous

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species begin to become more important and adsorption tends to start to decrease. The result is a "window" in which adsorption is maximized (usually between a pH of 6 and 8 su). The neutralization of the ARD to within the optimum adsorption range results in adsorption of metals onto sediments and removal from solution.

Coprecipitation
Coprecipitation of metals and arsenic with iron hydroxysulfate minerals such as schwertmannite and jarosite is likely occurring within the mine workings.

Precipitation of an amorphous iron oxyhydroxide phase with coprecipitation of copper, lead, zinc, and other metals is likely an important control on metals concentrations in the Avoca River where the adit water mixes with the river water. Deposits of "yellow boy" iron oxyhydroxide and iron sulfate precipitates are present at the point where the adit discharges enter the Avoca River.

Dilution
Dilution can result in dramatic decreases in aqueous metals concentrations, when the volume of dilution water is large. Using an average combined flow for the two adits of 34.8 l/s, a copper concentration of 1 mg/L for the adits and a flow of 1,087 l/s for the Avoca River results in an "in river" copper concentration of 0.05 mg/L (assuming 0.018 mg/L copper and a flow of 1,052 l/s in the Avoca River up-gradient of the adits). Dilution ranges from a low of about 80 in July (Avoca low flow) to 800 in January (Avoca high flow).

The effect of dilution on pH is complicated by the buffering that occurs due to the formation of weak acids, such as bicarbonate and by adsorption of protons (H^+) onto solid surfaces. In addition, pH is in log units, such that a dilution of 1000 (using neutral water) will change the pH from 3 to 6 (neglecting buffering).

ES4.3 Mass Balance Evaluation

The mass of each metal in the combined Deep Adit and Road Adit discharges (and the upgradient mass) was subtracted from the mass within the Avoca River downgradient of the site to obtain the mass contributed by diffuse flow. The results are shown in Table ES4-1 for the August 1995 data.

Table ES4-1 Metals Load in the Avoca River at Coalyard (August 23, 1995)[1]

Parameter	Concentration (mg/L)	Loading (kg/yr)	Deep Adit + Road Adit (kg/yr)	Percent Adits
Iron	2.293	50,546	75,951	150.3%
Aluminum	3.302	72,788	58,021	79.7%
Copper	0.185	4,078	513	12.6%
Zinc	1.482	32,669	28,882	88.4%
Lead	0.125	2,755	593	21.5%
Sulfate	60.5	1,333,642	947,584	71.1%
Flow (l/s) = 699				

[1] O'Suilleabhain (1996)

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In general, the adits contribute the majority of the metals load to the Avoca River. The low percentages for copper and lead are likely due to analytical uncertainties at the low concentrations measured within the Avoca River. The results are consistent with those obtained for the Pilot Study (Unipure 2006). For aluminum and zinc, the adits contribute 80 percent and 88 percent of the load in the Avoca. These values are consistent with previous estimates that diffuse flow accounts for 10 to 20 percent of the metal load in the Avoca River. However, as shown, the amounts of copper and lead accounted for by the adits are much lower than for aluminum, zinc, and sulfate. The amount of iron contributed by the adits is calculated to be above 100 percent. Clearly some iron is being removed (precipitated) in the River. The variability in these values clearly indicate that additional evaluations are needed.

ES4.4 ARD Generation at the Avoca Site

Tailings

The Shelton Abbey tailings are relatively low in metals compared to the mine spoils. However, based on the low pH high conductivity water ponded at the base of the tailings, significant ARD production is taking place. Despite the fact that a large fraction of the sulfide minerals were extracted from the tailings, the volume of material is large and the grain-size small, promoting pyrite oxidation. The tailings ponds are not properly capped, allowing oxygenated surface water and precipitation to infiltrate into the impoundment.

In some areas, such as in various areas along the berm, tailings are directly exposed at the surface and are actively eroding. These tailings are under ideal conditions for pyrite oxidation, namely alternating wetting and drying. The extent to which a reaction such as pyrite oxidation proceeds is determined by the limiting reagent. The oxidation of pyrite requires both oxygen and water. Saturated tailings contain abundant water but very little oxygen and dry tailings contain abundant oxygen (if near or at the surface) but very little water. Under each of these circumstances, pyrite oxidation is not favored due to the limiting reagents. Alternating wetting and drying cycles provide both abundant water and oxygen and represent a worse case scenario for pyrite oxidation by oxygen.

The normal progression of the water quality within a tailings impoundment is from process water (contained in the tailings from milling) to neutralized ARD to low pH ARD (USEPA 1994). The pyrite oxidation of most tailings ponds and spoil heaps begins until the pH reaches a critical threshold, somewhere around 3 to 3.5 su, at which point iron hydroxide becomes soluble, resulting in the production of ferric iron. The ferric iron produced then reacts with fresh pyrite, which produces acidity much more rapidly than oxidation by oxygen. As no pore water or direct spring analyses are available for the tailings to measure the pH, it is difficult to determine if the pyrite is oxidized by oxygen and/or ferric iron. The pH of the pond at the base of the tailings berm adjacent to the Avoca River was 3.7 su in April 2007, which would suggest that pyrite oxidation by oxygen is the dominant reaction. However, the pond water may have been neutralized to some extent or diluted by other water sources.

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Knowing the relevant pyrite oxidation mechanism is very important when considering remediation alternatives. Oxidation by oxygen is normally controlled by limiting either water or oxygen (usually via capping or flooding, respectively). Limiting ferric iron oxidation requires pH adjustment, such as liming the tailings. Williamson et al. (2006) found that increasing the pH of the water in contact with pyrite from 2 to 4 su decreases the pyrite oxidation rate by five orders of magnitude (100,000 times).

Spoil Heaps

The spoil heaps have an estimated volume of about 1.5 million m^3, contain significant pyrite, are generally fine grained or have a fine-grained matrix, and are subject to alternating wetting and drying conditions. The conditions are optimal for ARD production, which is evident from the limited seep water quality data for spoil heaps SP20 (Mount Platt) and SP2 (Tigroney West). Iron and aluminum concentrations on the order of 1,000 mg/L, sulfate concentrations up to 12,000 mg/L and pHs as low as 2 su have been measured in spoils leachate. Given the low pH values and the very high iron concentrations, it is apparent that significant pyrite oxidation by ferric ion is occurring within the heaps.

O'Suilleabhain (1996) estimated vertical hydraulic conductivities within the spoil heaps of 10^{-1} to 10^{-3} cm/s, which the author considered to be fairly low. However, as the values were estimated using a combination of falling head permeameter and grain-size analyses, the permeability estimates are likely underestimated. Flow is most likely controlled by preferential flow pathways along fractures or coarser material.

As the spoil heaps sometimes overlie collapsed mine workings (SP5, SP8, SP10, and SP28 are the known examples), leachate from the piles could be conveyed directly into the mine workings, adding to the load of the Deep Adit. In addition, the low pH of the water could dissolve iron hydroxide within the workings creating ferric iron, which aggressively oxidizes pyrite within the workings. Ferric iron oxidation of pyrite can even occur in areas of the mine which are low in oxygen, as long as a constant supply of low pH ferric iron-containing water is supplied. Under such circumstances, ferrous iron would accumulate until oxygenated conditions are reached where bacteria catalyze the oxidation of the ferrous iron back to ferric iron.

Spoil heaps which are not in communication with the underground workings can contribute ARD to the open pits (and ultimately the underground workings), surface drainages, and to the shallow groundwater (within the fractured upper surface of the bedrock and thin alluvium). The ARD would then enter the Avoca River through tributaries and interflow. The contribution of the spoil heap leachate to the river is likely to occur in pulses following storm events and would not be detected during low flow sampling.

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Pit Walls

The pit walls contain significant concentrations of sulfides and metals, in some cases of ore grade and are subject to wetting and drying conditions. Evidence of staining, resulting from oxidation of pyrite to iron oxyhydroxides is evident on many of the pit walls.

The surface area of the sulfides is relatively low, which would slow the oxidation of the sulfides. However, given the large areas of sulfide-bearing pit walls present at the site, a contribution is probably being made to the quality of the pit lakes, and ultimately the underground workings, but it is less than for the spoils or the mine workings located above the water table.

The water quality of pit ponds at many sites can often be attributed to wall rock interactions with surface water. However, the Cronebane and East Avoca Pits ponds not only have inputs of ARD from the walls, but also from adit discharges and from spoils leachate, which does not allow for the contribution of the pit walls to be separated from the spoils seepage and adit inputs. Jerz and Rimstidt (2004) determined that the rate of pyrite oxidation within above-drainage workings is controlled by the relative humidity.

Unsaturated Underground Mine Workings

Mine workings which are above the water table, sometimes referred to as "above-drainages," often have high concentrations of oxygen due to the ventilation systems provided to allow the miners to work underground. The oxygen, combined with water provided in the form of adit drainages and humidity in the air allows for rapid pyrite oxidation. Jerz and Rimstidt (2004) found that pyrite oxidation by moist air is much more effective at oxidizing pyrite than flowing water (due to the presence of both oxygen and water).

The rapid rate of pyrite oxidation within the above-drainage underground workings at the Avoca site is evident in the extremely poor water quality issuing from the Cronebane Shallow and Intermediate adits. Iron and aluminum concentrations above 2,000 mg/L, copper concentrations around 50 mg/L, zinc concentrations from 180-440 mg/L, sulfate of 6,000 to 22,000 mg/L and pH values of about 2.2 su were measured in 1993. The Intermediate adit alone, assuming an estimated flow rate of 2 l/s provides nearly 100 percent of the zinc load and 7.5 percent of the lead of the Deep Adit, while over 100 percent of the iron, aluminum, copper, and sulfate can be accounted for from this single adit input. Obviously, the parameters that are input by the Intermediate Adit at a greater loading than the Deep Adit output are being removed within the workings or discharges at another point. More recent analyses (fall of 2006) may indicate that the quality has improved.

Assuming the 1993 analyses are still valid, the discharges from the above-drainage underground workings appear to be very important and have significant implications for the remediation strategies considered for the site. Treatment of the Intermediate

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and Cronebane Shallow adits before being allowed to re-enter the underground workings could significantly reduce the rate of pyrite oxidation within the lower workings by essentially eliminating the rapid ferric iron oxidation of pyrite.

Saturated Underground Mine Workings
In general, completely saturated "below-drainage" mine workings are not nearly as important sources of ARD as are unsaturated workings. The oxidation of pyrite, under such conditions is limited by the amount of oxygen dissolved in the water, which can be quickly consumed by the pyrite but can not be quickly replaced due to slow diffusion of atmospheric oxygen.

Skousen et al. (2006) in a study of several coal mines in the eastern United States found that after the first few mine volumes of water passes through the system the water becomes much less acid or even net alkaline.

ES4.5 Metals Attenuation at the Site

The metals produced at the site may be coprecipitated with jarosite or schwertmannite within the mine workings (based on the loading of the Intermediate Adit) in response to partial neutralization of the ARD by silicate minerals such as chlorite and plagioclase. Some of the remaining metals that reach the Avoca River via the adits (Deep Adit and Road Adit) are coprecipitated with iron oxyhydroxides in response to mixing with higher pH water.

The remaining concentrations of metals flow within the Avoca River are adsorbing mostly to organic matter, iron oxyhydroxides manganese dioxide, and clay minerals within the fine grain-size fraction of the sediment. As the pH of the river increases down-gradient, the adsorption of metals increases resulting in lower dissolved concentrations. The coprecipitated and adsorbed metals would act as a secondary source once the ARD inputs are removed or eliminated, which could prolong the recovery of the river.

Metals derived from spoil heaps and present within interflow would be at least partially neutralized by the fractured bedrock, and alluvium through which it flows. The same reactions would take place as for the adit discharges, except to a greater extent, due to the greater residence time between the silicate minerals and the interflow and the higher surface area of the alluvium as compared to the walls of the underground workings. The initial jarosite precipitation (with metals coprecipitation) would occur as coatings on soil grains and cement between grains. As the interflow pH increases, coprecipitation of metals with iron oxyhydroxides would occur, followed by adsorption onto manganese dioxides, clays, and organic matter. The adsorbed and coprecipitated metals would likely act as a secondary source should the spoil heaps be remediated.

ES5 Data Gaps

ES5.1 Water and Gas Analyses

Water samples should be collected and analyzed for field parameters (Eh, pH, conductivity, dissolved oxygen [DO], and temperature), metals (including iron speciation), arsenic, and major anions and cations. The following waters should be sampled:

- **Pit Ponds** (Cronebane and East Avoca)

- **Adits (**Kilmacoo, Madam Butler's, Intermediate, Cronebane Shallow, Wood, Ballygahan, Spa Adit)

- **Seeps** (base of Mount Platt, Shelton Abbey berm and pond at the base of the impoundment, Ballygahan, Seasonal seeps from spoil heaps and pit walls)

- **Avoca River** (regular intervals between White's Bridge and Avoca Bridge, and in the vicinity of Shelton Abbey)

- **Tributaries to the Avoca River** (Red Road, Sulphur Brook, Vale View, and Aughrim)

- **Wells** (Shelton Abbey, and in select areas where flow is believed to be entering the Avoca River; existing homeowner wells in the East Avoca mine area; existing wells associated with the County Wicklow landfill)

- **Lysimeters** (Shelton Abbey and emergency tailings along the Avoca)

- **Soil Gas Probes** (Shelton Abbey Tailings)

Water quality data (and flows) will be used to determine loadings, evaluate the relative importance of various sources of ARD including diffuse loading to the Avoca River and help to determine remedial alternatives.

ES5.2 Flows

Flow measurements should be taken at the same locations as the surface water locations, with the exception of the pit ponds. Flows will be used along with water quality to determine loadings and determine mass balances.

ES5.3 Spoil Heap Analyses

Analyses of the spoil heap materials for metals, arsenic and acid-base account will be required in order to further evaluate the source potential of each heap and to update the human health and ecological risk assessments.

Both surface and subsurface (test pit or borehole samples) samples should be collected in order to determine variations with depth, such as zonation within the piles. Subsurface samples will be particularly important for Mount Platt.

ES5.4 Tailings Analyses

The characteristics of the tailings material should be determined by use of cores collected during well installation or possibly from test pits. The uniformity of the tailings, in terms of physical (i.e., grain size, sorting, staining, etc.) and chemical properties (arsenic and metals analyses) should be determined.

ES5.5 Hydrogeology

Present gaps in the understanding of groundwater hydraulics relate to diffuse groundwater discharges along the Avoca River, and ZOCs of the mine system. To provide verification on water balance estimates, discharges and ZOCs, monitoring of groundwater levels are needed, which would require the installation of small-diameter wells throughout the mining area.

To verify the conceptual model of flow mechanisms, wells would have to be installed in both shallow and deep bedrock, as well as the overburden along the river. Wells near the open pit areas would be bedrock wells only. For ZOC delineation, some wells should be located closer to the N-S trending faults that cut through the ore bodies. The need for verification of ZOC estimates is probably a lower priority than verification and understanding of diffuse discharges. Therefore wells along the river would be considered more important. Water levels should be measured in the existing wells associated with the Ballymurtagh landfill and the existing homeowner wells in the East Avoca mine area. Existing data should be integrated into the proposed site monitoring activities.

Flow monitoring of the Avoca River downstream of the mines is recommended. A hydrometric gauging station downstream of the confluence between the Avoca and Aughrim Rivers would serve multiple purposes, including both Avoca and WFD-related needs.

ES5.6 Other Activities

Aerial Survey of Current Tailings Topography
An aerial survey of the tailings topography should be conducted to determine the tailings volume and for remedial alternative/design purposes.

Tracer Study
A tracer study could be performed to obtain accurate flow measurements for the Avoca River, particularly in areas where significant underflow (flow beneath the bed of the river within the alluvium) is suspected.

Electron Microprobe (EMP) Analyses

The EMP analyses can be used to explain why some wastes are more acid generating than others and why arsenic is so immobile. The forms of metals, such as copper, zinc, and lead can also be determined and related to leachability and bioavailability.

Section 1
Introduction

1.1 Purpose of the CSM

The purpose of the Phase 1 preliminary Conceptual Site Model (CSM) is to use the existing site data and the results of a limited site investigation to make an evaluation of the geochemical and hydrological processes that result in acid rock drainage (ARD) input to the Avoca River. The development of the preliminary CSM will help to identify any additional information needs (data gaps) that would need to be filled in order to prepare a Final CSM and focus additional field investigations (Phase 2). The results of the CSM will be used to help select appropriate remedial and management alternatives at the site.

1.2 Previous Investigations

CDM relied on a number of previous investigations to prepare the Conceptual Site Model (CSM), including the following:

- <u>Biorehabilitation of the Acid Mine Drainage Phenomenon by Accelerated Bioleaching of Mine Waste</u> (1993) – Work carried out by the GSI under an eight week contract with the European Union designed to provide site characterization data in preparation for the bioleaching studies (Flynn, 1994).

- <u>Avoca/Avonmore Catchment Conversion Life Project</u> (1995-96) – Carried out by GSI with assistance from Trinity College Dublin (TCD) for Wicklow County Council (WCC) under the EU Life Programme. The project consisted of creating several reports on the geology, ecology, and hydrogeology of the site to facilitate reclamation activities.

- <u>Published Papers</u> – Articles published in scientific journals and conference proceedings covering various aspects of the Avoca site (e.g., journal articles by Gray and Sapsford) and acid mine drainage investigations from various sites around the world.

1.2.1 Biorehabilitation of the Acid Mine Drainage Phenomenon by Accelerated Bioleaching of Mine Waste

Data collected for the characterization report produced for the investigation (Flynn, 1994) included:

- Discharge gauging of the Deep Adit

- Chemical analyses for 34 water samples collected from adits, seeps, pit ponds, surface flows, and groundwater (for November and December 1993)

- Groundwater level data

Using the data collected and information from previous sources the following evaluations and figures were performed:

- Precipitation map and recharge rate calculations
- Zone of contribution for the mine site
- Groundwater level map
- Water quality tables and trilinear plots
- WATEQ Equilibrium modeling

1.2.2 Avoca/Avonmore Catchment Conversion Life Project

Reports from the Avoca/Avonmore Catchment Conversion Life Project (hereafter the "Life Project") that were used in the current evaluation included the following:

- *Characterization of the Avoca Mine Site: geology, mining features, history, and soil contamination study.* GSI Technical Report MS/97/1(Gallagher and O'Connor 1997).

- *Hydrogeology of the Avoca Mine Site and Surrounding Area, Co. Wicklow.* GSI Technical Report MS96/3 (O'Suilleabhain 1996).

The characterization report included the following:

- Descriptions, and area and volume estimates of the spoil heaps onsite

- Descriptions of all site features, including pits, adits, shafts, engine houses, and other features

- A summary of the ore deposits, mineralogy, and mining history of the site

- Soil analytical data collected from farm fields and other areas adjacent to the site

- Recommendations for remediation and historic preservation of the site

The hydrogeology report included the following:

- Flow gauging for the Avoca River (Meeting of the Waters, White's Bridge, Coalyard, and opposite Avoca Handweavers down-stream from Sulphur Brook)

- Flow Gauging on Red Road Stream (four locations)

- Flow gauging on Sulphur Brook (one location)

- Flow gauging of the Deep Adit and Road Adit

- Rain gauge installation at Cronebane and Pond Lode Pits

- Installation of six wells

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- Permeability Testing (pumping tests on four sites, variable head tests on four wells, grain size analysis)

- Surface Water Sampling (Avoca-Lion's Bridge, Avoca-White's Bridge, Avoca-Coalyard, Red Road, Sulphur Brook, and Vale View)

- Adit Sampling (Deep Adit and Road Adit)

- Groundwater Sampling (45 wells)

- Groundwater level monitoring

1.3 Site Visit and Screening-Level Evaluation

CDM, GWP Consultants, and GSI personnel visited the site on April 2-4, 2007. The purpose of the visit was to become acquainted with the site, to test field procedures to be used for the July-August sampling effort, to perform a safety audit (GWP Consultants), and to provide preliminary data to be used in the CSM, risk assessments, and preliminary remedial alternatives reports.

During the site visit, the following sites were visited:

- Shelton Abbey Tailings Impoundment
- West Avoca Spoils Piles
- Connary Area Spoil Heaps
- East Avoca Spoil Heaps
- Mount Platt/Cronebane Spoil Heaps
- Tigroney West Spoil Heaps and ore bins
- Cronebane Pit
- East Avoca Pit
- Cronebane Shallow Adit
- Deep Adit
- Road Adit
- Ballygahan Adit
- Spa Adit
- Avoca River from Meetings of the Waters to Avoca Bridge and Adjacent to Shelton Abbey Tailings
- Sulphur Brook
- Red Road Stream
- Vale View Stream
- Aughrim River
- Monitoring wells on County Wicklow property near the road adit
- Monitoring wells at the Shelton Abbey Tailings

At the adits, rivers, and wells, pH and electrical conductivity measurements were measured using field portable instruments.

Analyses of spoil heap materials were performed using a field portable X-ray fluorescence (XRF) instrument (Niton XLi 700 series with a radioactive source). Both "direct shoot" analyses of the in-place waste and analyses of sieved samples placed in XRF cups with a mylar film analysis windows (designated by an "S" following the sample ID) were performed.

The results from the site visit are provided in various sections to follow.

1.4 Site Geology and Deposit Description

1.4.1 Local Bedrock Geology

The Avoca ore deposit is hosted by the Avoca Formation of Ordovician age, which comprises three basic Members (from old to young):

- Castlehoward – mainly sericitic tuffs with felsic horizons.
- Kilcashel – mainly chloritic tuffs, silicified and frequently altered.
- Tigroney – mainly sericitic lithic and crystal tuffs, and felsites.

Pale coloured rhyolites, rhyolitic tuffs, and breccias are evident in some exposures within the open pits. The volcanic host rocks are also interbedded with sediments of marine origin, and include mudstones, shales, and metamorphic phyllites.

The Avoca Formation and its enclosing sediments dip steeply (50 degrees +) to the southeast. The Formation varies in total thickness from 1,500-2,500 metres, depending on location. In Wicklow, the Avoca Formation takes on a lenticular shape which trends NE-SE and varies in width between 2-4 km. The sequence is at its thickest within the Avoca River valley.

There are numerous basic igneous intrusions in vicinity of the mines, including the Carrigmore Diorite to the northeast of East Avoca. The Cronebane pit shows marked heterogeneities, with exposed surfaces of porphyry, schist, rhyolite, shales, and tuffs.

1.4.2 Local Quaternary Geology

The overburden materials in the Avoca area consist of bedrock-derived tills and alluvium (including small sand and gravel bodies) along the valley floors. Although the thickness of the alluvium has not been mapped, limited well drilling in the area suggests the alluvial deposits can be greater than 10 m in some places. The soil and subsoil profiles associated with upland areas are thin, generally less than 1 m thick.

1.4.3 Structural Geology

The main structural features of Avoca are:

- NE-SW trending D1 cleavage which affects most lithologies (notably visible in the Cronebane open pit)

- Several N-S trending faults, of which the most significant is the "Great Fault" that displaces the main Avoca ore body southwards on the western side of the Avoca River

The mineralized ore bodies occur in vicinity of dip-slip ductile D2 shear zones.

1.4.4 Mineralization

The Avoca ore bodies occur primarily as banded, massive sulphides near the top of the Kilcashel Member, which has been the main target of mining. The banded, massive sulphides can be several meters thick, and more than 95 percent of the associated ore is composed of Pyrite (FeS_2), the remainder comprising chalcopyrite ($CuFeS_2$), sphalerite (ZnS), and galena (PbS). Magnetite, hematite, arsenopyrite, pyrrhotite, bismuthinite, and native bismuth are trace constituents, while gold is rare.

Banded ore bodies occur in the Pond lode and North lode in West Avoca and Main lode in East Avoca.

Stringer sulphides and bands of lead-zinc ore are less prevalent and are associated with alteration of the host rock (e.g., silicification – precursor of vein mineralization). In stringer ore bodies, pyrite, chalcopyrite, sphalerite and galena occur within a silicious matrix. Minor constituents are arsenopyrite, pyrrhotite, bismuthinite, native bismuth, tetrahedrite, galenobismuthinite, and bournonite. Trace elements are cobaltite and lillianite. In lead-zinc ores, sphalerite, galena, and pyrite occur with minor arsenopyrite and chalcopyrite in a chloritic matrix. Tetrahedrite and bournoniite are rare.

Interpretation of the paragenetic sequence for the different ore types suggests that banded ores are syngenetic in origin (i.e., sea-floor deposition of mineralizing solutions) while stringer and lead-zinc ores reflect remobilization and recrystallization of earlier ore deposition (triggered by structural deformation events).

1.4.5 Size of Mines and Ore Bodies

The Avoca mines occupy a total surface area of about 1.6 km^2. The network of underground mine shafts follow the above-ground boundaries of pits and spoil heaps reasonably closely.

For East Avoca, the mined area occupies about 0.9 km^2 (3,000 m long, 300 m wide), while the network of underground shafts is approximately 27 km in total length.

For West Avoca, the mined area occupies about 0.67 km^2 (1,100 m long, 600 m wide), while the network of underground shafts is approximately 20 km in total length.

The deepest levels in East and West Avoca are 129 and 254 meters below sea level, respectively. Shafts below the Avoca river elevation (ca. 30 m OD) are flooded.

Estimates of total ore reserves are as follows:

- West Avoca: 4,737,890 Tonnes
- East Avoca: 14,438,680 Tonnes, excluding Cronebane and Connary
- Total: 19,381,010 Tonnes (at 0.62 percent Cu), excluding Cronebane and Connary

Published ore reserve totals do not exist for Cronebane and Connary.

1.5 Mining History

Industrial-scale copper mining began at Avoca around 1720 although iron had earlier been exploited in small deposits in the district. From 1839 onwards pyrite mineralization provided economic sulphur ore which became the main product at Avoca. Mining of copper and sulphur continued until 1888 when the mines became derelict. During the 18th and 19th centuries, it was estimated that 0.22 Mt of copper ore grading 6.45 percent Copper and 2.4 Mt of pyrite ore grading 35 percent S were produced.

The mines were re-opened during World War II to provide an emergency supply of sulphur and this was followed by two further periods of continuous mining for copper. Production was recommenced in West Avoca in 1958 by St. Patrick's Copper Mines Ltd when the mine was deepened to 200 m below sea level but production problems led to a further cessation of mining in 1962. Avoca Mines Ltd subsequently re-opened the mine in 1969, with underground workings eventually extending to depths of 300 m below sea level. During the same phase of mining, open pit exploitation was also implemented, in the Pond Lode open pit (in West Avoca, which commenced production in 1973), the Cronebane open pit (east of the river, excavated 1971-1975) and East Avoca open pit (excavated between 1978 and 1982). Mining finally ceased in the Avoca area in 1982, by which time an estimated 12 Mt of ore had been extracted from the mines over their working life (Wright et al. 1999). An attempt at gold extraction in the Cronebane Pit in the late 1980's proved unsuccessful and was not pursued.

Section 2
Source Evaluation

An evaluation of sources of potentially toxic metal contamination that may have human and ecological impacts and the sources of ARD that are likely contributing to the ARD input to the Avoca River are important parts of the CSM as well as the determination of remedial alternatives for the site. The following descriptions are based largely on the work of Gallagher and O'Connor (1997) with more minor inputs from Jadebay (2003) and the results of the site visit conducted by CDM and GWP Consultants in April 2007.

2.1 Pits

The pits likely contribute to the loading of ARD to the Avoca River in a number of ways, including the following:

1. ARD is generated directly as precipitation flows along the pit walls and through spoil heaps located within and near the pits.

2. The pits can collect ARD from overland flow or interflow from surrounding areas or from direct adit discharge (in the cases of the Cronebane and East Avoca Pits).

3. All of the pits are in contact with the underground workings to one degree or another and provide a pathway to transport ARD to adit discharges and diffuse flow to the Avoca River.

A summary of the area, volume, and important features of each pit is provided in Table 2-1.

Table 2-1 Summary of Pits at the Avoca Mine Site

Pit	Location	Years Excavated	Notes	Area (m^2)	Volume (m^3)
Cronebane	East Avoca	1971-75, 1978	Banded pyrite ore and fine-grained sphalerite and galena (kilmacooite) are exposed in the pit walls. About 40% of the area is filled with spoils. Two or three mine openings may discharge intermittently to the pit. One of them, adjacent to the pond, may occasionally take in water from the pond.	62,080	700,000
East Avoca	East Avoca	1978-1982	Also referred to as the "Tigroney Pit" in some reports. Chalcopyrite quartz/chlorite schist breccia and pyrite veinlets are exposed in the pit walls. The Intermediate Adit discharges into the pit, through fractures and into the underground workings below, eventually reaching the Deep Adit in Tigroney West and possibly contributing to diffuse discharges.	20,437	375,720
Pond Lode	West Avoca	1973-1979	Also called the "Ballymurtagh Pit." Currently backfilled with municipal waste and capped.	29,779	?

Table 2-1 Summary of Pits at the Avoca Mine Site

Pit	Location	Years Excavated	Notes	Area (m²)	Volume (m³)
North Lode	West Avoca	1850s	The ore was a gossan cap of hematite (52% iron) which overlies the massive pyrite ore mined by the underground workings below. The pit is filled with 20th century tailings and spoils.	7,774	233,220
Weaver's Lode	West Avoca	Unknown	Also referred to as the "south North Lode." Believed to have been formed by the collapse of underground workings. Mineralized rock is exposed within the pit. Water entering the pit is believed to drain to the Spa Adit and may contribute to diffuse discharges.	~600	~6,000

A brief description of each pit follows.

2.1.1 Cronebane

The near surface ore in the area which later became the Cronebane Pit was long recognized as a significant ore body. In 1902, the Avoca Syndicate sank four shafts to a depth of 30 m and encountered a "soft clayey ore" at a depth of 10 m. The ore was relatively rich in metals, containing 2.8 percent copper, 1.5 percent zinc, and 0.3 percent lead. However, the material was too unstable to permit the use of underground mining. In 1969, when Avoca Mines Ltd. (AML) took over mining at the site, the deposit was recognized as a supervene enrichment zone overlying the banded pyrite ore and stringer ore.

AML began excavation of the 10 m of overburden in 1971, piling the spoils southwest of the pit to form the flat-topped mound known as "Mount Platt" (named after J.W. Platt of AML). Once exposed (by late 1973), the soft mineralogically distinct supergene ore was easily mined using rippers and bulldozers, but required a separate circuit at the mill located in West Avoca. By April 1975, mining of the Cronebane ore was suspended. Production was resumed in January 1978 and continued through September 1978. The later mining activities extended the production into the banded sulfide and stringer ore, which began at a depth of about 30 m.

The banded sulfide ore and stringer kilmacooite-bearing ore was exposed within the lower portions of the pit; the ores represent a potential source of ARD. A geologic cross section through the pit is presented in figure 6 of Jadebay Limited (2003). An analysis of the mineralized green rock (chloritic tuff?) exposed on the northwest wall of the pit is provided in Table 2-2.

Table 2-2 XRF Analysis of the Northwest Wall of Cronebane Pit

Sample	Area	Notes	Concentration (mg/kg)					
			Pb	**As**	**Zn**	**Cu**	**Fe**	**Mn**
SA-19	Mount Platt	NW wall of Cronebane Pit near boundary with SP20	1838	852	715	1729	304,273	<2,538

Another source within the Cronebane Pit is the spoils, which fill approximately 40 percent of the area of the pit. The spoils are approximately 200 m long by 30 m high by about 50 m wide (averaged with depth), with an estimated volume of 300,000 m³. According to the Jadebay cross section, banded sulfide ore is present within the pit walls beneath the spoils.

In addition, leachate from spoil piles SP21, SP22, SP26, SP27 (GSI designations from Gallagher and O'Connor, 1997, see Section 2.2.2 for pile descriptions and locations), and possibly the Connary area spoil piles drain into Cronebane Pit.

Several adits/levels were exposed by excavation of the pit, including Mackay's 3X, Mackay's 4X, 14 fm, 16 fm, 23 fm, and 29 fm, which likely provide communication between the surface drainage and the underground workings to some extent.

The spoils seepage and adit discharges form a pit pond on the northeast end of the pit. An analysis of the pit pond collected by GSI in 1993 (Flynn, 1993) is presented in Table 2-3.

Table 2-3 Water Quality Data for Cronebane Pit (November 1993 Data)[1]

Parameter[2]	Concentration (mg/L)
Iron	17.4
Aluminum	23
Copper	8.2
Zinc	9.0
Lead	0
Sulfate	330
pH (su)	2.5

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

2.1.2 East Avoca

The East Avoca Pit was excavated by AML in the area historically called the "Dead Ground" area, beginning in 1978 to replace the declining production from the Pond Lode and Cronebane Lode. The ore consisted of chalcopyrite-bearing quartz/chlorite schist breccia averaging 0.53 percent copper, which was mined using drill-blast methods. A portion of the Mount Platt spoil pile had to be removed to access the ore body.

Mineralized rock is exposed within the pit walls, providing a potential source of ARD. In addition, spoil heaps (SP12i, SP12ii, SP12iii, SP12iv, SP13, SP16, SP17, and SP20)

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up-gradient and around the rim of the pit likely drain into the pit and provide a source of ARD.

Several 18th and 19th century adits/levels are exposed in the East Avoca Pit, including the Cronebane Deep (in two places), the Grass Level, and Intermediate Level. The Intermediate Level is located on the southeast wall of the pit and discharges a flow of ARD into the pit, which flows across the bottom, eventually ponding on the southeast end of the pit. The pit pond is believed to drain via a fissure into the underground workings, eventually forming part of the Deep Adit discharge at Tigroney West. Prior to 1994, the Intermediate Level was plugged by a large boulder, which disrupted its discharge into the pit.

The Deep Level Adit appeared to be flooded (GWP, 2007) and may conduct pit water into the underground workings.

An analysis of the pit water collected by GSI in November 1993 is provided in Table 2-4.

Table 2-4 Water Quality Data for East Avoca Pit (November 1993 Data)[1]

Parameter[2]	Concentration (mg/L)
Iron	137.5
Aluminum	121.6
Copper	13.2
Zinc	81.6
Lead	0.5
Sulfate	1820
pH (su)	2.3

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

2.1.3 West Avoca -Pond Lode, North Lode, and Weaver's Lode

Pond Lode Pit

The Pond Lode Pit was excavated by AML between 1973 and 1979 on the surface extension of the Pond Lode, which had been previously mined by underground methods. Extensive caving of these workings occurred in the early 1960s due to "pillar robbing" by Saint Patrick's Copper Mining Company (SPCM).

In 1988, a gravel base and liner were installed in the pit in preparation for disposal of municipal refuse within the pit. The pit was completely filled by about 1999, and has since been capped and vegetated. Although the landfill is no longer in use, County Wicklow maintains a groundwater monitoring network and methane collection system.

Mineralized wall rock was once exposed within the Pond Lode Pit. P. McArdle of the GSI took photographs of the open pit in 1988, reporting the presence of 19th century cobbings (spoils), sericitic tuff, graphitic schist, black schist and banded pyrite. However, Jadebay (2003) states that the wall rock of the Pond Lode Pit exposed

dolomitized clastic sediments, which is the only reported occurrence of carbonate-bearing rock at the site.

North Lode Pit

The North Lode was a supergene cap overlying massive sulfide ore that was mined by the Wicklow Copper Mining Company in the 1850s. The ore reportedly consisted of a hematite gossan containing 52 percent iron. The pit was considered very large in the 1850s, measuring 300 m long by 30 m wide by 30 m deep. The North Lode was also mined by underground methods.

AML used the North Lode Pit as an emergency tailings disposal facility. The North Lode Pit is now completely filled with tailings and a covering of fine spoils (SP34). The surface has been largely revegetated through natural colonization and the Life Project revegetation trials.

Weaver's Lode Pit

Weaver's Lode Pit is a small pit with dimensions of about 60 m long by 10-15 m wide by 10 m deep. Gallagher and O'Connor (1997) speculate that it was excavated in the 1850s, but state also that Mianrai Teoranta (TM) on their 1951 map refer to the pit as the result of "caving, iron ore and ochre workings".

Apparently, ore host rocks are exposed within the pit walls and debris/spoils disposed of in the pit provide additional potential sources of ARD.

Weaver's Pit is connected to the underground workings that are drained by the Spa Adit about 200 m to the northeast of the pit.

2.2 Spoil Heaps (Waste Rock Areas)

Spoils at the Avoca site were generated both during the historical (1720-1888) and modern (1947-1982) periods. The methodology used in each period was very different, resulting in differences in the physical and chemical properties of the spoils.

Spoils Production (1720-1888)

In the 18th and 19th centuries, the high grade ore (>5 percent copper) was extracted from the underground mines via shafts or adits (the waste rock was left underground. Once at the surface, the ore was processed by women and children using hammers to break up the ore and separate the ore minerals from the "cobbings." The process was very crude and often resulted in spoils with copper concentrations as high as 0.75 percent. The cobbing-type spoils often exhibit a coarse stratification that is easily identifiable. Many of these historic spoils were reprocessed by AML during the first two years of operations.

Other spoils from this period consist of waste rock extracted by excavation of shafts, adits, and levels. These materials are typically located adjacent to or surrounding the

shafts. The spoils would typically consist of uneconomic host rock but may be significantly mineralized.

Spoils Production (1947-1982)

The modern spoils consist mainly of overburden from excavation of pits (e.g., Mount Platt). The modern underground mining employed an underground crusher that separated the ore from the waste rock. The ore was sent by conveyor to the mill in West Avoca, while the waste rock was used to backfill old workings. The mill produced tailings that were piped to Shelton Abbey as a slurry. Therefore, no surface spoils were generated due to ore processing, except for the deposits in the emergency tailings ponds adjacent the Avoca River.

The descriptions of the spoil piles is based on the classification scheme (SP designations) used by the GSI (Gallagher and O'Connor, 1997). The piles are divided into the following areas:

- Connary – Extends from Connary Cross Roads to the northeast edge of Cronebane Pit

- Cronebane-Mount Platt – Extends from the northeast rim of Cronebane Pit to the northeast rim of East Avoca Pit

- East Avoca – Extends from the northeast rim of East Avoca Pit to about 150 m southwest of Farmer's Shaft. The area has also been referred to as Tigroney-Castlehoward after a nearby estate, East Tigroney, and the "Dead Ground" area

- Tigroney West – Extends from about 150 m southwest of Farmer's Shaft to the Avoca River

- West Avoca – Includes all spoils west of the Avoca River

2.2.1 Connary Area

The locations of the spoils in the Connary Area are shown in Figure 2-1, while the volumes and areas of each heap are supplied in Table 2-5.

Legend

★ Avoca_XRF_Locations

▮ Spoil_EAvoca

▮ Spoil_WAvoca

▮ Open_Pit_EAvoca

▮ Open_Pit_WAvoca

OSI Licence No: EN 0047207

Meters

0 25 50   100   150   200

N
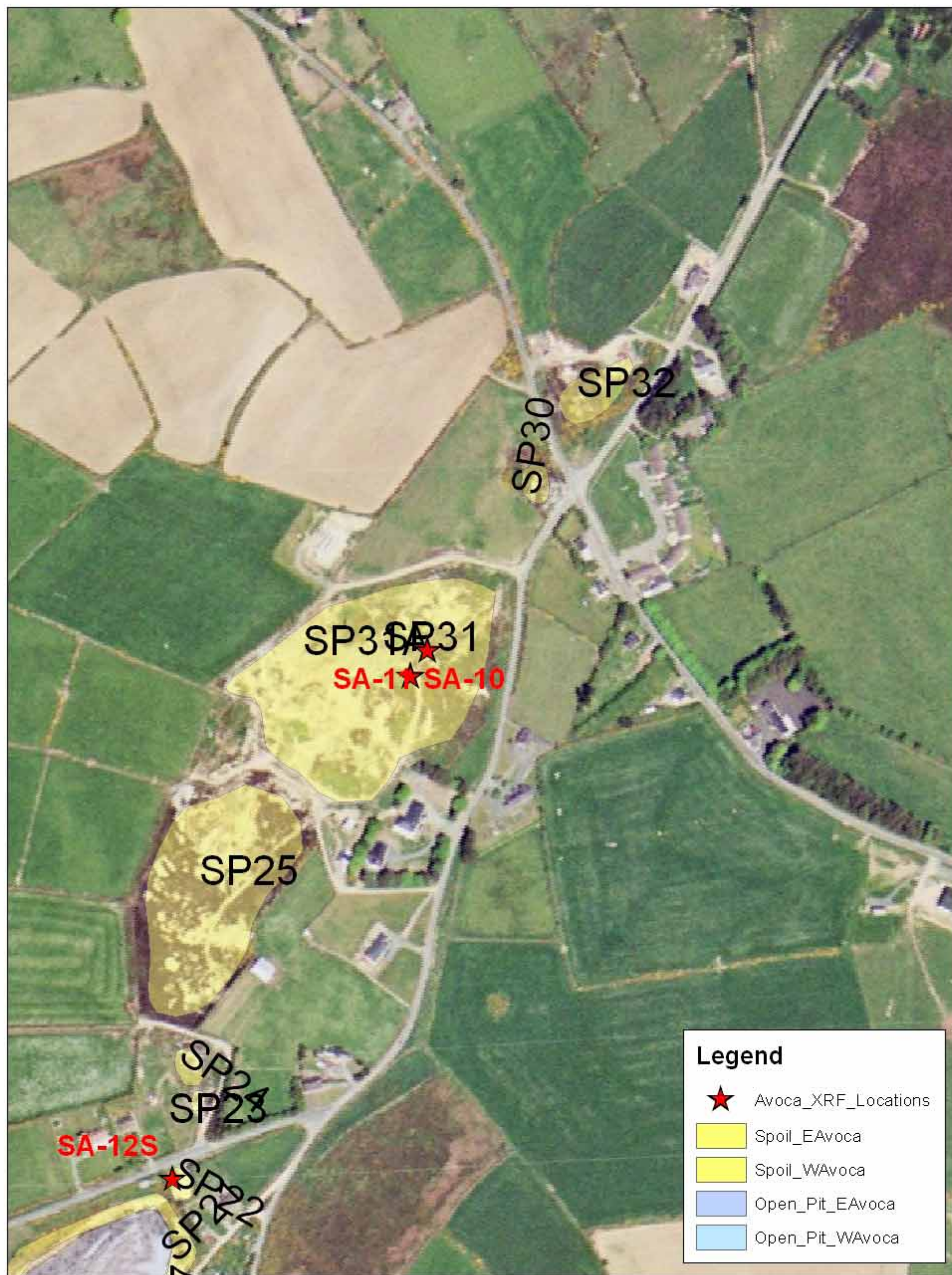
Fig 2- 1 Spoil heaps and XRF Locations in the Connary Area

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Table 2-5 Summary of Connary Area Spoil Heaps

Designation		Location	Notes	Area (m²)	Volume (m³)
GSI	GWP[1]				
SP22	None	Between Connary Engine House and Cronebane Pit	White, minor iron oxide, <1 mm – 200 mm grainsize	390	390
SP23	None		White-gray, pyritic black shale, 1-20 mm clasts in fine matrix	125	62
SP24	CO14, CO15	Within fence surrounding Reeds Shaft	Gray-white and red, 1-20 mm clasts in fine matrix. Some 20-100.	468	292
SP25	CO6	Adjacent to Connary Engine shaft	19th Century. Cobbles (0.2-0.5 m) in fine matrix. Variable oxidation.	12,849	69,450
SP29	None	SE rim of Cronebane Pit [Do you mean NE?]	Red-brown, oxidation extensive, 1-30 mm.	8,700	2,610
SP30	CO18	W of Connary Cross Roads	Gray-brown oxidized and fresh gray pyritic, 1-30 mm.	475	475
SP31	CO4, CO5, CO5a	Adjacent to Waggon Shaft engine house	19th Century. Red-brown oxidized, mostly fine matrix with 20-50 mm fragments	20,446	90,762
SP32	CO23	N of Connary Cross Roads	Gray-brown, oxidized, mostly 1-30 mm.	1,487	1,115
Total				**44,940**	**165,156**

[1]   GWP (2007)

The spoils in the Connary area represent about 11 percent of the total at the Avoca site (total spoils volume is 1,458,087 m³). Typically, the spoils are 19th century. Much of the material is vegetated, but some of the material has apparently been used by locals as a source of aggregate (GWP 2007). The descriptions of the spoils indicate that active oxidation has occurred in the past and significant pyrite is available for future ARD generation. Analyses of two of the heaps in the Connary area performed by CDM in April 2007 are provided in Table 2-6.

Table 2-6 XRF Analyses of Spoil Heaps in the Connary Area

SAMPLE	Notes	Concentration (mg/kg)					
		Pb	As	Zn	Cu	Fe	Mn
SA-10	Spoil Heap SP-31	17,808	1,366	499	608	55,207	<585
SA-11	Spoil Heap SP-31	6,631	371	199	53	42,023	<514
SA-10S	Same location as SA-10	18,676	1,247	1,064	746	59,609	654
SA-11S	Same location as SA-11	7,090	359	278	185	43,148	530
SA-12S	Spoil Heap SP-22	11,403	615	120	1,796	52,697	415

Lead concentrations are at percent levels (10,000 ppm = 1 percent), while concentrations of arsenic, zinc, and copper are typically in the hundreds of ppm.

2.2.2 Cronebane-Mount Platt Area

The locations of the spoil heaps in the Cronebane-Mount Platt area are shown on Figure 2-2, while the volume and area estimates and descriptions are provided in Table 2-7.

Table 2-7 Summary of Cronebane-Mount Platt Area Spoil Heaps

Designation		Location	Notes	Area (m²)	Volume (m³)
GSI	**GWP**				
SP19	None	NW edge of East Avoca Pit and Mt. Platt	Brown, extensively oxidized, small clasts in fine-grained matrix	3,151	1,575
SP20	CR29, CR30, CR31	Mount Platt	Material excavated from Cronebane Pit. Permeability is low, and AMD emerges as springs at the base of the heap. Oxidation variable, gray to red-brown, variable grain size, clasts in fine matrix	71,569	715,052
SP20A	CR28	Lobe extending to the NW from Mt. Platt		5,624	??
SP21	CR4	NE and NW rim of Cronebane Pit	Red-brown, extensive oxidation, 1-50 mm clasts in fine matrix	3,640	4,004
SP26	None	SE rim of Cronebane Pit	Mostly brown oxidized, but some fresh pyritic shale, 1-30 mm clasts in fine matrix typical	828	248
SP27	None	NE Side of Cronebane Pit	Red-brown, extensive oxidation, mostly 1-50 mm clasts in fine matrix	464	232
SP28	CR37B	Adjacent to Madam Butler's Shaft	<u>Overlies collapsed workings</u>. Red-brown, extensive oxidation, 20-50 mm clasts in fine matrix	348	261
Total				**85,624**	**721,372**
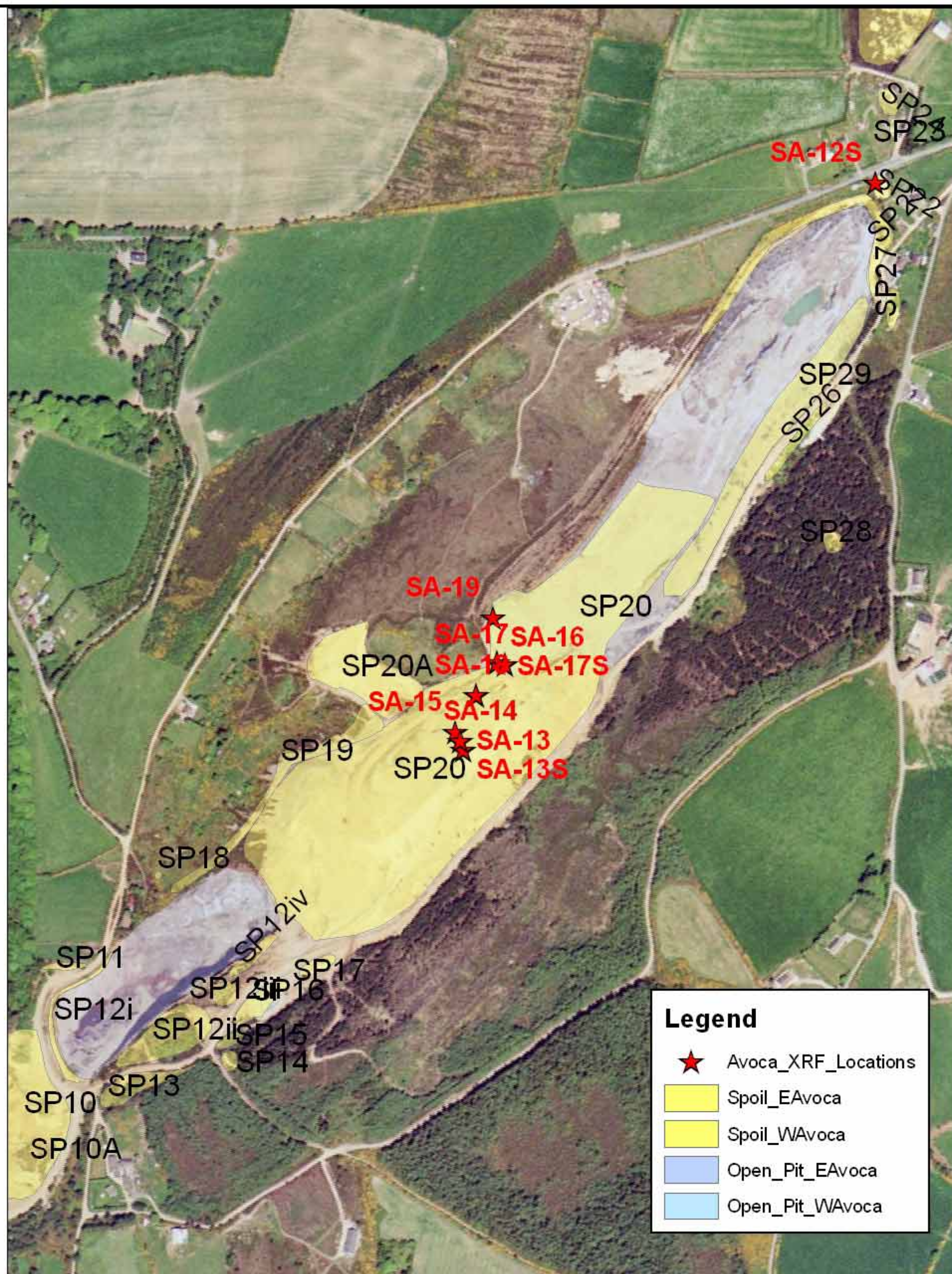
Fig 2- 2 Spoil heaps and XRF Locations in the Cronebane/Mount Platt Area

Legend

★ Avoca_XRF_Locations

Spoil_EAvoca

Spoil_WAvoca

Open_Pit_EAvoca

Open_Pit_WAvoca

OSI Licence No: EN 0047207

Meters

0   62.5   125   250   375   500

N

CDM

The spoils in the Cronebane-Mount Platt area represent about 50 percent of the total, mostly due to SP20. Several XRF analyses of the Mount Platt spoils conducted in April 2007 are presented in Table 2-8.

Table 2-8 XRF Analyses of Spoil Heaps in the Cronebane-Mount Platt Area

SAMPLE	Notes	Concentration (mg/kg)					
		Pb	As	Zn	Cu	Fe	Mn
SA-13	Spoil Heap SA-20 on top near SW edge	3,456	472	398	186	35,433	<430
SA-14	50 feet NE of SA-13	1,651	364	87	176	31,067	<555
SA-14	Invalid Result (insufficient duration)	2,043	421	215	170	38,408	1,692
SA-15	50 feet NE of SA-14	1,520	252	122	134	27,737	<413
SA-16	SP20 NW slope - gray material	3,406	267	220	80	11,648	36
SA-17	SP20 NW slope - red material	2,101	441	<96	280	66,238	72
SA-18	SP20 on top near NW edge	3,721	652	143	1,008	97,822	95
SA-13S	Same location as SA-13	4,013	548	508	319	43,647	392
SA-14S	Same location as SA-14	2,036	306	161	326	31,926	237
SA-16S	Same location as SA-16	3,467	243	179	167	10,640	228
SA-17S	Same location as SA-17	2,333	427	89	316	75,881	557
SA-18SF	Same location as SA-18	4,153	698	168	1,230	116,379	828

The metals concentrations are fairly uniform and typically lower than for the Connary area. The difference is probably due to the fact the Mount Platt spoils are modern overburden, while the Connary spoils are historic.

The Mount Platt spoils likely drain into both the Cronebane and East Avoca pits, which are connected with the underground workings. Some workings are located directly beneath Mount Platt, but it is unknown if there are mine workings (ventilation shafts) or bedrock fissures connecting the Mount Platt leachate water to the workings. GWP (2007) noted a spring with a flow of about 1 liter/minute issuing from the base of Mount Platt on the northeast slope which flowed into a small iron-stained pond. The presence of this spring and others noted by Gallagher and O'Connor (1997) at the base of the heap, suggests that either an impermeable layer is present (i.e., clay) or the bedrock beneath Mount Platt is relatively unfractured. The quality of the spring water issuing from the Mount Platt spoils pile was measured by GSI in 1993 (Flynn 2004), although it is difficult to tell from the map if it is the same spring as observed by GWP (2007). The 1993 GSI results are provided in Table 2-9.

**Table 2-9 Water Quality Data for Seepage from Mount Platt
(November 1993 Data)[1]**

Parameter[2]	Concentration (mg/L)
Iron	1,698
Aluminum	938
Copper	251
Zinc	373
Lead	26
Sulfate	12,100
pH (su)	2

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

The pH is one of the lowest, if not the lowest value measured onsite, while the metals concentrations are very high.

The Madam Butler spoils (SP28) are believed to overlie collapsed workings, as a depression has been observed within the heap (GWP 2007).

2.2.3 East Avoca (Tigroney-Castlehoward Area)

The locations of the spoils in the East Avoca Area are shown in Figure 2-3, while the volumes and areas of each heap are supplied in Table 2-10.

Table 2-10 Summary of East Avoca (Tigroney-Castlehoward) Area Spoil Heaps

Designation		Location	Notes	Area (m²)	Volume (m³)
GSI	GWP				
SP5	EA137, EA138	Adjacent to Farmers shaft extending SW	Overlies collapsed workings. Red-brown, extensive oxidation, 20-50mm clasts in fine matrix, some 100-300mm	5,828	27,640
SP6	None	Just E of Baronets stack	Extensively oxidized, 1-10mm clasts in fine matrix, some 10-40mm	402	300
SP7i	None	E. of Baronet's Stack	Extensive oxidation in upper layer, gray pyritic below, 1-20mm clasts in fine matrix	424	318
SP7ii	None		Extensive oxidation, 10-40 mm clasts in fine matrix	488	366
SP8	None		Overlies collapsed workings. Red-brown, extensive oxidation, 10-30mm clasts in fine matrix	1,494	1,494
SP10	EA143, EA144	Between Wood Adit shaft and SW end of East Avoca Pit	Overlies collapsed workings. Red-brown, extensive oxidation, 1-30mm clasts in fine matrix	9,450	53,632
SP11	None	NW side of East Avoca Pit (N of road)	Red-brown, extensive oxidation, 10-30mm clasts in fine matrix	264	132

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Table 2-10 Summary of East Avoca (Tigroney-Castlehoward) Area Spoil Heaps

| Designation | | Location | Notes | Area (m²) | Volume (m³) |
GSI	GWP				
SP12i	EA36	SW & W rim of East Avoca Pit	Red-brown, extensive oxidation, 1-20mm clasts in fine matrix	740	555
SP12ii	None	Between East Avoca Pit & Cronebane Shallow air shaft (just above Intermediate Adit)		3,265	2,449
SP12iii	None	Between East Avoca Pit & Cronebane Shallow air shaft		551	413
SP12iv	None	SE rim of East Avoca Pit		559	419
SP13	None	Surrounds Cronebane Shallow Adit SE of East Avoca Pit	18th Century. Red-brown, extensive oxidation, 10-40mm clasts in fine matrix	1,472	1,104
SP14	None	Adjacent to Cronebane Shallow air shaft	18th Century. Unmineralized, host rock, 1-40mm clasts in fine matrix	278	208
SP15	None	Just N of Cronebane Shallow air shaft	Red-brown, extensive oxidation, 10-40mm clasts in fine matrix	297	148
SP16	None	Within "island" formed by roads on SE side of East Avoca Pit	Mostly oxidized red-brown, some gray pyritic, 1-40 mm clasts in fine matrix	1,097	2,377
SP17	None		Red-brown, extensive oxidation, 1-40mm clasts in fine matrix	434	651
SP18	None	NW side of East Avoca Pit	Small pile of large blocks	44	20
Total				**27,087**	**92,226**

The spoil heaps in the East Avoca area represent approximately 6 percent of the total for the site. Heaps SP5, SP8, and SP10 are believed to overlie collapsed workings, which would provide a pathway for ARD from the spoils to enter the underground workings.
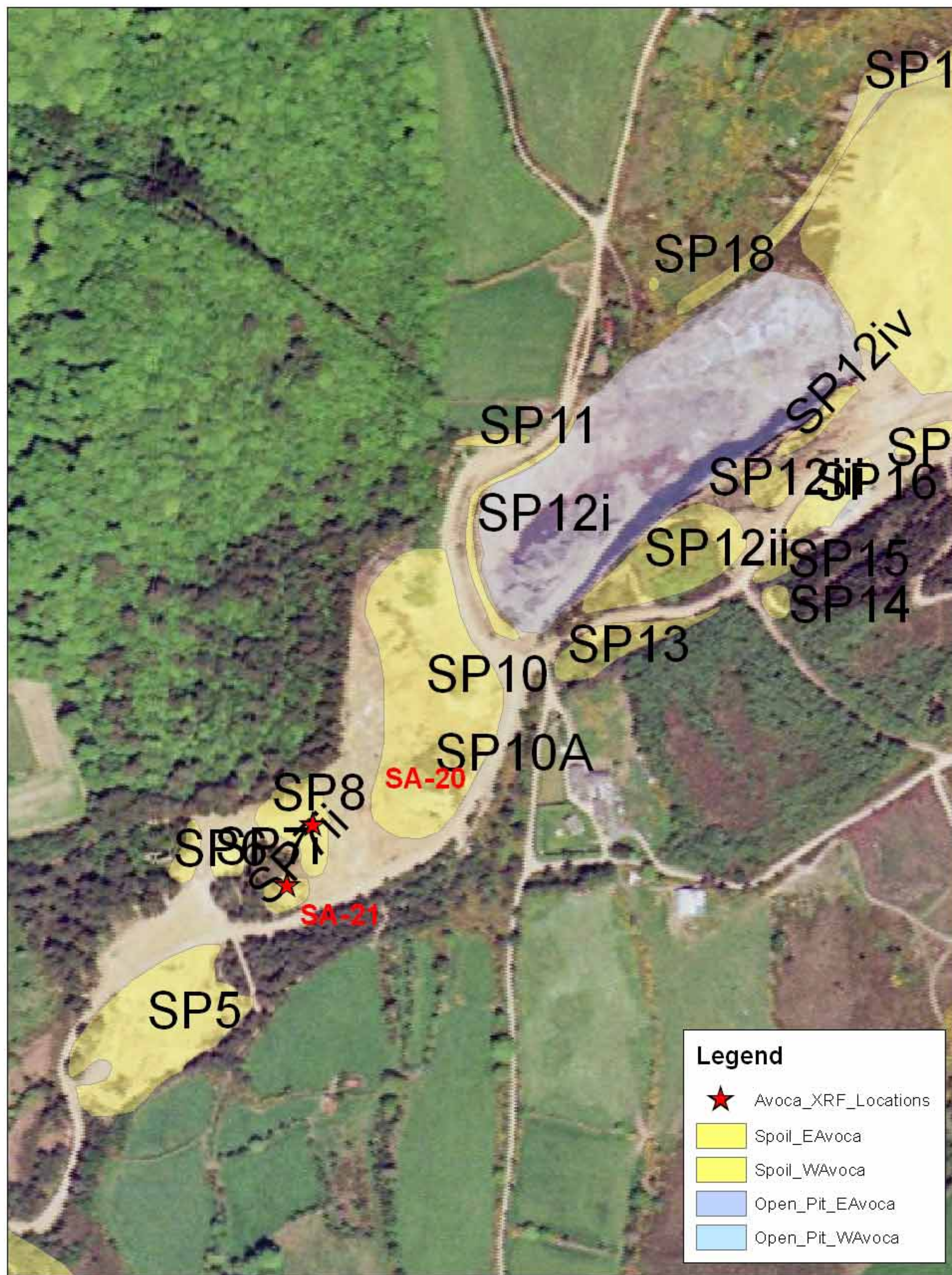
Fig 2- 3 Spoil heaps and XRF Locations in the East Avoca Area

Legend

★ Avoca_XRF_Locations

Spoil_EAvoca

Spoil_WAvoca

Open_Pit_EAvoca

Open_Pit_WAvoca

OSI Licence No: EN 0047207

Meters

0   25   50   100   150   200

SP1

SP18

SP12iv

SP11

SP12iii SP16

SP12i

SP12ii SP15

SP14

SP13

SP10

SP10A

SA-20

SP8

SP7ii

SP6 SP7i

SA-21

SP5

N

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XRF analyses conducted in April 2007 for two of the spoil heaps are presented in Table 2-11. Sample SA-21 (heap SP7ii) was a fine-grained gray material that represented a small fraction of the heap.

Table 2-11 XRF Analyses of Spoil Heaps in the East Avoca (Tigroney-Castlehoward) Area

SAMPLE	Notes	Concentration (mg/kg)					
		Pb	As	Zn	Cu	Fe	Mn
SA-20	Spoil Heap SP8 - Coarse red material	4,735	597	31	719	164,280	<1,403
SA-21	Spoil Heap SP7ii - Fine-grained gray material	24,314	1,482	584	1,562	79,960	<555

The concentrations of SP8 are consistent with the other spoils on the site, with the exception of iron, which was roughly three times higher than the other heaps. The small area of gray material within SP7ii contained 2.4 percent lead, which was one of the highest lead concentrations measured.

2.2.4 Tigroney West

The locations of the spoils in the Tigroney West Area are shown in Figure 2-4, while the volumes and areas of each heap are supplied in Table 2-12.

Table 2-12 Summary of Tigroney West Area Spoil Heaps

Designation		Location	Notes	Area (m²)	Volume (m³)
GSI	GWP				
SP1	None	W. Tigroney - Between millrace and RR tracks (SW of RR)	Brown, oxidized, some dark graypyrite rich, <20-40mm	2,025	6,280
SP2	TI43, TI47, TI49, TI50	W. Tigroney - Above Ore Bins	Buries 850 Adit. Mostly red-brown oxidized, but some gray pyritic zones	14,190	38,115
SP2A	None	W. Tigroney - NW side of RR and S of Flat rod tunnel	Red-brown, extensive oxidation, 1-400mm	1,152	1,152
SP3	None	Above Ore Bins adjacent to wooded area	Extensive oxidation in red-brown surface layer with gray pyritic material beneath, <20mm clasts in fine matrix	619	3,456
SP4	EA160	W. Tigroney - Extends NW from Williams shaft and stack on hill above Ore Bins	Mostly red-brown oxidized, but some gray pyritic zones, 1-40mm clasts in fine matrix	8,052	8,052
Total				26,038	57,055

The Tigroney West area spoils represent about 4 percent of the total onsite. However, the piles are on a hillside and the leachate from these piles likely drains directly into the Avoca River via interflow (subsurface flow on the sloped surface of the bedrock). ARD may also enter the underground workings through the 850 adit beneath SP2.
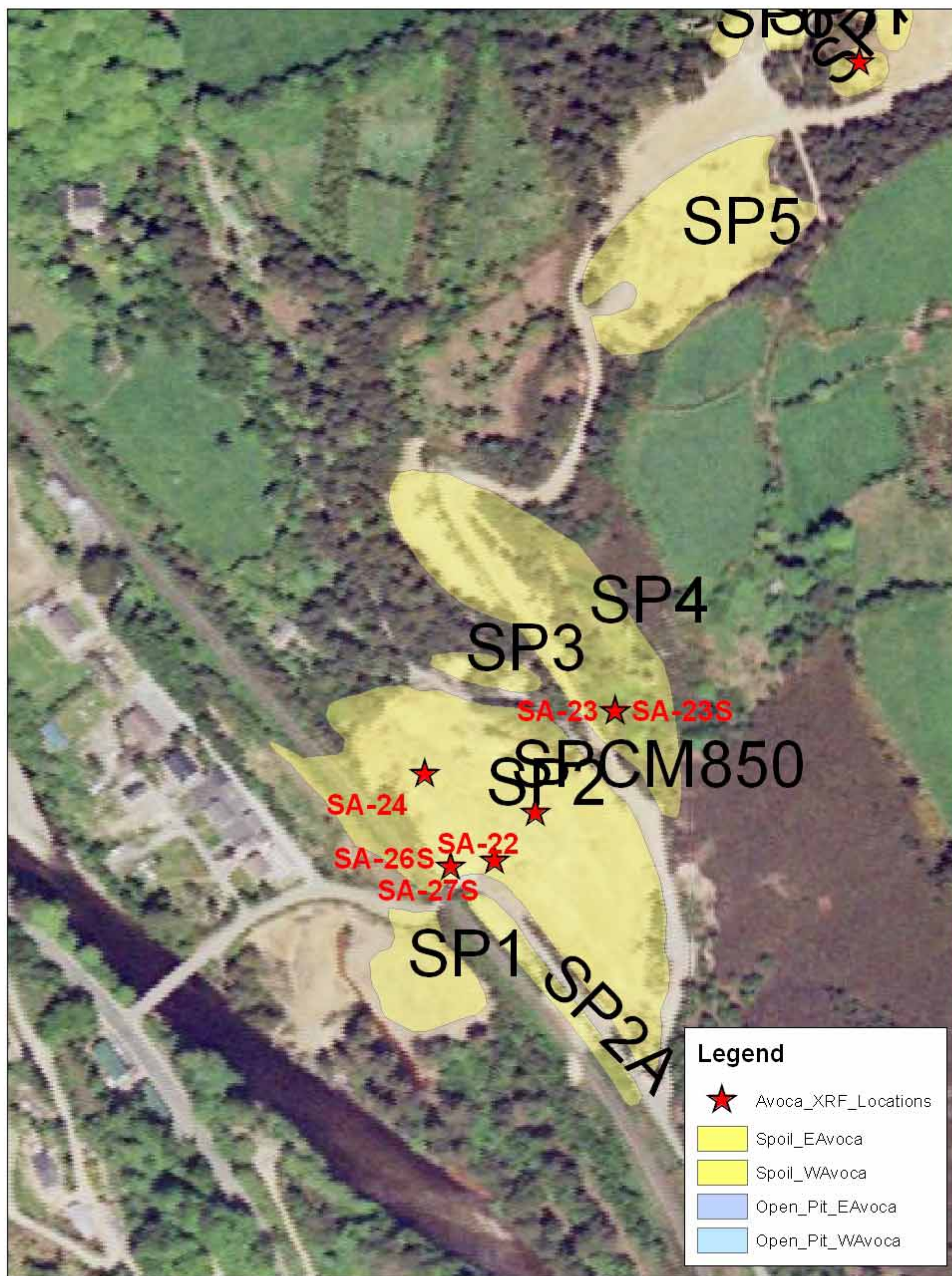
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Fig 2- 4 Spoil heaps and XRF Locations in the Tigroney West Area

XRF analyses for spoils conducted in April 2007 from heaps SP2 and SP4, and the ore bins are presented in Table 2-13.

Table 2-13 XRF Analyses of Spoil Heaps in the Tigroney West Area

SAMPLE	Notes	Concentration (mg/kg)					
		Pb	As	Zn	Cu	Fe	Mn
SA-22	Spoil Heap SP2 - Fine-grained gray material probably brought in from another location	200	51	136	30	12,970	<546
SA-23	Spoil Heap SP4 - Red material on slope between road and wooded area	3,030	364	54	298	70,902	607
SA-24	Spoil Heap SP2 - Fine-grained gray material	4,088	629	174	5,480	170,011	<1042
SA-23S	Same location as SA-23	5,008	516	83	496	111,205	1,218
SA-26S	Evaporative precipitate from cribbing on ore bins	70	83	827	7,253	95,463	573
SA-27S	Material from within ore bins	4,962	497	<150	500	241,225	246

Sample SA-22 was from a small pile of gray material that looks like it was brought in from another source. The chemical content is much different from the surrounding spoils. The material from the ore bins (SA-27S) is not particularly rich in copper (0.05 percent) and does not appear to be of economic grade for copper. However, the iron content is high (24 percent) compared to the spoil heaps. The material in the ore bins was supposed to have been stockpiled by SPCM from the underground workings at the 850 Adit during the period 1958-1962.

Sample SA-26S was a light yellow evaporative crust collected from the cribbing which holds back the ore. The precipitate represents the quality of the leachate in terms of the ratios of metals present. The very low arsenic concentration in the material (83 mg/kg) explains why arsenic is not present in the ARD above the detection limit (<0.05 mg/L) and is not a problem in the river. Lead is also relatively low, reflecting the lower lead concentrations in the ARD. The copper concentrations are roughly an order of magnitude higher than the zinc concentrations, which is the reverse of the concentrations in the ARD. In the Deep Adit, dissolved copper concentrations are an order of magnitude less than the zinc concentrations (see Tables 2-21 and 2-22). The data suggests that copper is attenuated (adsorbed or precipitated) to a greater extent than is zinc.

An analysis of a seep in the vicinity of the ore bins was performed by GSI in 1993 (Flynn, 1994). The analysis is reproduced in Table 2-14.

Table 2-14 Water Quality Data for Seepage from Spoil Heap SP2 (November 1993 Data)[1]

Parameter[2]	Concentration (mg/L)
Iron	79
Aluminum	161
Copper	4.4
Zinc	90
Lead	1.4
Sulfate	2,080
pH (su)	3.2

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

The metals concentrations are fairly high, especially zinc. Given the close proximity of the seep to the Avoca River, the load of metals to the river during and following precipitation events could be significant (depending on the flow).

2.2.5 West Avoca

The locations of the spoils in the West Avoca Area are shown in Figure 2-5, while the volumes and areas of each heap are supplied in Table 2-15.

Table 2-15 Summary of West Avoca Area Spoil Heaps

Designation		Location	Notes	Area (m²)	Volume (m³)
GSI	GWP				
SP33	WA123	N of Ballymurtagh Landfill (Pond Lode Pit). The Knight Tunnel is on the NE side.	19th Century. Red-brown, extensive oxidation, 20-50mm clasts in fine matrix	7,253	7,253
SP34	WA14	Fills upper part of and extends NE from North Lode Pit	The lower portion of the North Pit (excavated in the 19th century) is filled with 20th century tailings and capped with 20th century spoils. Red-brown, extensive oxidation, 1-100mm clasts in fine matrix	14,304	233,220
SP34A	WA33	NE of Wheatley's Shaft and N of Weaver's Pit	19th Century. Red-brown, extensive oxidation, 10-100mm clasts in fine matrix	1,034	20,680

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Table 2-15 Summary of West Avoca Area Spoil Heaps

Designation		Location	Notes	Area (m²)	Volume (m³)
GSI	**GWP**				
SP34B	WA8, WA9	Northwest of the Ballymurtagh Landfill (Pond Lode Pit). The Tramway Arch is located on the SE side.	19th Century. Sapsford and Williams (2005) conducted humidity cell testing on this material. Red-brown, extensive oxidation, 1-100mm clasts in fine matrix	25,028	25,028
SP35	WA120	SW of Western Whim Chimney and Engine House	19th Century. Red-brown, extensive oxidation, 10-200mm clasts in fine matrix	242	4,840
SP36	WA37A	Between Tramway Arch & Tramway Engine House Stack	19th Century. Light colored on surface, red-brown, extensive oxidation underneath, 10-30mm clasts in fine matrix	808	3,232
SP37	None	SW of Ballymurtagh Landfill (Pond Lode Pit)	19th Century. Red-brown, extensive oxidation, 30-40% of clasts >20mm in fine matrix	17,902	17,902
SP38	None	Within S lobe of Pond Lode Pit		526	1052
SP39	WA124	S of Ballymurtagh Landfill (Pond Lode Pit)	19th Century. Red-brown, extensive oxidation, 10-50mm clasts in fine matrix	14593	109071
Total				**81,690**	**422,278**

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DRAFT

Fig 2- 5 Spoil heaps and XRF Locations in the West Avoca Area
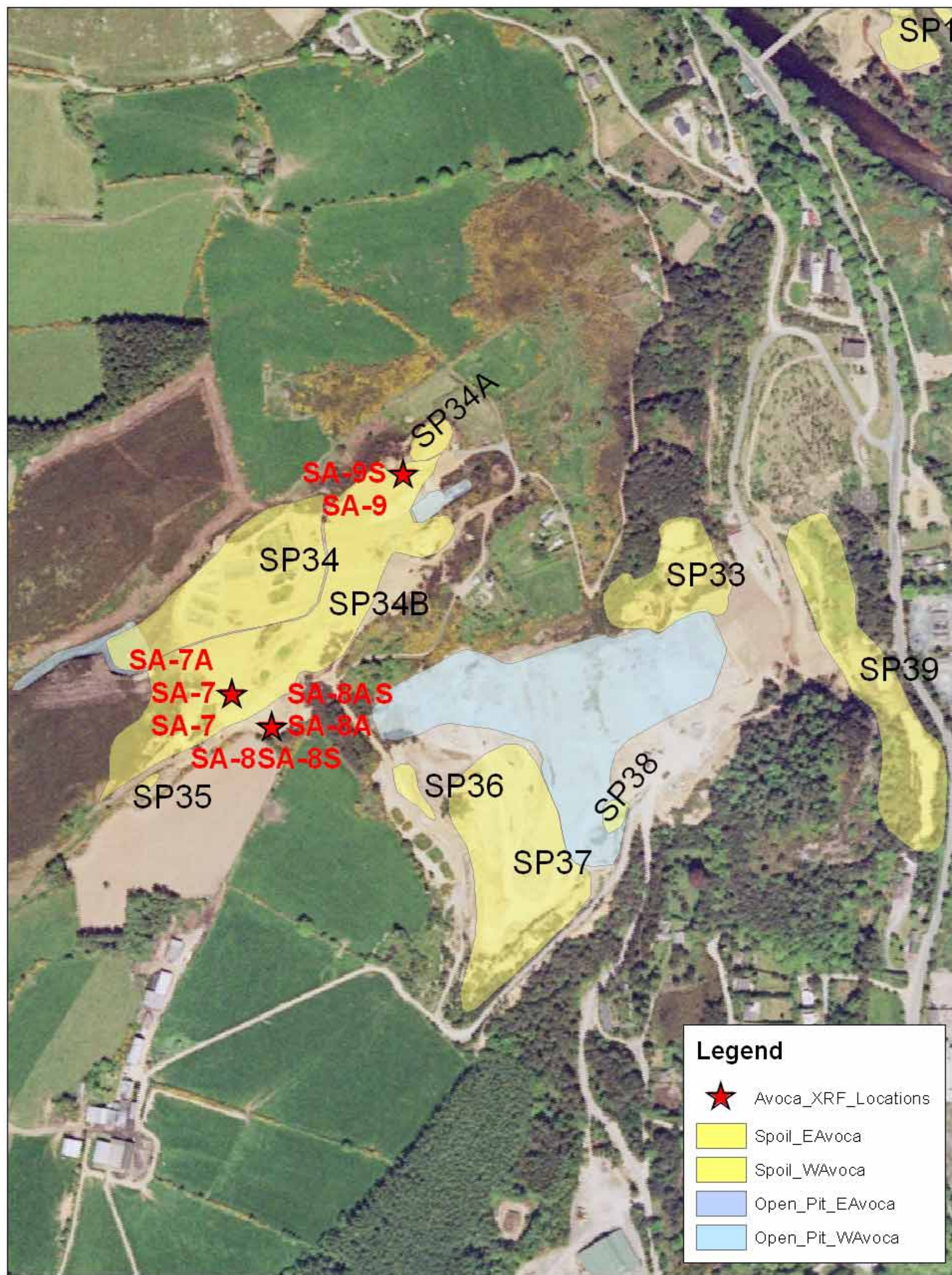
Legend

★ Avoca_XRF_Locations

Spoil_EAvoca

Spoil_WAvoca

Open_Pit_EAvoca

Open_Pit_WAvoca

Meters OSI Licence No: EN 0047207

0 50 100 200 300 400

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The spoils in West Avoca represent 29% of the total. Much of the material that would have otherwise become surface spoils was disposed of within the underground workings during the modern mining area. Some of the overburden from the excavation of the pits may have been used as backfill by AML. Gallagher and O'Connor (1997) state that for a time, AML used a cut-and-fill mining method which "required backfilling using waste trucked in from elsewhere."

XRF analyses for the West Avoca spoils conducted in April 2007 are presented in Table 2-16.

Table 2-16 XRF Analyses of Spoil Heaps in the West Avoca Area

SAMPLE	Notes	Concentration (mg/kg)					
		Pb	As	Zn	Cu	Fe	Mn
SA-6	Spoil Heap SP34B	169	24	41	<108	27,636	117
SA-7	Spoil Heap SP34B	719	675	<142	307	191,532	219
SA-7	Spoil Heap SP34B	755	671	<178	78	191,285	381
SA-7A	Spoil Heap SP34B	908	725	<96	285	200,600	<667
SA-8	Spoil Heap SP34B	443	382	<89	208	127,703	182
SA-8A	Spoil Heap SP34B	533	493	<97	275	151,777	129
SA-9	Spoil Heap SP34B	443	555	<124	<205	236,308	<830
SA-8S	Same location as SA-8	515	482	<104	334	146,140	752
SA-8AS	Same location as SA-8A	571	508	<116	415	154,983	552
SA-9S	Same location as SA-9	886	685	<150	295	326,576	1,503

In general, lead concentrations are in the hundreds of mg/kg as opposed to the other areas where concentrations are in the thousands of mg/kg. Concentrations of copper and zinc are also lower, while iron concentrations are higher. The apparent discrepancy may reflect the differences in the metals content of the overburden in West Avoca vs. the overburden from the Cronebane pit, for example.

Humidity cell tests were performed by Sapsford and Williams (2005) on the spoils from SP34B adjacent to the Tramway Arch. Sulfate concentrations as high as 6,000 mg/L and iron concentrations of about 2,000 mg/L were obtained during the testing.

2.3 Tailings
2.3.1 Shelton Abby Tailings

The tailings at Shelton Abbey were deposited between 1958 and 1982 by SPCM and AML. The tailings were slurried in a pipe from the mill at West Avoca to the Shelton Abbey Tailings facility. The decant water from the tailings was piped directly to the Avoca River. Remnants of the decant line are evident southeast of the tailings pond. The estimated volume of tailings (calculated from the reported production and grade) are presented in Table 2-17.

Table 2-17 Quantity of Tailings at Shelton Abbey Based on Production Records

Source	Years Produced	Tailings Mass (tonnes)[1]	Tailings Volume (m³)[2]	Copper Concentration (mg/kg)[3]
SPCM	1958-1962	2,961,267	1,794,707	1103
AML	1970-1982	8,636,342	5,234,147[4]	209
Total	**1958-1982**	**11,597,609**	**7,028,854**	**-**

[1] Compiled in Gallagher and O'Connor (1997). For the SPCM data, Imperial long tons were converted to metric tons (tonnes) using a factor of 1 long ton = 1.016047 tonnes

[2] Calculated using a bulk density of 1.65 kg/L

[3] Calculated from the grade and quantities of concentrate and ore mined

[4] Approximately 233,220 m³ of this total was placed in the North Lode Pit by AML (neglecting the volume of spoils on top)

SPCM = Saint Patrick's Copper Mines Ltd

AML = Avoca Mines Ltd

The concentration of copper within the tailings was also calculated from the grade and quantity of the ore and concentrate. The AML process appears to have been more efficient than the SPCM process. The measured metals concentrations for tailings samples collected in April 2007 are presented in Table 2-18.

Table 2-18 XRF Results for Shelton Abbey Tailings

SAMPLE	Notes	Concentration (mg/kg)					
		Pb	As	Zn	Cu	Fe	Mn
SA-2	On top adjacent to the north side of access road which enters from the east	29	27	4.9	41	28,635	791
SA-3	Duplicate of SA-2	48	39	<87	<147	32,201	317
SA-4	Tailings from embankment near top within roadcut on NW side	164	37	25	31	31,169	112
SA-5	Tailings from base of embankment	960	184	17	60	36,216	148
SA-25	Tailings from SW embankment between the perimeter road and the river	955	792	<96	283	213,224	510
SA-7A	Same location as SA-25	962	741	<119	387	215,593	1082

The actual copper concentrations from the embankment (283-387 mg/kg) are reasonably close to the value calculated for the AML tailings. The relatively low lead and high iron in these samples has a West Avoca type signature. However, the tailings from on top of the pond are significantly lower than the calculated value for AML.

Leachate issuing from springs within the dike drain ARD to a pond south of the main embankment. The pH 3.7 pond water flows directly into the Avoca River. Diffuse flow of ARD to the Avoca River through the bottom and sides of the tailings facility may also be occurring.

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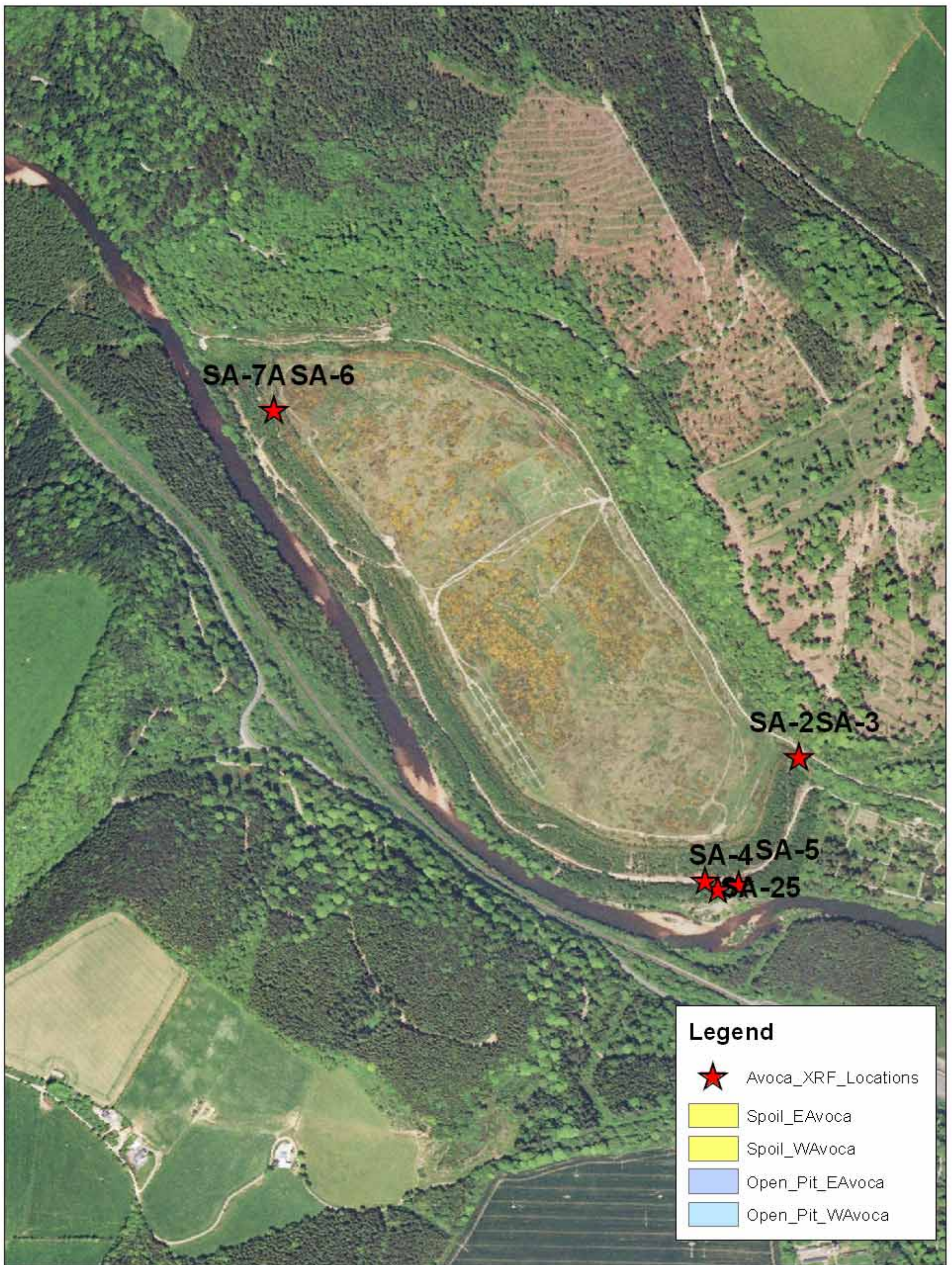
Fig 2- 6 XRF Locations at the Shelton Abbey Tailings Impoundment

2.3.2 Emergency Tailings Near Ballygahan Adit

Adjacent to the Avoca River in the vicinity of the Ballygahan Adit a low area was used as a tailings impoundment during the modern mining era. An attempt was made to locate the tailings during the April 2007 site visit, but the area could not be found. Subsequently, historical documents showing the tailings were provided so that sampling could be performed during the next sampling event in July or August 2007.

2.4 ARD Discharges

ARD discharges are the most direct source of metals to the Avoca River. Of the adits located on site, some are consistently dry, some only flow seasonally, while other flow year round. Only the adits that flow at some point over the year are discussed.

Some of the adits are buried and contribute surface flows via seeps. These adits will be considered as flowing for the purposes of the source evaluation.

2.4.1 Kilmacoo Adit

The Kilmacoo Adit is located along the road that leads northwest from Connary Crossroads and is buried. A seep discharges contaminated leachate in the immediate vicinity seasonally and is believed to be discharge from the adit or seepage resulting from the blockage of the portal. The discharge is believed to be the only known surface flow issuing from the upper parts of the Connary mine workings. The flow and water quality are unknown.

2.4.2 Madam Butler's Adit

Madam Butler's Adit drains the upper parts of the underground workings in the Cronebane area. The adit was apparently plugged at some point. Gallagher and O'Connor (1997) state that the discharge occurs within a copse of trees behind some farm buildings. The farmer stated in April that the flow had dried up as the grass in his field was no longer poisoned (GWP, 2007). However, it is unlikely that the discharge has dried up because southeast Ireland is not experiencing drought conditions. The discharge is believed to have been piped to an unknown location (Vincent Gallagher personal communication).

2.4.3 Intermediate Level Adit

As discussed previously, the Intermediate adit discharges ARD from the southeast wall of the East Avoca Pit, which flows into the pit pond, which seeps into the underground workings. The quality and flow of the discharge as measured by GSI in 1993 are presented in Table 2-19.

Table 2-19 Water Quality Data for Intermediate Adit (November 1993 Data)[1]

Parameter[2]	Concentration (mg/L)
Iron	2,311
Aluminum	2,153
Copper	53
Zinc	440
Lead	0.8
Sulfate	22,000
pH (su)	2.2

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

The water quality of the Intermediate Adit has by far the highest metals and sulfate concentrations of any water analyzed to date, and is likely a significant load to the Deep Adit.

2.4.4 Cronebane Shallow Adit

The Cronebane Shallow Adit is located just south of the East Avoca Pit and drains the upper levels of the Cronebane area workings. AML began a copper cementation project using the discharge from the Cronebane shallow adit in 1971, at which time the flow was 1.6-1.9 l/s. Currently, the water flows into a pond, through a culvert under the road, and to some unknown point where it soaks into the ground. The current water quality and flow are unknown.

Table 2-20 Water Quality Data for Cronebane Shallow Adit (November 1993 Data)[1]

Parameter[2]	Concentration (mg/L)
Iron	410
Aluminum	493
Copper	45
Zinc	182
Lead	5.1
Sulfate	6,350
pH (su)	2.3

[1] Flynn (1994)
[2] Units in mg/L unless noted otherwise

2.4.5 Wood Adit

The Wood Adit is located within an estate called Castlehoward about 175 m west of the southwest rim of the East Avoca Pit. Gallagher and O'Connor (1997) state that water no longer flows from the adit, but recent evidence suggests that flow may occur seasonally (GWP, 2007).

2.4.6 Deep Adit

The deep adit is located in Tigroney West and is sometimes referred to as the Tigroney Adit or the Tigroney Deep Adit to distinguish it from the Ballygahan Deep Adit in West Avoca. The adit extends for a distance of nearly 800 m northwest to the portal, and drains all levels of the mine below the Cronebane Shallow Adit. The discharge flows through a portion of the old mill race through a ditch and into the Avoca River about 100 m southeast of White's Bridge.

Flow is measured by use of a electronic staff gauge within the mill race portion of the discharge channel. Flows have ranged from 10 l/s in the summer to 72 l/s in February. Average flows were reported in the University of Newcastle report (Doyle et al., 2004) of 17.7 l/s for the period October 2001 and September 2002.

The most recent water quality for metals are presented in Tables 2-21 and 2-22.

Table 2-21 Summary of Analyses for the Deep Adit for the Period October '01 – June '03 (mg/L)

Parameter	Range	Average	Number of Analyses
Iron	0.3-293	33	15
Aluminum	32-107	82	17
Copper	2-16	5	18
Zinc	20-173	51	18
Lead	0.3-2.8	1.2	18
Sulfate	1146-1335	1214	13
pH	2.9-3.2	3.1	18

Analytical results from the treatability study (Unipure, 2006) are shown in Table 2-22.

Table 2-22 Summary of Analyses for the Deep Adit for the Period March-April '06 (mg/L)[1]

Parameter	Range	Average	Number of Analyses
Iron	14-55	33	8
Aluminum	71-131	104	8
Copper	0.7-4.3	2.3	8
Zinc	40-71	52	8
Lead	-	-	-
Sulfate	916-1428	1136	8
pH	2.6-3.0	2.7	8

[1]   Unipure (2006)

Using the average flows and the average concentrations, the sulfate and metals loadings into the Avoca River from the Deep Adit were calculated and are presented in Tables 2-23 and 2-24.

Table 2-23 Metals Loading by the Deep Adit to the Avoca River (2001-2003 Data)

Parameter	Average Concentration (mg/L)	Loading (kg/yr)
Iron	33	18,420
Aluminum	82	45,771
Copper	5	2,791
Zinc	51	28,468
Lead	1.2	670
Sulfate	1214	677,639

Table 2-24 Metals Loading by the Deep Adit to the Avoca River (2006 Data)

Parameter	Average Concentration (mg/L)	Loading (kg/yr)
Iron	33	18,614
Aluminum	104	57,795
Copper	2.3	1,273
Zinc	52	29,036
Lead	-	-
Sulfate	1136	633,891

2.4.7 Road Adit

The Road Adit is also referred to as the Ballymurtagh Adit, and is the main discharge point for the West Avoca underground workings. The adit was used in the 19th century to drain water pumped from the Ballygahan Shaft. Today, the flow issues from the adit at the base of the Ballymurtagh Landfill, flows through a ditch along the road and into the Avoca River via a pipe under the Avoca-Rathdrum Road. A weir and electronic level sensor (maintained by County Wicklow) records the flow from the adit, which ranges from 6 l/s to an annual high of about 35 l/s. A peak flow as high as 58 l/s was recorded.

The most recent water quality ranges and averages for the Deep Adit are reported in Table 2-25 for the period April-June 2003 and Table 2-26 for the period March-April 2006.

Table 2-25 Summary of Analyses for the Road Adit for the Period April '03 – June '03 (mg/L)

Parameter	Range	Average	Number of Analyses
Iron	113-147	128	4
Aluminum	32-35	33.5	7
Copper	0.7-1.2	0.9	7
Zinc	16-18	17	7
Lead	0.4	0.4	7
Sulfate	1482-1660	1587	4
pH	3.9-6.3	4.2	7

Table 2-26 Summary of Analyses for the Road Adit for the Period March-April '06 (mg/L)[1]

Parameter	Range	Average	Number of Analyses
Iron	102-136	115	9
Aluminum	26-31	28	9
Copper	0.36-0.49	0.4	9
Zinc	12-16	14	9
Lead	-	-	-
Sulfate	1048-1577	1366	9
pH	3.0-3.5	3.3	9

[1]   Unipure (2006)

Using the average water quality data in Tables 2-25 and 2-26, and the average flow of 17.1 l/s reported by Doyle et al. (2004), results in the metal and sulfur loadings presented in Tables 2-27 and 2-28.

Table 2-27 Metals Loading by the Road Adit to the Avoca River

Parameter	Average Concentration (mg/L)	Loading (kg/yr)
Iron	128	69,026
Aluminum	33.5	18,065
Copper	0.9	485
Zinc	17	9,168
Lead	0.4	216
Sulfate	1587	855,815

Table 2-28 Metals Loading by the Road Adit to the Avoca River (2006 Data)

Parameter	Average Concentration (mg/L)	Loading (kg/yr)
Iron	115	62,220
Aluminum	28	15,304
Copper	0.4	237
Zinc	14	7,550
Lead	-	-
Sulfate	1366	736,637

2.4.8 Ballygahan Deep Adit

The Ballygahan Deep Adit was used in the 19th century to convey water pumped from the Ballygahan old engine shaft, which was located where the Pond Lode Pit was later excavated. The flow from the adit was reported by Gallagher and O'Connor (1997) to flow through a pipe under the Avoca-Rathdrum road to the bank of the Avoca River where it discharged. However, the flow was recently observed seeping through the bank of the river (GWP 2007). Apparently, the pipe has become clogged since 1997, as no flow was observed in April 2007. The water quality and flow are unknown

2.4.9 Spa Adit

The Spa Adit drains the underground workings beneath Weaver's Pit. A recent observation by CDM indicated that the flow was approximately 0.15 l/s, the pH was 2.68 su, and the conductivity 2,400 umhos/cm.

2.5 Underground Workings

The underground workings at the Avoca mine site are extensive, with an aggregate of 30 km of shafts, adits, and levels in East Avoca, and 16-21 km in West Avoca. The total does not include stopes, the extent of which is unknown. The flooded portions of the workings, while in contact with large quantities of sulfide minerals, probably do not produce ARD nearly as fast as the workings that receive only periodic flow from infiltration water. The difference in ARD production rates is caused by the concentrations of oxygen in the systems, as will be discussed in detail in Section 4.

Section 3
Site Hydrology/Hydrogeology

3.1 Hydrological Summary

The Avoca River catchment, shown in Figure 3-1, drains eastward from the Wicklow Mountains to Arklow on the coast. It covers an area of approximately 645.6 km², and includes the Avonbeg and Avonmore Rivers which form the Avoca River at their confluence at the Meeting of the Waters, approximately 1.5 km north of the mine. The Avoca River subsequently merges with the Aughrim tributary about 5 km to the south of the mine area.

Topography is characterized by steep-sided river valleys and undulating upland areas. Land use is dominated by forestry and blanket bogs in the upper parts of the Avoca catchment and pastures in the lower reaches. Within the Avoca mining area, the abandoned mines are located along a NNW-SSE trending topographic ridge surrounded by flat-lying pasture.

Several tributaries empty into the Avoca River in the vicinity of the mine. The important tributaries include:

- Vale View
- Red Road
- Sulphur Brook

Figure 3-1 Avoca Catchment

3.1.1 Vale View

The Vale View tributary empties into the Avoca River upgradient of the mine site. O'Suilleabhain (1996) did not measure the flow of the Vale View tributary. In 1995, sulfate concentrations ranged from 7.5-57.8 mg/L while copper and zinc concentrations ranged from <0.005-<0.01 and 0.18-0.60 mg/L, respectively. A sample collected by CDM in April 2007 had a pH value of 7.95 and a conductivity of 160 μmhos/cm. The conductivity was elevated compared to other tributaries perhaps indicating some input from other sources (fertilizer, septic, etc.).

3.1.2 Red Road

The Red Road tributary empties into the Avoca River across the street from the Toyota dealership on Avoca-Ratdrum Road. The flow in 1995 ranged from 0.045 to 4.42 l/s with an average of 0.999 l/s. In 1995 the pH was in the 6.4 to 6.8 range, while in April 2007 a pH of 7.29 was measured. The sulfate concentrations measured in 1995 ranged from 7.7-30.5 mg/L, while copper and zinc concentrations ranged from <0.005-0.01 and 0.11-0.38 mg/L, respectively. According to Gallagher and O'Connor, (1997), TM drained water from the twin shafts along the 22 fm adit to Red Road stream. The red staining observed along the stream in April 2007 is likely a result of the previous use of the stream to convey mine water. However, it is apparent that much of the effects of the mine water drainage were largely gone by 1995.

3.1.3 Sulphur Brook

Sulphur Brook empties into the Avoca River near the Avoca Handweavers about 500 meters north of the Avoca Bridge. The flow, as of August 1995 was about 23 l/s, and at the time represented only 3% of the flow of the Avoca River (O'Suilleabhain, 1996). As of 1995, pH values in Sulphur Brook were around 6.3, however, in April 2007 the pH was in the 7.6-7.7 su range. In 1995 sulfate concentrations ranged from 20-40 mg/L, while copper and zinc vales were 0.37-0.45 mg/L and 0.88-1.4 mg/L, respectively. Apparently, the diversion of Madam Butler's Adit to a different drainage has had a positive effect on Sulphur Brook.

3.1.4 Precipitation

A significant rainfall gradient occurs from west to east across the catchment. Median annual rainfall (1961-1990) ranges from greater than 2,000 mm/yr in the mountains to 990 mm/yr on the coast. Median annual rainfall at the mining site is approximately 1,100 mm/yr, while potential evapotranspiration (PE) is estimated to be approximately 540 mm/yr (Met Eireann, 2007). Actual evapotranspiration (AE) is expected to be 90 percent of the PE.

3.1.5 Flow

No stream flow gauges exist on the Avoca River near the mine site. The nearest stream gauge with good rating curves is Station 10002 (Rathdrum) on the Avonmore River, approximately 7 km to the north. The flow record of Station 10002, reproduced in Figure 3-2, shows measured flows ranging from >40 m³/s (following major rainfall events) to less than 1-2 m³/s during the low-flow season in late summer. While a permanent gauging station does not exist at the Avoca mine site, flows have been estimated from rainfall-runoff modeling as part of the Eastern River Basin District project. Calibrating initially to measured flows at Station 10002 on the Avonmore River and Station 10028 on the Aughrim River, the total estimated flow just downstream of the Avoca mine site is depicted on Figure 3-3. The flashy nature of the rivers within the Avoca catchment reflects a rapid response to rainfall.
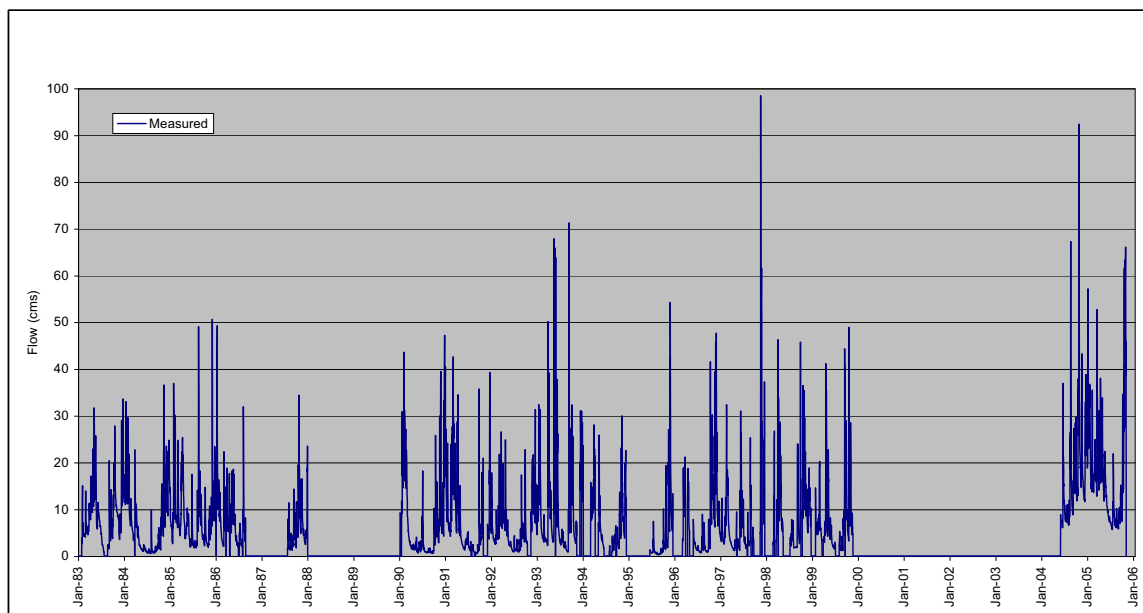
Figure 3-2 Measured Flow at Station 10002 on the Avonmore River
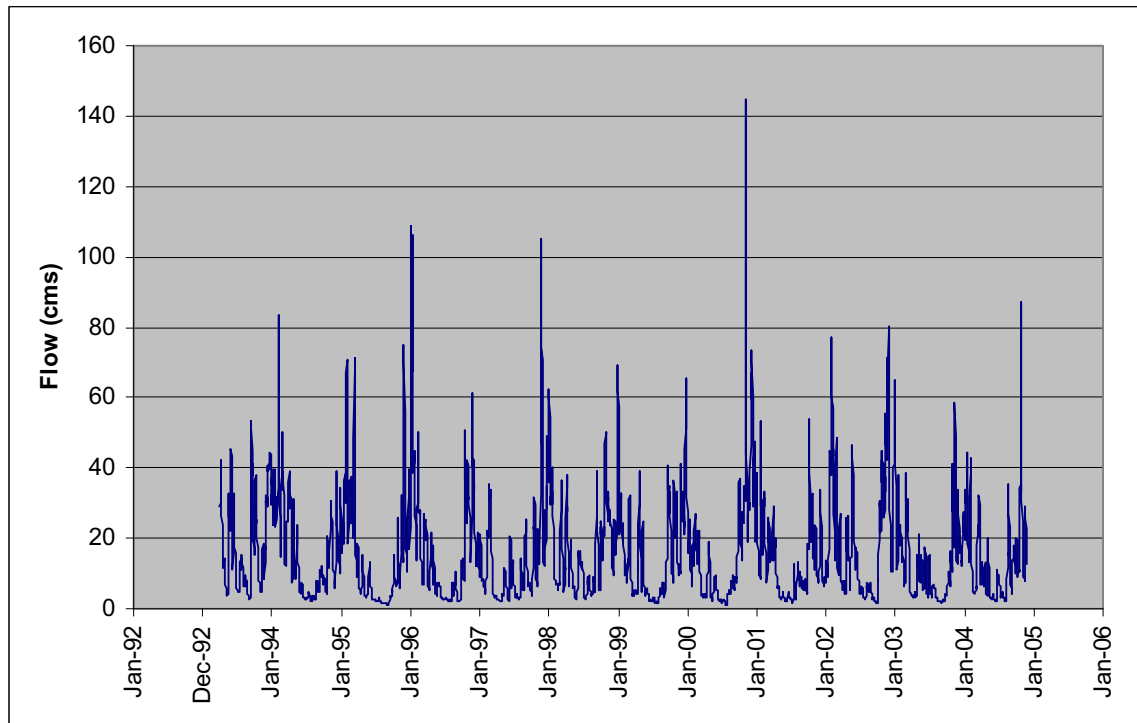
Figure 3-3 Net Simulated Flow of the Avoca River Near the Avoca Mines

While a permanent gauging station does not exist at the Avoca site, and flows are estimated from rainfall-runoff modeling, most of the tributaries within the Avoca catchment have similar physical characteristics (topography, geology, land use) and transposing flows from one location to another is reasonable. However, care must be taken with model-derived flows as they cannot take account of site-specific characteristics of surface water and groundwater interactions. Water level data from wells near the river suggest that the Avoca River is a gaining river, although limited direct flow measurements by GSI in the summer of 1995 (O'Suilleabhain 1996) suggested the river may partly be a loosing stream between the Meeting of the Waters and the abandoned coal yards downstream of the mines (O'Suilleabhain, 1996). It should be pointed out that the latter conclusion was not regarded definitive on account of questions surrounding the flow measurements. Apparently, significant flow occurs within the alluvium forming the bed of the river. A tracer study could provide true flow values in this area.

Within the mine area, all surface water drains to the Avoca River. Groundwater discharges to the river either via the main adits of East and West Avoca or as "diffuse" groundwater discharge. A conceptual model of flow mechanisms is described below.

3.2 Conceptual Model of Flow Mechanisms

Surface drainage follows topography and is influenced by the man-made excavations on both sides of the Avoca River. Surface drainage influenced by the open pits collects in pools within the pits, from where it infiltrates into groundwater and the underground systems of mine workings (shafts, tunnels, etc.). Groundwater pathways are more difficult to decipher, due to paucity of data and the expected influence of the underground mine system.

The Avoca mine site is underlain by rocks which the GSI classified as poorly productive:

- Pl – Poor aquifer, generally unproductive except for local zones
- Pu – Poor aquifer, generally unproductive

Water transport in this hydrogeological setting is broken down in three primary flow mechanisms:

- Surface runoff
- Interflow
- Deep groundwater flow

Terminology aside, interflow is defined in this report as the flow that takes place in the top few meters of bedrock. The interface between the top of bedrock and overburden materials is weathered and comprises a network of shallow fractures which conceptually is more dense and interconnected than the fractures of the deep groundwater flow system. The shallow fractured zone is therefore regarded as being more transmissive than deeper bedrock.

Drilling data from Avoca substantiates this conceptual model. As reported by O'Suilleabhain (1996), highly fractured rock was found to depths of 20-30 m. Water levels in bedrock in 1995 were measured 5-15 meters below ground surface and flow gradients are steep. Groundwater flow systems are localized, and flow lengths between recharge areas and the Avoca River (discharge zone) are only a few hundred meters.

The presence of the underground mine workings and open pits will significantly influence groundwater flow directions, by serving as hydraulic sinks. Deeper groundwater flow will also be influenced locally by lithological variations and the presence of faults. The present existence and distribution of wells does not allow for a precise definition of groundwater flow directions in deep bedrock.

The conceptual model would suggest that flow gradients in the shallow fractured zone would be equally steep (approximating topography) and would also be influenced by the mine shafts and pits. Evidence of groundwater seeps can be seen on the exposed faces of the open pits (e.g., Cronebane). These seeps reflect the natural

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water table within the shallow fractured zone. Chemical weathering and staining above the seeps indicate where historically the water table would have been prior to mining. As hydraulic sinks, the mine shafts divert groundwater flow, and under present conditions, the mines actually have a zone of contribution away from their geometric positions. The zone of contribution would be expected to be smaller for the shallow bedrock zone than the deeper bedrock zone, as the shallow bedrock zone partly occurs above the levels of the shafts. This is discussed further below.

Albeit of a preliminary nature, the groundwater flow map presented by Flynn (1994), reproduced in Figure 3-4, is a reasonable depiction of the potentiometric surface near the mines. Most of the wells identified, surveyed and measured are believed to be installed in the shallow fractured zone (up to 30 metres), though some wells may be deeper.

Recharge to, and drainage from, the shallow bedrock zone is expected to be quick as a function of limited overburden thickness in upland recharge zones and steep gradients. Water level fluctuations would therefore also be rapid, and depending on climatic conditions, the shallow bedrock zone may also be dry for parts of the year (notably on the steeper valley slopes).

Deeper bedrock has a finite ability to accept recharge on account of its low storage and transmissive properties. Hence, recharge that is rejected from the deeper system accumulates and flows through the shallow fractured zone under prevailing gradients (dictated by topography). The weathered nature of the shallow bedrock zone would impart heterogeneity to groundwater

*Figure 3-4 Potentiometric Surface Map of East Avoca, February 1994
(from Flynn 1994)*

occurrence and flow. When the recharge capacity of the shallow zone is reached, surface runoff (overland flow) is augmented.

To account for rejected recharge, a maximum recharge limit or 'cap' has been suggested for areas underlain by poorly productive rocks (Working Group on Groundwater, 2005). Based on GSI estimates of throughflow for Pl and Pu aquifers, a maximum recharge rate of 100 mm/yr is used.

The mining spoil areas represent a particular hydrological setting. A significant proportion of rainfall will run off the spoil heaps to low-lying spots due in part to their low-permeability characteristics. Exposed cross-sections on Mount Platte show layering of waste materials. Water that infiltrates will accumulate above low-permeability layers and seep laterally outwards following paths of least resistance. At the Shelton Abbey Tailings, a water level of 7 metres was measured in April 2007 in one existing piezometer located at the edge and close to the top of the dam. This implies that perched water beneath the dam is seeping out along the face of the dam. Such seeps (which reportedly also occur on Mount Platte) are lost through evapotranspiration (e.g., uptake by plants), follow surface water drainage courses, or infiltrate further into bedrock.

3.3 Water Balance

The discharges at the East and West Avoca adits represent groundwater flow collected and discharged by a tiered and complex system of underground mine workings. As a hydraulic sink, the underground mine system has an associated zone of contribution, which is shaped according to the groundwater recharge distribution across the mines area. This in turn is influenced by geological structures, flow components, hydrogeological characteristics of the bedrock, as well as the geometry of the underground mine workings.

The combined reported average discharges from the mine adits are:

- West Avoca: 17.1 l/s
- East Avoca: 17.7 l/s

On average, the total recharge to the mine system equals the measured outflows. The mine shafts have a finite storage, and although quantities of water flowing into and out of the system vary seasonally and with rainfall events, it is appropriate to estimate the hydraulic influence, or zone of contribution, of the mine system under average conditions.

An average water balance for the East and West Avoca mine system is presented in Table 3-1. Water enters the mine system as direct or indirect groundwater recharge. Recharge components include:

- Infiltration of water within the open pits: (a) from rainfall directly, and (b) from surface runoff from areas adjacent to the pits;

- Infiltration into the bedrock aquifer system adjacent to the pits.

The long-term (30-year) median precipitation (P) over the Avoca mine area is estimated to be 1,082 mm/yr. The estimated potential evapotranspiration (PET) rate is approximately 540 mm/yr (Met Eireann, 2007). The actual evapotranspiration (AET) is assumed to be about 90 percent of PET, or 486 mm/yr. This leaves 598 mm/yr as potential recharge (PR = P-AET). Due to the steep slopes of the mines area, it is further assumed that about 50 percent of rainfall runs off as overland flow, which leaves approximately 298 mm/yr as available recharge (AR).

From Table 3-1, and using the derived available recharge rate of 298 mm/yr, the volume of water that accumulates and infiltrates through the open pit areas is estimated, on average, to be:

- West Avoca: 3.5 l/s
- East Avoca: 6.4 l/s

The difference between these volumes and the measured average discharges form the East (Deep) and West (Road) adits represent groundwater recharge and flow from a larger area adjacent to the mine shaft system – i.e., the zone of contribution (ZOC). Based simply on water balances, these areas would cover approximately 1.23 km^2 and 1.50 km^2 for the East and West Avoca areas, respectively. In the case of East Avoca, the ZOC would be elongated along the axis of the underground mine workings, covering area 3.5 km long (along axis of ore bodies) by 350 m (perpendicular to the axis). In the case of West Avoca, the ZOC would cover an area that is nearly rectangular, as a function of the layout of underground mine workings. The calculated ZOC areas are in addition to the land areas of the open pits.

Table 3-1:
Preliminary Water Balance

		mm/yr	Source
Precipitation	P	1082	Met Eireann 1961-1990
Potential Evapotranspiration	PET	540	Met Eireann 1961-1990
Actual Evapotranspiration (90% of PE)	AET	486	
Potential Recharge (P-AE)	PR	596	
Runoff (50% of PR)	R	298	ERBD rainfall runoff modeling
Available Recharge (PR-R)	AR	298	
Deep Groundwater Recharge Cap	CAP	100	National Groundwater Working Group

WEST AVOCA

Direct Rainfall Into Pits:				
P is used for direct rainfall over open pit areas		1082	mm/yr	
West Pit Areas		33181	m²	
Volume in Pits from Rainfall		35901.84	m³/yr	
Surface Runoff Into Pits:				
Surface Area Draining to Pits		101819	m²	
R that drains to Pits		298	mm/yr	
Volume in Pits from Surface Runoff		30342.06	m³/yr	
Total Volume Accumulating in Pits from P and R		66243.90	m³/yr	
		2.10	l/s	
Recharge in Pits from P and R		2.10	l/s	
Contribution from Spoil:				
Area		81690	m²	
50% of P on spoil runs off into pits		541	mm/yr	
Volume in Pits from Spoil		44194.29	m³/yr	
Total Volume Accumulating in Pits from Spoil		44194.29	m³/yr	
		1.40	l/s	
Total Recharge in Pits (Direct Rainfall, Surface Runoff, Spoil)		3.50	l/s	
Measured Average Flow in East Adit		17.1	l/s	
Difference (Measured - Contribution from Pits)		13.60	l/s	
Recharge from Other Areas Needed to Make Up Difference		13.60	l/s	
Available Recharge over Other Areas		298	mm/yr	
Zone of Contribution needed to arrive at Measured Adit Flows		1500000	m²	1000 m x 1500 m
Zone of Contribution needed to arrive at Measured Adit Flows if Recharge Cap Applies		4600000	m²	2000 m x 2200 m

EAST AVOCA

Direct Rainfall Into Pits:				
P is used for direct rainfall over open pit areas		1082	mm/yr	
East Pit Areas		20500.00	m²	Tigroney
		62000.00	m²	Cronebane
Volume in Pits from Rainfall		89265.00	m³/yr	
Surface Runoff Into Pits:				
Surface Area Draining to Pits		41500	m²	Both pits
R that drains to Pits		298	mm/yr	
Volume in Pits from Surface Runoff		12367.00	m³/yr	
Total Volume Accumulating in Pits from P and R		101632.00	m³/yr	
		3.22	l/s	
Recharge in Pits from P and R		3.22	l/s	
Contribution from Spoil:				
Area		183689.00	m²	
50% of P on spoil runs off into pits		541.00	mm/yr	
Volume in Pits from Spoil		99375.75	m³/yr	
Total Volume Accumulating in Pits from Spoil		99375.75	m³/yr	
		3.15	l/s	
Total Recharge in Pits (Direct Rainfall, Surface Runoff, Spoil)		6.37	l/s	
Measured Average Flow in East Adit		17.70	l/s	
Difference (Measured - Contribution from Pits)		11.33	l/s	
Recharge from Other Areas Needed to Make Up Difference		11.33	l/s	
Available Recharge over Other Areas		298	mm/yr	
Zone of Contribution needed to arrive at Measured Adit Flows		1225000	m²	350 m x 3500 m
Zone of Contribution needed to arrive at Measured Adit Flows if Recharge Cap Applies		3675000	m²	1050 m x 3500 m

The available recharge defined above represents recharge both to the shallow bedrock and deep groundwater zones. Of the 298 mm/yr available, it is estimated that recharge to deeper groundwater would be on the order of 100 mm/yr or less, as the deep bedrock is less fractured and has lower storage and transmissive characteristics. The 100 mm/yr is based on throughflow characteristics of different rock types using ranges of field-derived values of hydraulic conductivity and transmissivity. The

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implication is that the bulk of recharge migrates in the shallow, more fractured and more transmissive zone near the top of bedrock as described in Section 3-2.

The actual shape of the ZOC would therefore be different in shallow and deep bedrock, and would be further influenced by geological structures, notably the N-S trending faults (which cut across the mine shafts and probably deliver groundwater to the shafts system) and the southeasterly dip direction (i.e., the ZOC may extend further away from the mine system to the NW than SE). The actual shape of ZOCs will also be influenced by heterogeneities in the underlying shallow and deep bedrock, as well as dynamic (transient) changes in hydrological conditions.

In reality, surface water and groundwater flow mechanisms and contributions are more complex than described in this report, however, without monitoring wells and tracer studies, it may not be possible to precisely define ZOCs. What is reasonably certain is that the combined ZOCs to the mine system are localized features, not regional.

A good illustration of the complexity of pathways is the shallow Cronebane adit which discharges about 1.5 l/s into the East Avoca open pit, from where it partly percolates into the ground. The adit discharge originates as recharge from areas of higher elevations to the north and northeast of the East Avoca pit and Mount Platte, and represents water that has been collected in shallow mine workings in this area. The water that percolates through the open pit floors is expected to discharge from the Deep adit, following preferential pathways associated with the underground mine workings. Other useful illustrations of the complexities of pathways are described by Gallagher and O'Connor (1997), notably in relation to descriptions of smaller water discharge points in East Avoca (Kilmacoo, Wood, and Madam Butler's adits).

One of the key implications of these observations is that the contribution of "diffuse" groundwater which may be impacted chemically by the mine system is considered to be small and mostly limited to stretches of river SE of each mine area. Without installation of monitoring wells along the river banks, it is not possible to determine the length of river that may be affected. Wells located in alluvium and bedrock downgradient of the Ballymurtagh landfill are impacted by low pH and high conductivity, possibly as a result of acid and metal impacted groundwater from the West mines area and/or shaft systems adjacent to and at a lower elevation than the Avoca River.

In April 2007, CDM collected groundwater from both a deep and shallow well located upgradient of the road adit on the east side of the road. The pH values were 3.57 and 3.68 for the shallow and deep wells, respectively. The conductivity was 1,940 and 1,550 µmhos/cm for the shallow and deep wells. Some of this groundwater enters the Avoca mine via visual seeps on the river bank.

The EPA-reported Q_{95} flow of hydrometric gauge 10002 at Rathdrum is 0.97 m³/s (970 l/s) for a catchment area of 233 km². This represents the flow that is exceeded at least 95% of the time, and is mostly represented by groundwater contributions during the drier, late-summer season. On the assumption that all of the Q_{95} flow is groundwater, the specific contribution, per km² of catchment area, is 4.16 l/s/km², equivalent to 130 mm of recharge per year. This value is close to the estimated recharge cap of 100 mm/yr for deep groundwater contribution, and less than the estimated total available recharge of 298 mm/yr.

Using data generated by GSI (GSI, 2005), throughflow and discharge from Lower Palaezoic bedrock to streams in the Avoca area would be expected to be in the order of 100 m³/day per km of river length. This represents natural flow in shallow and deep bedrock, and is not associated with mine impacts.

Rainfall-runoff modeling results also suggest that on average, deep groundwater flow and interflow each contribute about 20% of total streamflow. Guided by input parameters from the ongoing, national study on groundwater surface water interaction, the breakdown of the three primary flow mechanisms to simulated streamflow in the Avoca River is shown in Figure 3-5 (blue = deep groundwater; red = interflow; green = surface runoff).
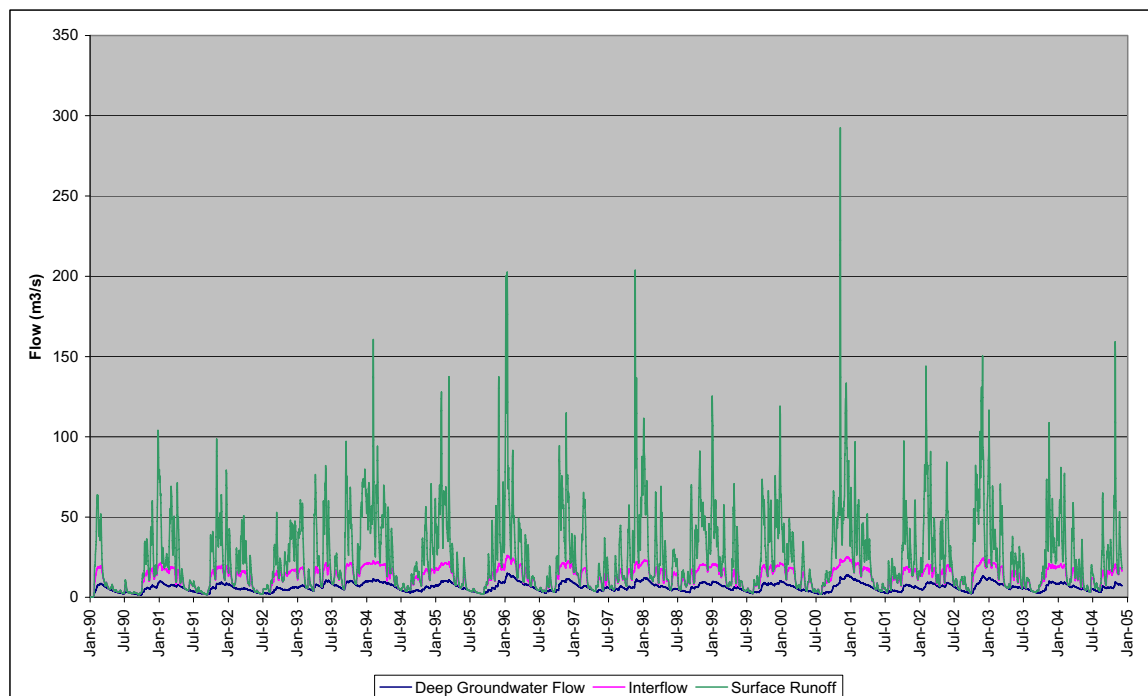
Figure 3-5 Simulated Flow Components on the Avoca River

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"Diffuse" groundwater in bedrock discharges mostly to alluvium, so pathways, redirection and attenuation factors in the alluvium are important from both a delivery and loading perspective.

3.4 Conclusions

Pathways of water to and from the mined areas are complex. The discharges from adits reflect both direct and indirect groundwater recharge, and groundwater flow is strongly influenced by the underground drainage system. Insufficient groundwater data exist to precisely delineate the zones of contribution (ZOCs) of the mine system, however, reasonable estimates of the sizes of respective ZOCs in East and West Avoca can be made on the basis of water balance considerations and geological interpretations. The ZOC for East Avoca is estimated to cover an area of 1.23 km^2, not including the open pits, and is elongated along the axis of the mined ore bodies. The ZOC for West Avoca is estimated to cover an area of 1.50 km^2, not including the open pits. Hydrogeological heterogeneities and faults that cut through the ore deposits may influence shape of ZOCs further.

Hydraulic characteristics of the bedrock in the mined areas have been partly quantified from drilling and basic hydraulic testing. Past studies indicate that the top 20-30 meters of bedrock are of variable quality, with rock quality designation values <30 percent, and with derived transmissivity values of 0.04-11.5 m^2/day.

Most of the groundwater discharging from the adits originates as direct or indirect recharge in areas near and adjacent to the open pits. Whether or not all of the hydrochemically impacted groundwater is 'captured' and discharged by the underground drainage is not known. Water balance deliberations and geological interpretations would suggest that only small quantities of impacted groundwater would escape capture by the mine system.

Water level data from wells downstream of West Avoca indicates that the Avoca River is a gaining river, although flow paths and head gradients may change over short distances as a result of heterogeneities in the bedrock and alluvium. Using the reported range of transmissivity values and hydraulic gradients in poorly productive bedrock, diffuse discharges from the top 30 meters of bedrock would be expected to be on the order of 100-500 m^3/day (0.003-0.015 l/s) per kilometer of river length.

O'Suilleabhain (1996, section 7.3, Box 7.1, page 40) has estimated ARD contaminated groundwater baseflow of 3 l/s to 6 l/s to the Avoca River on the basis of hydrochemical data over a 2.5 km stretch or river. This is approximately 10 to 20 percent of the average discharge from the Deep and Road Adits (35 l/s). Because of the difference in the various estimates of diffuse flow and the importance of the diffuse flow (contribution to metal concentrations in the Avoca River are difficult to treat), additional evaluations are recommended (see Section 5).

Section 4
Fate and Transport

4.1 Geochemistry of Contaminants of Concern (CoCs)

Four parameters were selected for detailed geochemical evaluations, copper, zinc, lead, and arsenic. Copper, zinc, and lead are important in terms of the ecological health of the Avoca River, while lead and arsenic were selected due to potential human health issues. The following sections summarize the fate and transport of the four elements in the environment. More details are provided in Appendix A.

4.1.1 Copper

Copper exists in oxidation states of 0 (metallic copper), +1, and +2. Only monovalent (Cu^+) and divalent (Cu^{2+}) oxidation states exist in the aqueous environment. At pH values less than 7, Cu^{+2} is the dominant form of divalent copper in solution, while at pH values between 7 and 13, $Cu(OH)_2^0$ predominates. $Cu(OH)_4^{-2}$ is important above a pH of about 13. $Cu(OH)_3^-$ and $Cu(OH)^+$ are of minor importance, representing less than 10% of the divalent copper at all pH values.

Monovalent copper is present only within a very narrow stability range due to the formation of metallic copper (at Eh < 0.1 volts). In natural waters other ions are present that can complex Cu^+, such as chloride, which can form important species such as $CuCl^0$, $CuCl_2^-$, and $CuCl_3^{-2}$. In general, divalent copper complexes with sulfate and bicarbonate do not represent a significant fraction of the dissolved copper, except under unusual circumstances, such as within acid rock drainage (sulfate concentrations are typically high) where the copper-sulfate complex ($CuSO_4^0$) can be important.

Copper Pure Phase Minerals
Divalent copper forms hydroxide, hydroxycarbonate, and possibly cupric ferrite ($CuFe_2O_4$) pure phase minerals, while zero-valent copper forms metallic copper. Monovalent copper phases form mainly within a sulfide environment, where minerals such as covellite (Cu_2S) can form.

Copper hydroxide only forms at high pH values, which means the aqueous concentrations of copper can be quite high when the pH is less than 7. The solubility of copper increases by roughly 100 times for every unit decrease in pH (in the pH range 4-6). However, the correlation is not exact due to the formation of copper hydroxide complexes. The complexing effect is most noticeable at pH values above 7. In fact, the decrease in copper solubility that would be expected as the pH increases does not occur due to the formation of copper hydroxide complexes.

Copper is more likely controlled by an amorphous coprecipitate with ferric hydroxide, as discussed in the next section. Under high pH and alkaline conditions, hydroxycarbonate phases can form ($Cu_2(OH)_2CO_3$). Such a phase is more likely to

form within carbonate aquifers and in alkaline soils dominated by calcite or other carbonate minerals.

The control of copper by a pure phase solid will only occur under two circumstances;

1. If a copper phase is released at a site and does not dissolve completely; or

2. If the soil particles become saturated with adsorbed copper to the point where the solution concentration rises to the solubility limit of a copper phase under the given conditions.

Waters in which the dissolved copper concentration is less than the solubility limit of the pure phase copper compounds suggests that aqueous copper concentrations are controlled by either coprecipitation or adsorption.

Copper Coprecipitation

In addition to forming pure compounds, copper can also precipitate as a trace element within other phases, most commonly with iron hydroxide. The general reaction is as follows:

$$2x\ Fe^{+3} + 3\text{-}3x\ Cu^{+2} + 6\ OH^- \rightarrow Fe_{2x}Cu_{3\text{-}3x}(OH)_6\ (s) \tag{4-1}$$

Where "x" is the fraction of iron in the phase. As a result of reaction (4-1), copper can coprecipitate from solution as a result of the oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) and/or an increase in the pH. In reality, equation (4-1) is likely to be much more complex, with other cations such as aluminum (Al^{+3}), and divalent metals (i.e. Pb^{+2}, Zn^{+2}, Ni^{+2}, etc.) substituting for iron, and anions such as arsenate (AsO_4^{-3}), chloride (Cl^-), and phosphate (PO_4^{-3}) substituting for hydroxide. In mine impacted waters where the pH is low and sulfate concentrations are high (>1,500 mg/L), significant sulfate substitution can occur, resulting in a schwertmannite or jarosite type hydroxysulfate coprecipitate. The phases are typically amorphous (no crystal structure) when first formed, but tend to crystallize (and become less soluble) over time.

Copper Adsorption

Copper adsorbs to solid surfaces due partly to interactions between the positively charged ions and a negatively charged surface. Therefore, copper adsorption tends to be favored for solid materials which are negatively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other cations in solution.

At low pH values, the water and mineral surfaces have higher concentrations of hydronium ion (H_3O^+) which imparts a positive charge to the surface. As the pH increases, the hydronium ion concentration decreases relative to the hydroxide ion (OH^-) concentration in both the water and the solid materials within the water. At a specific threshold pH value called the pH of the zero-point-of-charge (ZPC), the

surface charge transitions from positive to neutral to negative. Once the surface charge becomes negative, adsorption of the positively charged copper ions become possible. Materials with a lower pH_{ZPC} are able to maintain a negative charge at a lower pH than for materials with a higher pH_{ZPC}. Amorphous silica and montmorillonite clay are among the best cation adsorbents at higher pH values (above 2-2.5).

Amorphous ferric hydroxide has a pH_{zpc} of 8.5, which means that for pH values of less than 8.5, the surface charge is positive. Divalent copper exists predominantly as a positively charged or neutral species below a pH of about 7 (Cu^{+2} or $Cu(OH)_2^0$). Therefore, coulombic-type adsorption (attraction of a charged ion to an oppositely charged surface) of copper onto amorphous ferric hydroxide will not occur to any degree below a pH of 7. Copper tends to adsorb (coulombically) to clay minerals and manganese oxides, which have much lower pH_{zpc} values. However, copper does adsorb to amorphous ferric hydroxide below pH 7 by a process called "specific adsorption" in which the positively charged ions or neutral species attach to specific sites on the surface which are favorable.

In waters high in sulfate, such as acid mine drainage or sea water, the presence of sulfate has been observed to increase the adsorption of copper onto goethite.

Organic matter, such as peat, and especially manganese dioxide have much higher copper adsorption capacities than ferric hydroxide. The affinity of copper for manganese dioxide and organic matter can be used to evaluate the fate and transport of copper when exposed to soils of varying manganese and organic matter contents.

The presence of other divalent cations, especially calcium, results in decreased adsorption of copper due to competition for adsorption sites. The presence of lead, zinc, and cadmium have little effect on the adsorption of copper onto iron hydroxide. Anions, such as chloride can increase copper adsorption onto crystalline ferric hydroxide due to the formation of aqueous chloride complexes.

4.1.2 Zinc

Zinc exists in oxidation states of 0 (metallic zinc) and +2. Only the divalent (Zn^{2+}) oxidation state exists in the aqueous environment. At pH values less than 8, Zn^{+2} is the dominant form of zinc in solution, while at pH values between 8 and 11, $Zn(OH)_2^0$ predominates. $Zn(OH)_3^-$ and $Zn(OH)_4^{-2}$ are important above a pH of about 11. $Zn(OH)^+$ is of minor importance, representing less than 15 percent of the zinc at all pH values.

In natural waters, other ions (besides hydroxide) are present that can complex Zn^{+2}, such as sulfate, especially in acid rock drainage (ARD) water. Above a pH of 8.2, zinc carbonate complexes can also be important. Complexes with chloride, fluoride, and bromide, are generally insignificant unless unusually high concentrations of these ions are present in solution.

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Zinc Pure Phase Minerals

Zinc forms hydroxide and carbonate pure phase minerals, while zero-valent zinc forms metallic zinc. Zinc hydroxide only forms at high pH values, which means the aqueous concentrations of zinc can be quite high when the pH is less than 8 or 9. The solubility of zinc increases by roughly 100 times for every unit decrease in pH (in the pH range 4-7).

Under high pH and alkaline conditions, carbonate or hydroxycarbonate phases can form. Such phases are more likely to form within carbonate aquifers and in alkaline soils dominated by calcite or other carbonate minerals.

Waters in which the dissolved zinc concentration is less than the solubility limit of the pure phase zinc compounds suggests that aqueous zinc concentrations are controlled by either coprecipitation or adsorption.

Zinc Coprecipitation

In addition to forming pure compounds, zinc can also precipitate as a trace element within other phases, most commonly with iron hydroxide. The general reaction is as follows:

$$2x\ Fe^{+3} + 3\text{-}3x\ Zn^{+2} + 6\ OH^- \rightarrow Fe_{2x}Zn_{3\text{-}3x}(OH)_6\ (s) \tag{4-2}$$

Where "x" is the fraction of iron in the phase. As a result of reaction (4-2), zinc can coprecipitate from solution as a result of the oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) and/or an increase in the pH.

Zinc Adsorption

Zinc adsorbs to solid surfaces due partly to interactions between the positively charged ions and a negatively charged surface. Therefore, zinc adsorption tends to be favored for solid materials which are negatively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other cations in solution.

Organic matter, such as peat, and especially manganese dioxide have much higher zinc adsorption capacities than ferric hydroxide. The affinity of zinc for manganese dioxide and organic matter can be used to evaluate the fate and transport of zinc when exposed to soils of varying manganese and organic matter contents.

pH also has a significant effect on the adsorption capacity of zinc. The increase of the adsorption capacity is a function of both the surface charge on the solids (which is negative at higher pH) and on the zinc speciation

The presence of other divalent cations, especially calcium, results in decreased adsorption of zinc due to competition for adsorption sites. Zinc adsorption onto soil is significantly inhibited by the presence of >40 mg/L calcium or magnesium. However, the presence of lead, copper, and cadmium have little effect on the adsorption of zinc

onto iron hydroxide. Anions, such as chloride, nitrate, and perchlorate have little affect on zinc adsorption, while adsorption is enhanced by the presence of chromate, selenite, arsenate, and phosphate.

4.1.3 Lead

Lead exists in oxidation states of 0 (metallic lead), +2, and +4. Only Pb^{2+} exists in the aqueous environment, as Pb^{4+} is outside of the stability range of water. At pH values less than 7.7, Pb^{+2} is the dominant form of lead in solution, while at pH values between 7.7 and 9.4, $PbOH^+$ predominates. $Pb(OH)_2^0$ and $Pb(OH)_3^-$ are only important above a pH of 9.4.

In groundwaters, aqueous lead exists as the uncomplexed ion Pb^{2+} under acidic conditions and as lead-carbonate complexes under alkaline conditions. Within acid rock drainage, where sulfate concentrations are typically high, lead-sulfate complexes are also important.

Lead Pure Phase Minerals
Aqueous lead concentrations can be controlled by pure phase lead minerals, such as lead hydroxide, lead carbonate (cerrusite), and lead phosphates. Lead hydroxide only forms at high pH values, which means the aqueous concentrations of lead can be quite high when the pH is less than 7. The solubility of lead increases by roughly 100 times for every unit decrease in pH. However, the correlation is not exact due to the formation of lead hydroxide complexes.

Lead hydroxide is the most likely pure phase control in waters with very low alkalinity and phosphate concentrations. However, when as little as 50 mg/L alkalinity is present, the mineral cerrusite ($PbCO_3$) can form, resulting in much lower lead solubility than for lead hydroxide at the same pH. The presence of even lower concentrations of phosphate can result in the precipitation of lead phosphate, which has even lower lead solubility.

Waters in which the dissolved lead concentration is less than the solubility limit of the pure phase lead compounds suggests that aqueous lead concentrations are controlled by either coprecipitation or adsorption.

Lead Coprecipitation
In addition to forming pure compounds, lead can also precipitate as a trace element within other phases, most commonly with iron hydroxide. The general reaction is as follows:

$$2x\ Fe^{+3} + 3\text{-}3x\ Pb^{+2} + 6\ OH^- \rightarrow Fe_{2x}Pb_{3\text{-}3x}(OH)_6\ (s) \tag{4-3}$$
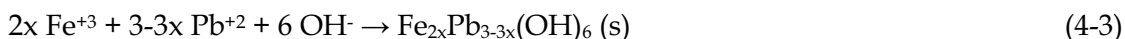
Where "x" is the fraction of iron in the phase. As a result of reaction (4-3), lead can coprecipitate from solution as a result of the oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) and/or an increase in the pH.

Lead Adsorption

Like the other divalent metals, lead adsorption tends to be favored for solid materials which are negatively charged. Iron hydroxide and manganese dioxide have much higher lead adsorption capacities than organic matter or clay minerals.

pH also has a significant effect on the adsorption capacity of lead. Due to the surface charge changes that occur as the pH increases (becomes negative at high pH) and the speciation changes, the lead adsorption capacity of solids tends to increase with increasing pH.

4.1.4 Arsenic

Arsenic occurs in two oxidation states in natural waters, +3 (arsenite) and +5 (arsenate). As^{+5} exists predominantly as a negatively charged ion (anion) above a pH of about 2. As^{+5} is predominantly monovalent (charge of -1) over the pH range of 2 to 7 ($H_2AsO_4^-$), divalent from pH 7 to 11.5 ($HAsO_4^{2-}$) and trivalent at pH values above 11.5 (AsO_4^{3-}).

As^{+3} is predominantly a neutral species ($H_3AsO_3^0$) below a pH of about 9. $H_2AsO_3^-$ and $HAsO_3^{-2}$ do not become important until the pH exceeds 9 su, which is higher than observed in the vast majority of natural waters.

Arsenic Pure Phase Minerals

Pure phase arsenic minerals such as orpiment (As_2S_3), realgar (AsS), and arsenopyrite ($FeAsS$) occur mainly in ore deposits formed from hydrothermal fluids within the Earth's crust. A few pure phase arsenic minerals occur under low temperature and low pressure conditions at the Earth's surface, such as scorodite ($FeAsO_4 \cdot 2H_2O$ at low pH), and arsenic sulfides (under reducing conditions). However, the vast majority of pure phase arsenic minerals are too soluble to be present in soils that are in contact with water.

Arsenic Solid-Solution Phases

Arsenic forms solid-solution phases with ferric hydroxide and iron hydroxysulfates such as jarosite ($HFe_3(OH)_6(SO_4)_2$) and schwertmannite ($Fe_8O_8(OH)_6SO_4$) and with amorphous silica. Arsenate, like silicate, has a tetrahedral form (a central atom coordinated with four oxygen atoms) which may facilitate the incorporation of arsenate into amorphous silica.

Amorphous phases such as ferric hydroxide or schwertmanite tend to substitute hydroxide or sulfate for arsenate. A reaction to form an iron-arsenic solid-solution is as follows:

$$Fe^{+3} + xAsO_4^{-3} + (3-3x)\ OH^- \rightarrow [FeAsO_4\ 2H_2O]_x[Fe(OH)_3]_{1-x}\ (s) \tag{4-4}$$

The amount of substitution of arsenic into ferric hydroxide is determined by the pH of the solution (more arsenic substitution occurs at lower pH values) and the

concentration of arsenic in solution (higher arsenic concentrations result in more substitution).

Arsenic Adsorption

Arsenic adsorbs to solid surfaces due partly to interactions between the negatively charged ions and a positively charged surface. Therefore, arsenic adsorption tends to be favored for solid materials which are positively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other anions in solution.

At low pH values, the water and mineral surfaces have higher concentrations of hydronium ion (H_3O^+) which imparts a positive charge to the surface. As the pH increases, the hydronium ion concentration decreases relative to the hydroxide ion (OH^-) concentration in both the water and the solid materials within the water. Once the surface charge becomes negative, adsorption of the negatively charged arsenate ions become less prevalent.

Under typical Eh/pH conditions, As^{+3} is a neutral ion and does not adsorb well to negatively or positively charged surfaces. Therefore, As^{+3} is roughly 4-10 times more mobile than As^{+5}. In addition, As^{+3} is about 60 times more toxic to humans than arsenate.

Arsenic has a strong affinity for iron phases and minerals. Strong correlations between arsenic and iron have been found in soils, in ores, within ferrihydrite impurities in phosphate pebbles, and in sediments impacted by arsenic-containing groundwaters.

Iron hydroxide has a much higher arsenate adsorption capacity than montmorillonite or kaolinite clays. The affinity of arsenate for iron minerals such as iron hydroxide can be used to evaluate the fate and transport of arsenate when exposed to soils of varying iron contents.

pH also has a significant effect on the adsorption capacity of arsenic. The pH dependence is due to the speciation of arsenic and the surface charge of the solid at different pH values. Arsenate is a negatively charged ion (anion) at pH values greater than about 2, while the aluminum and iron hydroxides tend to be positively charged. However, as the pH increases, the surfaces of the solids become less positive and the arsenate species become increasingly negative resulting in fewer adsorption sites. Arsenite, being a neutral species below pH 9, is relatively insensitive to changes in pH.

Phosphate competes with arsenate for adsorption sites resulting in less arsenate adsorption and greater mobility. Other ions such as chloride, sulfate, and nitrate have little or no effect on arsenic adsorption.

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4.2 ARD and Metals Production Processes

4.2.1 Pyrite Oxidation

Pyrite is the most abundant sulfide mineral in the Avoca mine wastes. There are two main oxidants of pyrite, dissolved molecular oxygen (O_2) and aqueous ferric ion (Fe^{3+}). Although pyrite oxidation is a complex reaction that involves many reaction steps, it can generally be characterized by four reaction steps (reactions 4-5 through 4-8 below).

Oxidation of pyrite by dissolved O_2 proceeds according to the following reaction:

$$FeS_2 \text{ (s)} + 7/2O_2 \text{ (aq)} + H_2O \text{ (l)} \rightarrow Fe^{2+} \text{ (aq)} + 2SO_4^{2-} \text{ (aq)} + 2H^+ \text{ (aq)} \tag{4-5}$$
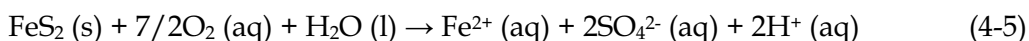
In reaction 4-5, O_2 oxidizes the sulfide in pyrite to aqueous sulfate (SO_4^{2-}), releasing ferrous ions (Fe^{2+}) and protons (H^+). The ferrous ions (Fe^{2+}) released by reaction 4-5 are also oxidized by dissolved O_2 according to the following reaction:

$$Fe^{2+} \text{ (aq)} + 1/4O_2 \text{ (aq)} + H^+ \text{ (aq)} \rightarrow Fe^{3+} \text{ (aq)} + 1/2H_2O \text{ (l)} \tag{4-6}$$
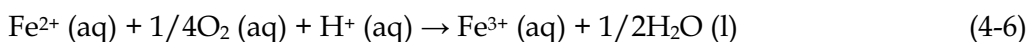
In reaction 4-6, O_2 oxidizes Fe^{2+} to Fe^{3+}. Above a pH of about 3.5, Fe^{3+} is unstable and will hydrolyze to form solid iron hydroxide [$Fe(OH)_3$] according to the following reaction:

$$Fe^{3+} \text{ (aq)} + 3H_2O \text{ (l)} \rightarrow Fe(OH)_3 \text{ (s)} + 3H^+ \text{ (aq)} \tag{4-7}$$
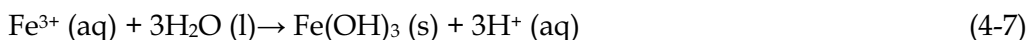
In reaction 4-7, hydrolysis of ferric iron (Fe^{3+}) produces solid $Fe(OH)_3$ and releases additional H^+, which further lowers the pH. Reaction 4-7 controls the amount of Fe^{3+} available as an additional pyrite oxidant. Since $Fe(OH)_3$ is a relatively insoluble solid phase, the amount of Fe^{3+} available to oxidize pyrite is very low at pH conditions above 3.5. However, when the pH is below 3.5, hydrolysis (reaction 4-7) is insignificant and Fe^{3+} is available as a pyrite oxidant according to the following reaction:

$$FeS_2 \text{ (s)} + 14Fe^{3+} \text{ (aq)} + 8H_2O \text{ (l)} \rightarrow 15Fe^{2+} \text{ (aq)} + 2SO_4^{2-} \text{ (aq)} + 16H^+ \text{ (aq)} \tag{4-8}$$
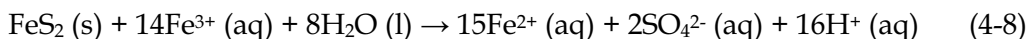
In reaction 4-8, Fe^{3+} oxidizes the sulfide in pyrite to SO_4^{2-}, releasing Fe^{2+} and H^+. The Fe^{2+} released by reaction 4-8 can be oxidized by reaction 4-6, resupplying Fe^{3+} for continued oxidation via reaction 4-8 and initiating a cycle that leads to very low pH levels and high SO_4^{2-} concentrations. Oxidation of pyrite by ferric iron is an order of magnitude faster than oxidation by oxygen. Sapsford and Williams (2005) conducted humidity cell tests on wastes from the Avoca site and found that the most rapid oxidation rate of pyrite occurred when the ferric iron concentrations were the highest.

Under relatively high pH conditions (pH>3.5), pyrite is oxidized only by dissolved O_2 (reaction 4-5), since Fe^{3+} is unavailable (i.e., it is removed by precipitation of $Fe(OH)_3$; reaction 4-7). The abiotic rate of pyrite oxidation via reaction 4-5 is about log k = -2 per

day for pH between about 3.5 and 8. At low pH (pH<3.5), pyrite is oxidized by Fe^{3+} (reaction 4-8) much more rapidly than by O_2 (reaction 4-5). The rate of pyrite oxidation by Fe^{3+} is about log k = -0.5 to 1.2 per day. However, the oxidation of Fe^{2+} to Fe^{3+} (reaction 4-6) is extremely slow under low pH conditions, with a rate of about log k = -4 per day. For this reason, reaction 4-6 is considered the rate limiting step in pyrite oxidation under low pH conditions.

The rate of pyrite oxidation is also influenced by the morphology of the pyrite grains. Framboidal pyrite, which consists of spherical agglomerations of very fine grains is the most reactive, while coarse euhedral crystals are the least reactive. The smaller grain size framboidal pyrite provides a much greater surface area for reaction than for coarse crystalline forms. The framboidal form of pyrite is much more common within sedimentary environments, while the hydrothermal variety tends to be coarser and crystalline. The pyrite at the Avoca site tends to be euhedral to subhedral granular or colloform phases, which would tend to be less reactive than framboidal pyrite. However, forms such as botryoidal (framboidal?) pyrite have been described. Other forms of iron sulfide, which are more reactive than pyrite are also described, such as melnikovitic pyrite, which is actually a mixture of pyrite, mackinawite (FeS), greigite (Fe_3S_4) and iron oxyhydroxides.

4.2.2 Role of Bacteria in Pyrite Oxidation

Bacteria such as *Thiobacillus ferrooxidans* and *Leptospirillum ferrooxidans* are acidophilic chemolitrophic bacteria that are ubiquitous in geologic environments containing pyrite. *T. ferrooxidans* and *L. ferrooxidans* catalyze the oxidation of Fe^{2+} to Fe^{3+} in the presence of dissolved O_2 (reaction 4-6). These bacteria typically increase the rate of reaction 4-6 by several orders of magnitude under low pH conditions, thereby allowing pyrite oxidation to be controlled by reaction 4-8.

T. ferrooxidans can also catalyze the oxidation of sulfide to sulfate (reaction 4-5). The related species *Thiobacillus thiooxidans* is an obligate aerobe, meaning that it is limited to catalyzing the oxidation of sulfide to sulfate. When *T. ferrooxidans* and *T. thiooxidans* are present under low pH conditions, pyrite oxidation rates can be increased by as much as five orders of magnitude over abiotic oxidation rates.

4.2.3 Other Metal Sulfide Oxidation

Trace elements such as arsenic may be mobilized indirectly by pyrite oxidation because they are typically present in pyrite in trace amounts. In addition, the low pH conditions resulting from pyrite oxidation tend to enhance the solubilities of oxide or hydroxide phases that could limit aqueous metals and arsenic concentrations.

Metals and arsenic present in the mine waste as reduced sulfide phases can be directly oxidized by O_2 or Fe^{3+} in a manner similar to that of pyrite. For example, if arsenopyrite (FeAsS) is present, reactions 4-6 and 4-8 for the oxidation of pyrite can be replaced with the following reactions:

$$FeAsS \text{ (s)} + 7/2O_2 + H_2O \rightarrow Fe^{2+} + SO_4^{2-} + AsO_4^{3-} + 2H^+ \qquad (4\text{-}9)$$

$$FeAsS \text{ (s)} + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + SO_4^{2-} + AsO_4^{3-} + 16H^+ \qquad (4\text{-}10)$$
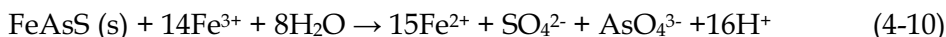
In these reactions, FeAsS is oxidized by either O_2 or Fe^{3+}, releasing arsenic to the aqueous phase.

Oxidation of sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and galena (PbS) by oxygen occur according to the following reactions:

$$ZnS(s) + 2O_2(aq) \rightarrow Zn^{+2}(aq) + SO_4^{-2}(aq) \qquad (4\text{-}11)$$

$$CuFeS_2(s) + 4O_2(aq) \rightarrow Fe^{+2}(aq) + Cu^{+2}(aq) + 2SO_4^{-2}(aq) \qquad (4\text{-}12)$$

$$PbS(s) + 2O_2(aq) \rightarrow Pb^{+2}(aq) + SO_4^{-2}(aq) \qquad (4\text{-}13)$$
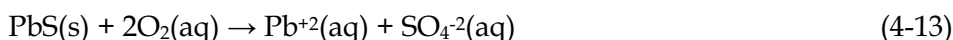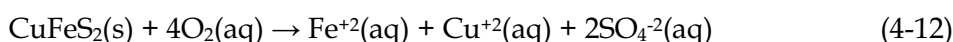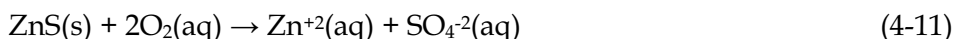
As with pyrite, oxidation of the zinc, iron-copper, and lead sulfides is catalyzed by bacteria such as *T. ferrooxidans* and *T. thiooxidans* under low pH conditions. The oxidation reactions for sphalerite, chalcopyrite, and galena do not directly result in a lowering of the pH (no H^+ ions are produced), but acidity is produced in the form of ferrous iron and other metal ions that can complex hydroxide ions or precipitate as a hydroxide, which lowers the pH.

4.2.4 Oxygen Diffusion Rate versus Pyrite Oxidation Rate

As indicated by reactions 4-5, 4-6, and 4-9, oxidation of pyrite and other sulfides requires the presence of dissolved O_2. The amount of dissolved O_2 available for oxidation will be a function of the following processes:

- Diffusion of atmospheric O_2 through the air-filled pore spaces of the mine waste.

- Equilibrium between atmospheric O_2 and dissolved aqueous O_2.

- Diffusion of dissolved O_2 through the water phase in contact with pyrite and other sulfides.

The rate of diffusion of atmospheric O_2 will be a function of the fraction of air-filled pore space and the tortuosity factor for diffusion of O_2 through the air-filled pore spaces. Therefore, the rate of diffusion will depend primarily on the grain size and sorting characteristics of the mine wastes, and on the degree of water saturation.

The equilibrium between atmospheric O_2 and dissolved O_2 is determined by Henry's Law:

$$C_{eq} = K_H \cdot P_{gas} \qquad (4\text{-}14)$$

where C_{eq} is the equilibrium concentration of dissolved O_2, K_H is the Henry's Law constant for O_2, and P_{gas} is the partial pressure of O_2 in the atmosphere in contact with the water phase. K_H in equation 4-14 varies as a function of temperature. At 20° C, K_H for O_2 is 43.8 mg/L-atm. If the partial pressure of atmospheric oxygen is 0.21 atm, the dissolved O_2 concentration would be C_{eq} = (43.8 mg/L-atm)(0.21 atm) = 9.2 mg/L at equilibrium.

If the atmospheric and dissolved O_2 diffusion rates exceed the pyrite oxidation rate, the oxidation rate will be controlled by the rates of reactions 4-5, 4-7, and 4-8. Otherwise, the O_2 diffusion rates will control the pyrite oxidation rate. The rates of reactions 4-5 through 4-9, which are faster than the oxygen diffusion rate (Pantelis and Ritchie, 1991), can be assumed to be instantaneous.

4.2.5 Zonation in the Mine Wastes

The descriptions of the spoil heaps (section 2) indicate that in many cases, the degree of oxidation is variable and in some cases zoned. In addition, the tailings pond at Shelton Abbey is likely to be zoned, with different layers at depth. The following sections describe the zonation that is typically seen in mine waste materials.

Reactive Transition Zone

The oxidation of pyrite and other sulfides in the mine wastes will result in a zone of active oxidation, known as the reactive transition zone, with thickness dependent on the presence and consumption of dissolved oxygen. At the top of the reactive transition zone, pyrite oxidation will proceed at its maximum rate because of the continued resupply of dissolved O_2. With increasing depth, however, the rate of pyrite oxidation in the reactive transition zone will gradually decrease due to decreasing dissolved O_2. Dissolved O_2 is consumed in the lower levels of the reactive transition zone faster than it can be resupplied by diffusion processes. Thus, the reactive transition zone is characterized by decreasing dissolved O_2 levels and pyrite oxidation rates with depth. At the bottom of the reactive transition zone, dissolved O_2 levels are essentially zero and pyrite oxidation does not occur. Within the reactive transition zone, bacterial-catalyzed oxidation will result in pH values in the 2-3 range, high sulfate concentrations, and high trace element concentrations.

Oxidized Zone

The reactive transition zone will migrate downward through the mine wastes as the pyrite and other sulfides are removed by oxidation. As downward migration proceeds, a remnant oxidized zone, where sulfide minerals have been completely oxidized and removed, will develop above the reactive transition zone. In theory, the oxidized zone will no longer be capable of generating acid and releasing COCs and, therefore, the pH will tend to be near neutral. However, the oxidized zone is often observed to have slightly acidic pH values due to the depletion of the neutralizing capacity within the zone and the presence of remnant acidity in the form of iron or aluminum sulfates.

Reduced Zone

Beneath the reactive transition zone will be a reduced zone where atmospheric and dissolved O_2 levels will be essentially zero due to their removal in the overlying reactive transition zone. Acidity and metals generated in the reactive transition zone will be released to the underlying reduced zone where they will react with waste materials under the reduced geochemical conditions. If the reduced zone has acid neutralizing capacity, some metals will tend to precipitate or coprecipitate as various oxide, hydroxide, and carbonate phases. They may also adsorb onto solids. However, it is important to realize that "reduced" does not necessarily mean that oxidation-reduction (redox) conditions will be such that equilibrium with the sulfides in the reduced zone will occur, or that redox conditions necessary for precipitation of secondary sulfide minerals will exist. The reduced zone is more appropriately regarded as reduced relative to the reactive transition zone, in that dissolved oxygen is not present.

4.2.6 Desorption

Desorption of metals from soils and sediments is mainly a secondary source and is not likely to be important compared with the primary source (sulfide oxidation). Desorption is secondary, because the metals adsorbed to the soil and sediments from the ARD (from the primary source) as the neutralization of the water favored metals adsorption (see Section 4.3.2). Desorption would not occur until the primary source is removed and the quality of the water in contact with the soils/sediments improves. In general, desorption does not become important until the primary sources are removed.

4.2.7 Dissolution of Secondary Phases

Minerals such as jarosite and schwertmannite are likely present within the mine working and spoil heaps due to the partial neutralization of the mine waters by silicate minerals. These minerals can store metals and acidity until the geochemical conditions change (such as an increase in the pH) and they become unstable. The following reaction illustrates the breakdown of jarosite to form iron hydroxide (at pH>4 su):

$$KFe_3(SO_4)_2(OH)_6 \text{ (jarosite)} + 3H_2O \text{ (l)} \rightarrow 3Fe(OH)_3(s) + 3H^+(aq) + 2SO_4^{-2}(aq) + K^+(aq)$$

$$(4-15)$$
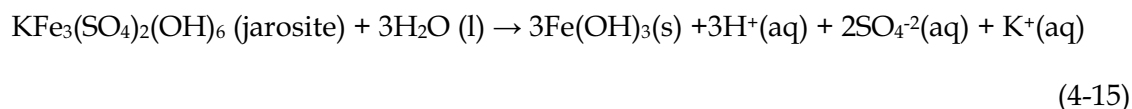
The presence of evaporative crusts has been observed at the Avoca site (an analysis is provided in Table 2-10). The crusts typically consist of metal sulfates, which form when leachate from a spoil heap or tailings pond evaporates to dryness. The material is very soluble and readily re-dissolves during precipitation events. Such secondary precipitates can effectively store ARD until a significant rain event dissolves the material and releases low pH metal-bearing water into the Avoca River as a "slug." The loading from such sources would not be recognized under normal sampling conditions, unless the sampling happened to occur following a storm event.

The ability of sulfates to store acidity is illustrated by the dissolution of ferrous sulfate.

$$FeSO_4 \text{ (s)} + \tfrac{1}{2} O_2 \text{ (aq)} + \tfrac{5}{2} H_2O \text{ (l)} \rightarrow 3Fe(OH)_3 + 2H+ + SO_4^{-2}\text{(aq)} \qquad (4\text{-}16)$$
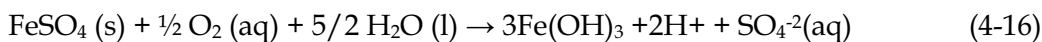
4.3 Metals and Neutralization Processes

4.3.1 ARD Neutralization

ARD is eventually neutralized by the dissolution of minerals from down-gradient bedrock or soil/sediments within the drainage basin. However, the ability of these materials to have an impact on the generation and persistence of ARD depends on the rate of dissolution of the neutralizing minerals compared to the rate of pyrite oxidation. The neutralizing mineral dissolution rate depends on the following factors:

- The grain size of the minerals
- The mineral type
- The pH of the ARD

The rate of dissolution of the minerals within the drainage basin depends on the grain size, due to the fact that a finer grain size mineral has a much higher surface area available for reaction than for a coarse material. For example, a single grain with dimensions of 1 cm on each side (a pebble) has a surface area of 0.0006 m^2, whereas the same volume of clay (10^{12} 1 μm diameter cubes) has a surface area of 6 m^2. Therefore, fine sediments tend to have faster reaction rates than bedrock surfaces or cobbles.

The mineral type has an important influence on the rate of neutralization of ARD. Carbonate minerals, such as calcite and dolomite, react very rapidly, and when present in large amounts effectively limit or prevent ARD from forming. The Avoca site contains no carbonate rocks such as limestone or dolostone and only very limited quantities of carbonate minerals. As mentioned previously, Jadebay (2003) mentions the presence of dolomite within the Pond Lode Pit in West Avoca. The reaction for the dissolution of dolomite is as follows:

$$CaMg(CO_3)_2 \text{ (dolomite)} + 2H^+ \text{ (aq)} \rightarrow Ca^{+2} \text{ (aq)} + Mg^{+2} \text{ (aq)} + 2HCO_3^- \text{ (aq)} \qquad (4\text{-}17)$$
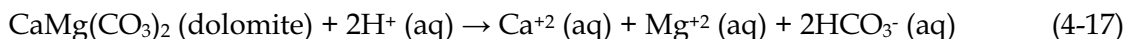
The host rocks of most ore bodies consist of silicates as opposed to carbonate rocks. In general, mafic rocks containing higher temperature minerals such as pyroxene, amphiboles, plagioclase, and olivine react faster than felsic rocks containing quartz, potassium feldspar or albite (Eary and Williamson, 2006). An example of a reaction illustrating the neutralization of ARD by anorthite (a type of plagioclase) is illustrated by equation 4-18.

$$CaAl_2Si_2O_8 \text{ (anorthite)} + 2H^+ + 6H_2O \text{ (l)} \rightarrow Ca^{+2} \text{ (aq)} + 2Al(OH)_3\text{(s)} + 2H_4SiO_4^0 \text{ (aq)}$$

$$(4\text{-}18)$$

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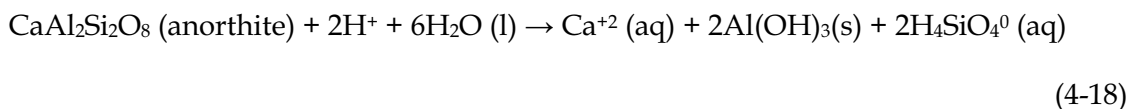
Day and Rees (2006) proposed the dissolution of chlorite from the propylitic alteration zone of porphyry copper deposits to explain the neutralization and magnesium content of the surface waters issuing from the spoil heaps associated with the mines.

The neutralization rate is also determined by the pH of the ARD, with lower pH waters generally reacting more rapidly than higher pH waters. pH also affects the relative reaction rates of the minerals as shown in Table 4-1.

Table 4-1 Relative Neutralization Rates of Various Rock Forming Minerals (Arranged from Highest to Lowest)[1]

pH 4	pH 7
Forsterite	Anorthite
Anorthite	Bytownite
Hornblende	Forsterite
Bytownite	Hornblende
Augite	Labradorite
Labradorite	Andesine
Andesine	Augite
Oligoclase	Oligoclase
K-Feldspar	K-Feldspar
Biotite/Albite	Biotite/Albite

Eary and Williamson (2006)

The neutralization of ARD by silicate minerals can buffer the pH to some extent. Eary and Williamson (2006) cited studies at the Aitik mine in Sweden that showed that biotite and plagioclase prevent the pH of the discharge from decreasing to below 3.5 su. However, the pH generally does not reach near neutral values within a mine or spoils heap due to reaction of the ARD with silicate minerals, because the rate of pyrite oxidation is generally faster than the rate of ARD neutralization.

Once the ARD leaves the sulfide-bearing materials, then the neutralization reactions have a chance to start catching up, so that the pH can increase. However, due to the pH effect on ARD neutralization by silicate minerals, the reactions occur at a continually slower rate as the neutralization proceeds. The effect of the pH buffering has several effects on the fate and transport of metals and the quality of the ARD, including;

■ The concentrations of ferric iron in solution and the rate of pyrite oxidation (as discussed previously)

■ The degree of adsorption

■ Precipitation/coprecipitation reactions

The neutralization of the ARD ultimately attenuates most of the metals, although zinc tends to persist at pH values up to 7 or 8 su.

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Neutralization at the Avoca site

Clues about the neutralization reactions occurring at the Avoca site can be obtained by evaluating the bedrock geology (see Section 1) and by evaluating the major ion chemistries of the adit discharges. Figure 4-1 is a Piper diagram showing the relative proportions of calcium, magnesium, and sodium plus potassium within the Deep Adit and Road Adit discharges for the period August 1993 through December 2002 and for February-March, 2006 (Unipure, 2006).
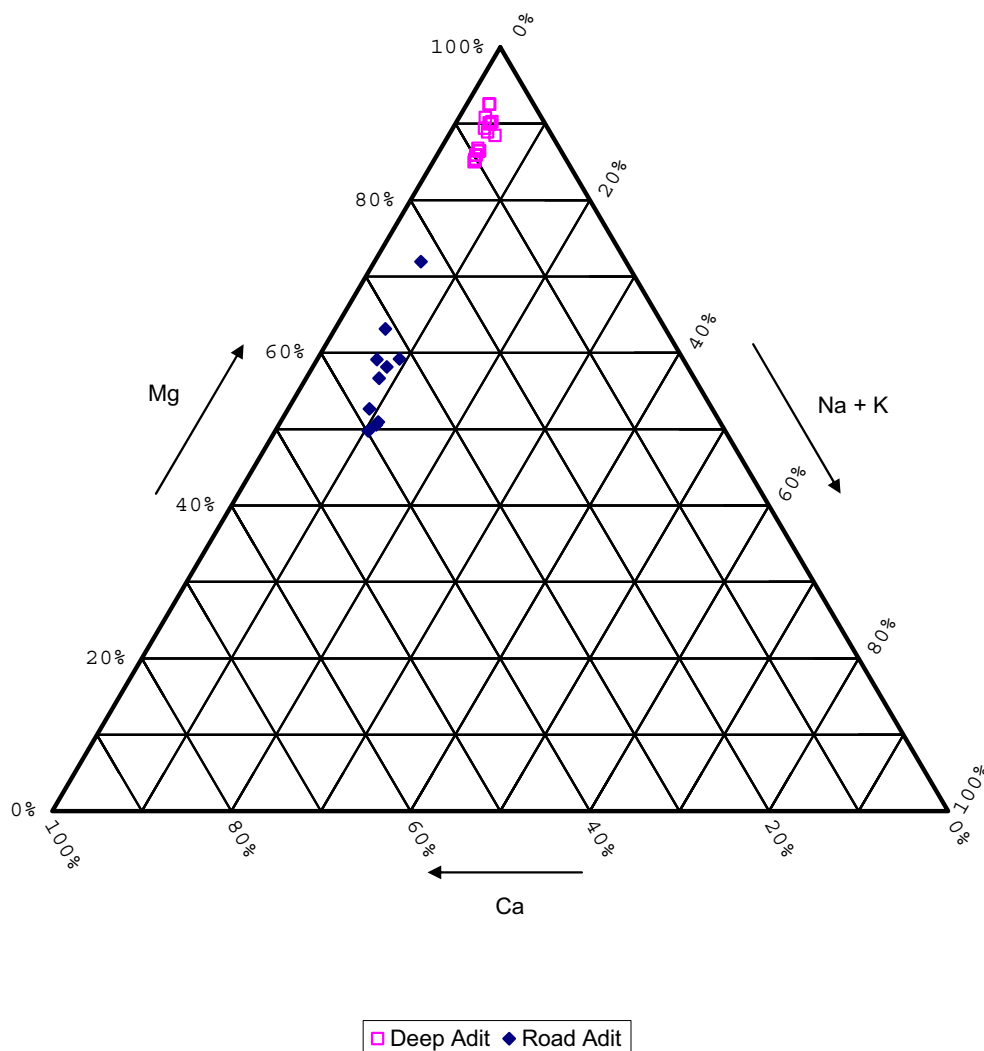
□ Deep Adit ◆ Road Adit

Figure 4-1 Piper diagram showing the major cation proportions for the Deep Adit (squares) and the Road Adit (diamonds) for the periods August 1993 through December 2002 and March-April 2006.

The Deep Adit cation chemistry is dominated by magnesium, suggesting that a magnesium-bearing mineral is dissolving within the mine workings or spoil heaps. In general, magnesium-bearing minerals are typical of more mafic lithologies, which tend to dissolve more rapidly than felsic minerals. Table 4-2 lists the rate constants for various minerals that have either been reported as gangue or accessory minerals or are likely to exist within the rock types known to be present at the site.

Table 4-2 Dissolution Rates of Various Minerals Under Low pH Conditions[1]

Mineral	Formula	Log k[2]	
Anorthite (Dolerite)	$CaAl_2Si_2O_8$	-3.5	**Fastest**
Hydrothermal Dolomite (Ore Zones)	$CaMg(CO_3)_2$	-3.76	
Augite (Diorite, dolerite)	$(Ca,Na)(Mg,Fe,Al)(Al, Si)2\ O6$	-6.82	
Hornblende (Diorite, tuffs)	$Ca_2(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH,F)_2$	-7	
Oligoclase (Tuffs, diorite)	$Na(90-70\%)\ Ca(10-30\%)\ (Al, Si)AlSi_2O_8$	-9.67	
Biotite (Tuffs, diorite)	$K(Fe,Mg)_3AlSi_3O_{10}(OH)_2$	-9.84	
K-spar (Tuffs, diorite)	$KAlSi_3O_8$	-10.06	
Albite (included as a plagioclase end member)	$NaAlSi_3O_8$	-10.16	
Chlorite (tuffs, especially Kilcashel Member)	$Mg_5Al_2Si_3O_{10}(OH)_8$	-11.11	
Muscovite (Sericite in Alteration Zones)	$KAl_3Si_3O_{10}(OH)_2$	-11.85	
Quartz (tuffs)	SiO_2	-13.4	**Slowest**

[1]   From Pilandri and Kharaka (2004)
[2]   k = Dissolution rate Constant

The most likely candidate for the Avoca site is the mineral penninite, a type of chlorite, with the composition $Mg_5Al_2Si_3O_{10}(OH)_8$, which is present in the chloritic tuff host rock and is closely associated with the banded sulfide ore (Gallagher and O'Connor, 1997). Biotite is another possible source of magnesium and reacts slightly faster than chlorite, but is less abundant and probably not is fine-grained as chlorite. In addition, the potassium concentrations are not in the correct stoichiometry if biotite is assumed to be the main source of magnesium.

The mix of minerals shown in Table 4-3 was obtained by assuming that all of the sodium present in the Deep Adit discharge was derived from dissolution of albite, all of the calcium was derived from dissolution of anorthite, all of the potassium was derived from the dissolution of sericite, and all of the magnesium from dissolution of penninite (chlorite).

Table 4-3 - Mineral Mixture Required to Produce the Major Ion and Aluminum Concentration for the Deep Adit (June 2003 Data)

Mineral	Moles	Al (molar)	Mg(molar)	K (molar)	Ca (molar)	Na (molar)
Chlorite (44.6%)[1]	0.00079	0.00157	0.00393	0	0	0
Sericite (3.4%)	0.00006	0.00019	0	0.00006	0	0
Anorthite (27.7%)	0.00049	0.00098	0	0	0.00049	0
Albite (24.3%)	0.00043	0.00043	0	0	0	0.00043
Total (molar)		**0.00318**	**0.00393**	**0.00006**	**0.00049**	**0.00043**
Total (mg/L)		**85.6**	**95.4**	**2.52**	**19.59**	**9.98**
Actual (6-5-03)		**84.34**	**95.4**	**2.52**	**19.59**	**9.98**

[1] Molar percent of the mineral

The resulting aluminum concentration from dissolving these minerals closely matches the observed aluminum concentration within the Deep Adit discharge (85.6 mg/L calculated vs. 84.3 mg/L measured). The proportion of plagioclase (if a single mineral) would be $An_{53}Ab_{47,}$ which corresponds to labradorite. However, the proportions are likely a result of the dissolution of several types of plagioclase rather than a single composition.

The Road Adit has a much greater proportion of calcium and slightly higher proportions of sodium and potassium (Figure 4-1), which suggest that other minerals may be dissolving and partially neutralizing the acidity in the ARD issuing from the Road Adit. The much lower aluminum concentrations within the Road Adit (34 mg/L vs. 84 mg/L for the Deep Adit) do not allow all of the calcium, magnesium, potassium, and sodium to derive from dissolution of silicate minerals alone, suggesting that the dissolution of dolomite $(CaMg(CO_3)_2)$ may be important. The lower aluminum within the Road Adit could also be the result of the precipitation of aluminum as a hydroxide, hydroxysulfate or as a coprecipitate with iron hydroxides or hydroxysulfates (such as jarosite).

Analyses of chemical oxygen demand (COD) and biological oxygen demand (BOD) within the Road Adit discharge conducted by the GSI in September and October 1995 (O'Suilleabhain, 1996), revealed that 14-17 mg/L BOD and 18-58 mg/L COD was present in the water. Apparently, the liner beneath the Ballymurtagh Landfill is somewhat leaky, resulting in the addition of landfill leachate to the underground workings drained by the Road Adit. The higher calcium, sodium, and magnesium may be due entirely to the landfill and have nothing to do with the neutralizing minerals being dissolved by the ARD in West Avoca. Therefore, a calculation to determine the minerals dissolved by the Road Adit ARD such as was done for the Deep Adit in Table 4-3, is probably not appropriate.

The Avoca River also appears to have the capacity to neutralize ARD, as the pH of the water in the river very quickly recovers a short distance down-stream from the adit discharges (based on April 2007 pH measurements taken in the Avoca River down-gradient from the Deep Adit discharge). As the alkalinity in the Avoca is very low (<20 mg/L as $CaCO_3$), the source of the neutralization is unknown. Carbonate

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minerals such as calcite are not known to be present within the Avoca River catchment. Silicate minerals, while present within the sediments should not react fast enough to neutralize the ARD.

4.3.2 Adsorption

As discussed previously, the adsorption of metals is enhanced at high pH due to the positive charge of the metals in solution and the negative surface charge of clay minerals and manganese dioxide. However, if the pH becomes too high, then neutral or negative aqueous species begin to become more important and adsorption tends to start to decrease. The result is a "window" in which adsorption is maximized (usually between a pH of 6 and 8 su). The neutralization of the ARD to within the optimum adsorption range results in adsorption of metals onto sediments and removal from solution.

The adsorption capacity of the metals varies depending on the pH, presence of competing ions, type, and proportion of minerals and surface coatings in the sediment, and the grain size of the sediment. In general, the adsorption capacity for metals is enhanced at near neutral pH, in the absence of competing ions (such as calcium), and when the sediment is fine grained and contains a high proportion of manganese dioxide, iron oxyhydroxides (i.e. amorphous ferric hydroxide), organic matter, and clay minerals.

4.3.3 Precipitation/Coprecipitation

Coprecipititation of metals and arsenic with iron hydroxysulfate minerals such as schwertmannite and jarosite is likely occurring within the mine workings. Based on reaction 4-5, the oxidation of one mole of pyrite by oxygen results in the production of two moles of sulfate. However, the molar SO_4^{-2}/Fe ratio in the adit discharges is much greater than two, suggesting that iron is being removed from solution within the mine workings. In fact, between November 2001 and January 2002, the iron concentration within the Deep Adit decreased by an order of magnitude and has remained around 10-20 mg/L through at least June of 2003. The reason for the decrease is unknown, but may be related to precipitation of an iron oxyhydroxide phase, as sulfate concentrations showed no obvious declines over the same time period. Therefore, a decrease in pyrite oxidation does not appear to be the reason for the decreasing iron concentrations.

The high sulfate concentrations relative to iron may also be due to the oxidation of other metal sulfides such as galena or sphalerite. However, based on the lead and zinc concentrations in the adit discharges, the concentrations of lead and zinc are not high enough to balance the sulfate present.

Precipitation of an amorphous iron oxyhydroxide phase with coprecipitation of copper, lead, zinc, and other metals is likely an important control on metals concentrations in the Avoca River where the adit water first mixes with the river water. Deposits of "yellow boy" iron oxyhydroxide and iron sulfates precipitates are

present at the point where the adit discharges enter the Avoca River. In addition, most sediments in the Avoca River are coated with red iron oxyhydroxide precipitates.

4.3.4 Dilution

Dilution can result in large decreases in aqueous metals concentrations, when the volume of dilution water is large. Using combined average flow for the two adits of 34.8 l/s, a copper concentration of 1 mg/L for the adits and a flow of 1,087 l/s for the Avoca River results in an in River copper concentration of 0.05 mg/L (assuming 0.018 mg/L copper and a flow of 1,052 l/s in the Avoca River up-gradient of the adits). Dilution ranges from a low of about 80 in July (Avoca low flow) to 800 in January (Avoca high flow).

The effect of dilution on pH is complicated by the buffering that occurs due to the formation of weak acids, such as bicarbonate and by adsorption of protons (H^+) onto solid surfaces. In addition, pH is in log units, such that a dilution of 1000 (using neutral water) would be required to change the pH from 3 to 6 (neglecting buffering).

4.4 Preliminary Mass Balance Evaluation and Interpretation

An estimate of the ARD contribution of the adits (vs. diffuse flow ARD contributions) to the Avoca River was made for use in selecting remedial alternatives and determining the effectiveness of point source (adit) discharge. A mass balance approach was used to estimate the proportion of the metals load which is due to diffuse (nonpoint source) flow. The following mass balance equation was used:

$$Q_{Dif}C_{Dif} = Q_DC_D - Q_UC_U - Q_{Adits}C_{Adits} - M_{attenuated} \tag{4-19}$$

Where,

$Q_{Dif}C_{Dif}$	=	The mass of metal contributed by diffuse flow
Q_DC_D	=	The mass of metal measured down-gradient of the mines
Q_UC_U	=	The mass of metal measured up-gradient of the mines
$Q_{Adits}C_{Adits}$	=	The combined mass of metal measured at the two adits
$M_{attenuated}$	=	The mass of metal attenuated (precipitated or adsorbed)

Assuming that the mass of attenuation (precipitation) is zero, the proportion of the mass contributed by the adits is given by:

$$\text{Percent of Mass Contributed by Adits} = (Q_{Adits}C_{Adits} / Q_DC_D - Q_UC_U) * 100\% \tag{4-20}$$

Using the flows and metals and sulfate concentrations from the August 23, 1995 data, results in the loadings provided in Tables 4-4 through 4-7. The August 1995 data were chosen because the data set was fairly complete and the data was collected during low flow when a greater fraction of the flow would consist of diffuse flow.

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Table 4-4 Metals Loading in the Avoca River at Whites Bridge (August 23 1995 Data)[1]

Parameter	Concentration (mg/L)	Loading (kg/yr)
Iron	0.105	3,484
Aluminum	0.1	3,318
Copper	0.005	166
Zinc	0.121	4,015
Lead	0.125	4,148
Sulfate	11.4	378,277
Flow (l/s) = 644		

[1] O'Suilleabhain (1996)

Table 4-5 Metals Loading by the Deep Adit to the Avoca River (August 23, 1995 Data)[1]

Parameter	Concentration (mg/L)	Loading (kg/yr)
Iron	103.6	33,808
Aluminum	119.8	39,095
Copper	0.694	226
Zinc	64.7	21,114
Lead	1.283	419
Sulfate	1429	466,332
Flow (l/s) = 10.348		

[1] O'Suilleabhain (1996)

Table 4-6 Metals Loading by the Road Adit to the Avoca River (August 23, 1995 Data)[1]

Parameter	Average Concentration (mg/L)	Loading (kg/yr)
Iron	143	42,143
Aluminum	64.22	18,926
Copper	0.972	286
Zinc	26.36	7,768
Lead	0.59	174
Sulfate	1633	481,252
Flow (l/s) = 9.345		

[1] O'Suilleabhain (1996)

Table 4-7 Metals Load in the Avoca River at Coalyard (August 23, 1995)[1]

Parameter	Concentration (mg/L)	Loading $(Q_D C_D - Q_U C_U)$(kg/yr)	Deep Adit + Road Adit (kg/yr)	Percent Adits
Iron	2.293	50,546	75,951	150.3%
Aluminum	3.302	72,788	58,021	79.7%
Copper	0.185	4,078	513	12.6%
Zinc	1.482	32,669	28,882	88.4%
Lead	0.125	2,755	593	21.5%
Sulfate	60.5	1,333,642	947,584	71.1%
Flow (l/s) = 699				

[1] O'Suilleabhain (1996)

The results are consistent with the mass balance performed in the pilot plant project (Unipure 2006) which concluded that the majority of the loading is contributed by the adits. For aluminum and zinc, the adits contribute 80 percent and 88 percent of the

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load in the Avoca. These values are consistent with previous estimates (see
Section 3.4) that diffuse flow accounts for 10 to 20 percent of the metal load in the
Avoca River. However, as shown in Table 4-7, the amounts of copper and lead
accounted for by the adits is much lower than for aluminum, zinc, and sulfate (see
Sections 4.5.2, 4.5.3, and 4.5.4 for additional discussion). The amount of iron
contributed by the adits is calculated to be above 100 percent. Clearly some iron is
being removed (precipitated) in the River. The variability in these values clearly
indicate that additional evaluations are needed (see Section 5.1).

4.5 ARD and Metals Fate and Transport at the Avoca Site

4.5.1 ARD Generation at the Avoca Site

A summary of the primary ARD sources at the Avoca site include the following
categories:

- Tailings
- Spoils Heaps
- Pit Walls
- Unsaturated Mine Workings
- Saturated Mine Workings

The categories listed are the sources that result in the generation of ARD.

Tailings

The Shelton Abbey tailings are relatively low in metals compared to the mine spoils.
However, based on the low pH high conductivity water ponded at the base of the
tailings, ARD production is taking place. Despite the fact that a large fraction of the
sulfide minerals were extracted from the tailings, the volume of material is large and
the grain-size small, promoting pyrite oxidation. The tailings ponds are not properly
capped, allowing oxygenated surface water and precipitation to infiltrate into the
impoundment. The collapse of the surface drainage culvert beneath the road has
resulted in a perched pond on top of the impoundment. The pond water has a neutral
pH and appears to contain dissolved fulvic acid based on the straw yellow color of
the water and the presence of dark brown-black fine sediment on the bottom of the
pond. The water is likely depleted in oxygen and may not represent a significant
source of oxygen to the underlying tailings. Saturating the tailings pore spaces with
oxygen depleted water could inhibit diffusion of oxygen into the impoundment. Some
tailings caps are designed using organic matter to provide an oxygen barrier as
opposed to a water barrier.

In some areas, such as in various areas along the outside of the berm, tailings are
directly exposed at the surface and are actively eroding. These tailings are under ideal
conditions for pyrite oxidation, namely alternating wetting and drying. The extent to
which a reaction such as pyrite oxidation proceeds is determined by the limiting
reagent. Based on equation 4-5, the oxidation of pyrite requires both oxygen and

water. Saturated tailings contain abundant water but very little oxygen and dry tailings contain abundant oxygen (if near or at the surface) but very little water. Under each of these circumstances, pyrite oxidation is not favored due to the limiting reagents. Alternating wetting and drying cycles provide both abundant water and oxygen and represent a worse case scenario for pyrite oxidation by reaction 4-5.

The normal progression of the water quality within a tailings impoundment is from process water (originally contained in the tailings from milling) to neutralized ARD to low pH ARD (USEPA, 1994). The pyrite oxidation of most tailings ponds and spoil heaps begins, via reaction 4-5 until the pH reaches a critical threshold, somewhere around 3 to 3.5 su, at which point iron hydroxide becomes soluble, resulting in the production of ferric iron (the reverse of reaction 4-7). The ferric iron produced then reacts with fresh pyrite by reaction 4-8, which produces acidity much more rapidly than by reaction 4-5. As no pore water or direct spring analyses are available for the tailings to measure the pH, it is difficult to determine if the pyrite is oxidized by reaction 4-5 or 4-8. The pH of the pond at the base of the tailings berm adjacent to the Avoca River was 3.7 su in April 2007, which would suggest that pyrite oxidation by oxygen is the dominant reaction. However, the pond water may have been neutralized to some extent or diluted by other water sources.

Knowing the relevant pyrite oxidation mechanism is very important when considering remediation alternatives. Reaction 4-5 is normally controlled by limiting either water or oxygen (usually via capping or flooding, respectively). Limiting reaction 4-8 requires pH adjustment, such as liming the tailings. Williamson et al. (2006) found that increasing the pH of the water in contact with pyrite from 2 to 4 su decreases the pyrite oxidation rate by five orders of magnitude (100,000 times).

Spoil Heaps

The spoil heaps have an estimated volume of about 1.5 million m^3, contain significant pyrite, are generally fine grained or have a fine-grained matrix, and are subject to alternating wetting and drying conditions. The conditions are optimal for ARD production, which is evident from the limited seep water quality data for spoil heaps SP20 (Mount Platt) and SP2 (Tigroney West) (Tables 2-9 and 2-14) and the humidity cell testing conducted by Sapsford and Williams (2005) on SP34B (West Avoca). Iron and aluminum concentrations on the order of 1,000 mg/L, sulfate concentrations up to 12,000 mg/L and pHs as low as 2 su have been measured in spoils leachate. Given the low pH values and the very high iron concentrations, it is apparent that significant pyrite oxidation by ferric ion (equation 4-8) is occurring within the spoils.

O'Suilleabhain (1996) estimated vertical hydraulic conductivities within the spoil heaps of 10^{-1} to 10^{-3} cm/s, which the author considered to be fairly low. However, as the values were estimated using a combination of falling head permeameter and grain-size analyses, the permeability estimates are likely underestimated. Flow is most likely controlled by preferential flow pathways along coarser material.

As the spoil heaps sometimes overlie collapsed mine workings (SP5, SP8, SP10, and SP28 are the known examples), leachate from the piles could be conveyed directly into the mine workings, adding to the load of the Deep Adit. In addition, the low pH of the water could dissolve iron hydroxide within the workings creating ferric iron, which aggressively oxidizes pyrite within the workings. Ferric iron oxidation of pyrite can even occur in areas of the mine which are low in oxygen, as long as a constant supply of low pH ferric iron-containing water is supplied. Under such circumstances, ferrous iron would accumulate until oxygenated conditions are reached where bacteria catalyze the oxidation of the ferrous iron back to ferric iron.

Spoil heaps which are not in communication with the underground workings can contribute ARD to the open pits (and ultimately the underground workings), surface drainages, and to the shallow groundwater (within the fractured upper surface of the bedrock and thin alluvium). The ARD would then enter the Avoca River through tributaries and interflow. The contribution of the spoil heap leachate to the river is likely to occur in pulses following storm events and would not be detected during low flow sampling.

Pit Walls

The pit walls contain significant concentrations of sulfides and metals (in some cases concentrations are ore grade) and are subject to wetting and drying conditions. Evidence of staining, resulting from oxidation of pyrite to iron oxyhydroxides is evident on many of the pit walls.

The surface area of the sulfides is relatively low, which would slow the oxidation of the sulfides. However, given the large areas of sulfide-bearing pit walls present at the site, a contribution is probably being made to the quality of the pit lakes, and ultimately the underground workings, but it is less than for the spoils or the mine workings located above the water table.

The water quality of pit ponds at many sites can often be attributed to wall rock interactions with surface water. However, the Cronebane and East Avoca Pits ponds not only have inputs of ARD from the walls, but also from adit discharges and from spoils leachate, which does not allow for the contribution of the pit walls to be separated from the spoils seepage and adit inputs.

Unsaturated Underground Mine Workings

Mine workings which are above the water table, sometimes referred to as "above-drainages," often have high concentrations of oxygen due to the ventilation systems provided to allow the miners to work underground. The oxygen, combined with water provided in the form of adit drainages and humidity in the air allows for rapid pyrite oxidation. Jerz and Rimstidt (2004) found that pyrite oxidation by moist air is much more effective at oxidizing pyrite than flowing water (due to the presence of both oxygen and water). Jerz and Rimstidt (2004) determined that the rate of pyrite oxidation within above-drainage workings is controlled by the relative humidity.

The rapid rate of pyrite oxidation within the above-drainage underground workings at the Avoca site is evident in the extremely poor water quality issuing from the Cronebane Shallow and Intermediate adits (Tables 2-19 and 2-20). Iron and aluminum concentrations above 2,000 mg/L, copper concentrations around 50 mg/L, zinc concentrations from 180-440 mg/L, sulfate of 6,000 to 22,000 mg/L and pH values of about 2.2 su were measured in 1993. The Intermediate adit alone, assuming an estimated flow rate of 2 l/s provides nearly 100 percent of the zinc load and 7.5 percent of the lead of the Deep Adit, while over 100 percent of the iron, aluminum, copper, and sulfate can be accounted for from this single adit input. Obviously, the parameters that are input by the Intermediate Adit at a greater loading than the Deep Adit output are being removed within the workings or discharges at another point. In addition, more recent measurements (fall of 2005) indicate that water quality from the Cronebane Shallow and Intermediate adits has improved.

Assuming the 1993 analyses are still valid, the discharges from the above-drainage underground workings appear to be very important and have significant implications for the remediation strategies considered for the site. Treatment of the Intermediate and Cronebane Shallow adits before being allowed to re-enter the underground workings could significantly reduce the rate of pyrite oxidation within the lower workings by essentially eliminating the rapid ferric iron oxidation of pyrite.

Saturated Underground Mine Workings
In general, completely saturated "below-drainage" mine workings are not nearly as important sources of ARD as are unsaturated workings. The oxidation of pyrite, under such conditions is limited by the amount of oxygen dissolved in the water, which can be quickly consumed by the pyrite but can not be quickly replaced due to slow diffusion of atmospheric oxygen.

Skousen et al. (2006) in a study of several coal mines in the eastern United States found that after the first few mine volumes of water passes through the system the water becomes much less acid or even net alkaline.

4.5.2 Copper

Dissolved copper is likely produced within the ARD as a result of the oxidation of chalcopyrite, as shown in reaction 4-12. The reaction of chalcopyrite is generally slower than for pyrite due to the rate limiting oxidation of sulfide to sulfate. Gerson and Thomas (2006) performed humidity cell testing on samples of pyrite and chalcopyrite and found that the pH of the pyrite samples reached values less than 2.5 su, while the chalcopyrite samples remained above 5 su.

The copper produced via reaction 4-12 may be coprecipitated with jarosite or schwertmannite within the mine workings (based on the loading of the Intermediate Adit) in response to partial neutralization of the ARD by silicate minerals such as chlorite and plagioclase. Some of the remaining copper that reaches the Avoca River via the adits (Deep Adit and Road Adit) is coprecipitated with iron oxyhydroxides in

response to mixing with higher pH water. The remaining copper discharges to the Avoca River and is adsorbing mostly to organic matter and manganese dioxide and clay minerals within the fine grain-size fraction of the sediment. As the pH of the river increases down-gradient, the adsorption of copper increases resulting in lower dissolved concentrations. The coprecipitated and adsorbed copper would act as a secondary source once the ARD inputs are removed or eliminated, which could prolong the recovery of the river.

Copper derived from spoil heaps and present within interflow would be at least partially neutralized by the fractured bedrock, and alluvium through which it flows. The same reactions would take place as for the adit discharges, except to a greater extent, due to the greater residence time between the silicate minerals and the interflow and the higher surface area of the alluvium as compared to the walls of the underground workings. The initial jarosite precipitation (with copper coprecipitation) would occur as coatings on soil grains and cement between grains. As the interflow pH increases, coprecipitation of copper with iron oxyhydroxides would occur, followed by adsorption onto manganese dioxides, clays, and organic matter. The Avoca valley contains peat beds in places (O'Suilleabhain, 1996), that if present within the flow path of the interflow would have a high capacity for adsorbing copper. Again, the adsorbed and coprecipitated copper would likely act as a secondary source should the spoil heaps be remediated.

4.5.3 Zinc

Zinc is dissolved during ARD production by the oxidation of sphalerite, as shown in reaction 4-11. Zinc is subject to the same series of attenuation mechanisms as copper (coprecipitation with jarosite, coprecipitation with iron oxyhydroxides, and adsorption). However, because zinc is more mobile than copper the attenuation reactions are not as efficient, leaving more zinc in solution. The net result is that the longer the transport distance, the greater the ratio of dissolved zinc to copper within the interflow will become.

4.5.4 Lead

Lead is produced by the oxidation of galena, as shown in reaction 4-13. The amount of lead dissolved into the ARD is much lower than for zinc and copper, despite the fact that lead concentrations were usually higher in the spoils, tailings, and wall rock than for zinc and copper. The highest known dissolved lead concentration measured to date was 5 mg/L in the Cronebane Shallow Adit (Table 2-20). The relatively low lead concentrations (compared to the other metals) is likely the result of slower oxidation kinetics for galena than for the other sulfides.

Lead undergoes the same attenuation reactions as for copper and zinc. Lead is less mobile than even copper and would likely be attenuated faster than copper and zinc. Given the lower initial concentrations and the greater attenuation of lead compared to the other metals, lead is unlikely to enter the Avoca River via interflow unless the

spoil heaps are close to the river, such as those in Tigroney West and SP39 in West Avoca.

4.5.5 Arsenic

Arsenic is predicted to dissolve via reactions 4-9 and 4-10. The fact that arsenic is present in relatively high concentrations within the wastes (24-1482 mg/kg with an average of 500 mg/kg) and significant arsenic is not present in the secondary sulfate phases (83 mg/kg at the ore bins in West Tigroney) or ARD (<0.05 mg/L in the Deep Adit and Road Adit) at the Avoca site suggests one or more of the following:

1. Arsenic is not present to a significant degree in the pyrite.

2. Arsenopyrite is coarsely crystalline (which slows the rates of reaction), is enclosed within other minerals, or is otherwise unavailable for reaction via equations 4-9 and 4-10.

3. Dissolved arsenic is attenuated soon after release from the source materials.

The reason that arsenic has not been detected in the ARD could be determined by performing an electron microprobe analysis, as described in Section 5 (Data Gaps).

Section 5
Data Gaps and Recommendations

The following data gaps were determined during the preparation of the CSM, and represent what is believed to be the most useful activities for understanding the site and for developing remedial alternatives.

5.1 Water/Gas Analyses
5.1.1 Pits

Water samples should be collected from the Cronebane and East Avoca pit ponds and analyzed for field parameters (Eh, pH, conductivity, DO, and temperature), metals (including iron speciation), arsenic, and major anions and cations. Analysis of the pit water is important, as this water appears to be in communication with the underground workings and is a likely source for the Deep Adit discharge.

5.1.2 Adits

The adits should be analyzed for the same set of parameters as the pit ponds. The adit discharges can be much more easily managed if the flows can be captured and treated before being allowed to infiltrate into the ground and re-enter the underground workings. The water quality will be required to determine the relative importance of the discharge and to evaluate treatment options. Analyses of the following adits should be performed (if flowing):

- Kilmacoo Adit
- Madam Butler's Adit
- Intermediate Adit
- Cronebane Shallow Adit
- Wood Adit
- Ballygahan Adit
- Spa Adit

Iron speciation of the waters using a field portable spectrophotometer would also be useful, as iron Fe^{+3}/Fe^{+2} is a more accurate and direct measure of the oxidation-reduction potential (Eh) than using a redox probe. The presence of high concentrations of ferric iron would suggest that the adit water would be highly reactive with any pyrite in which it comes into contact.

5.1.3 Seeps

The most important seeps identified to date are;

- At the base of Mount Platt
- Shelton Abbey berm and pond at the base of the impoundment
- Ballygahan (adjacent to the adit)
- Seasonal seeps from spoil heaps and pit walls

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The seeps should be sampled for the same set of parameters as for the adits and pit ponds.

5.1.4 Avoca River and Tributaries

The Avoca River and tributaries should be sampled for the same set of parameters as for the other water samples, with the possible exception of iron speciation. The water sampling locations should be collected at the same time and in the same place as the flow measurements are made.

The tributaries to be sampled include:

- Red Road stream
- Sulphur Brook
- Vale View stream
- Aughrim River

The Avoca River should be sampled at regular intervals from above White's Bridge to the Avoca Bridge. Samples should also be collected at regular intervals across from Shelter Abbey tailings.

5.1.5 Wells/Lysimeters

Wells

In order to determine the quality of the diffuse flow into the Avoca, relatively shallow wells would need to be installed in selected areas where interflow or baseflow is believed to be occurring. The results of the synoptic flow sampling and loading analysis may indicate a specific location or locations where the majority of the diffuse flow is entering the Avoca (such as where the bedrock is fractured or faulted of where the alluvium is thicker). The important areas could then be targeted for well installation.

Both water quality and head measurements could be obtained from the proposed wells, providing an independent measurement of metals loading to the Avoca River. The same set of parameters as for the other locations should be analyzed, for the possible exception of iron speciation (the pH may be too high to have ferric iron present). In the field, the decision to perform or not perform iron speciation could be made on a case by case basis once the pH values are measured. For example, iron speciation could be performed on all water samples with a pH of less than 4 su.

Wells should also be installed at the Shelton Abbey Tailings deposit to determine the water quality within the saturated zone and the groundwater flow directions.

Homeowner wells in the East and West Avoca mine areas should be located. In accessible, water samples at selected wells should be collected and analyzed.

Lysimeters

Lysimeters should be installed within the Shelton Abbey Tailings to provide a direct measurement of the water quality of the pore fluids within the unsaturated zone of the tailings. In particular, the pH and ferric iron content will be important for determining if pH adjustment (i.e. lime addition) or ferric iron removal (i.e. apatite addition) would be a necessary component of the tailings remediation. Lysimeters should be installed within each of the zones (oxidized, reduced, and reactive transition) if present.

Soil Gas Probes

Measurement of the oxygen concentrations within the tailings could be used to determine the type of cap to be used. The need for direct measurement of oxygen has been illustrated by several investigators (Eberling and Nicholson, 1996; Helgen et. al, 2000). Pantelis and Ritchie (1991) showed that the heat of reaction due to pyrite oxidation can produce thermal convection currents in tailings piles that accelerate oxygen transport. The process has been shown to be seasonal by Hockley et al. (2000), with more pronounced convection in the winter when the temperature of the tailings are higher than ambient temperatures. Increases in barometric pressure have been found to compress the pore gas within tailings piles, which causes the oxygen profile to shift downward.

Several methods are available for the direct measurement of oxygen diffusion through a soil cover (Eberling and Nicholson, 1996; Helgen et. al, 2000). According to Helgen et al. (2000) the changes in oxygen occur very near the surface, with stabilization at greater depths. Therefore, a cost-effective sampling procedure would be the use of a soil gas probe. Helgen et al. (2000) describe the procedure in detail. A soil gas probe with a retractable sampling port in the tip is first driven into the tailings to the desired depth using a slide hammer or sledge (the AMS soil vapor probe comes with an electric rotary hammer). Oxygen concentrations are then measured by lowering the inlet tube of an oxygen meter with sampling pump to the sampling port. Oxygen concentrations and temperatures should be measured at intervals of 0.75 meters to a total depth of about 4 meters, as the probe is advanced. Oxygen and temperature of the soil gas as well as the outside barometric pressure should be measured. Measurements should be taken both when ambient temperatures are hot (summer) and when temperatures are cool (winter).

5.2 Flows

5.2.1 Avoca River

Flow measurements in the Avoca River will be critical for determining the loading of metals and to target specific areas for remediation. Several locations between Whites Bridge and Avoca Bridge will be required. The closer the flow measurement spacing, the more accurately the important inflow locations can be determined using a mass balance approach.

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5.2.2 Avoca River Tributaries

The measurement of flows in the tributaries are necessary to determine the mass/water balance in the system.

5.2.3 Adits

Flows should be determined for the same adits for which water quality samples will be collected.

5.3 Spoil Heap Analyses

Analyses of the spoil heap materials for metals and arsenic will be required in order to further evaluate the source potential of each heap and to update the human health and ecological risk assessments.

Both surface and subsurface (test pit or borehole samples) samples should be collected in order to determine variations with depth, such as zonation within the piles. Subsurface samples will be particularly important for Mount Platt.

5.4 Tailings Analyses

The characteristics of the tailings material should be determined by use of cores collected during well installation or possibly from test pits. The uniformity of the tailings, in terms of physical (i.e. grain size, sorting, staining, etc) and chemical properties (arsenic and metals analyses) should be determined. Acid generating and neutralization potentials (acid-base accounting) should also be determined.

5.5 Hydrogeology

Present gaps in the understanding of groundwater hydraulics relate to diffuse groundwater discharges along the Avoca River, and ZOCs of the mine system. To provide verification on water balance estimates, discharges and ZOCs, monitoring of groundwater levels are needed, which would require the installation of small-diameter wells throughout the mining area.

To verify the conceptual model of flow mechanisms, wells would have to be installed in both shallow and deep bedrock, as well as the overburden along the river. Wells near the open pit areas would be bedrock wells only. For ZOC delineation, some wells should be located closer to the N-S trending faults that cut through the ore bodies.

The wells that were drilled in East Avoca in the mid-1990s have been located and are no longer usable. However, if accessible, existing homeowner wells should be located in the East and West Avoca mine areas and water levels measured.

It is recognized that installation of nested wells for the stated objectives would be costly, and is not factored into the scope or cost of the present feasibility study. One nested set of wells in "shallow" and "deep" bedrock may cost upwards of Euro 10,000 -

15,000 (including geophysical logging and hydraulic testing). The need for verification of ZOC estimates is probably a lower priority than verification and understanding of diffuse discharges. The wells along the river are therefore considered to be more important. Three clusters of wells to three different depths would be needed at a minimum at locations to the east of the river and southeast of the East Avoca mine. One similar cluster might be warranted downgradient of the Shelton Abbey tailings dam.

On the west side of the river, similar conclusions apply, and the existing wells associated with the Ballymurtagh landfill should be integrated into site monitoring activities. The latter could even be incorporated during the course of the feasibility study.

As previously discussed (Section 5.2.3), flow measurements from adits should continue. This includes adits in the East Avoca and Cronebane open pits.

Flow monitoring of the Avoca River downstream of the mines is recommended. A hydrometric gauging station downstream of the confluence between the Avoca and Aughrim river would serve multiple purposes, including both Avoca and WFD-related needs. Flow monitoring of the tributaries should also be conducted.

5.6 Other Activities

5.6.1 Aerial Survey of Current Tailings Topography

An aerial survey of the tailings topography should be conducted to determine the tailings and spoil pile volume and for remedial alternative/design purposes.

5.6.2 Tracer Study

A tracer study could be performed to obtain accurate flow measurements for the Avoca River, particularly in areas where significant underflow (flow beneath the bed of the river within the alluvium) is suspected. The hydrochemical work reported by O'Suillebhean (1996) also raises the question of residence times of water in the underground mine workings. Both the Deep and Road adits respond within a few days to rainfall events, yet the quantities of ARD suggests that residence time would have to be 'considerable'. It is expected that water flow through the mine system is complex, and that the water that discharges is a mix of waters of different ages. Tracer testing may be warranted to examine travel times (and related changes in water quality) through the mine system (focusing on the Deep Adit). Tracers would be "injected" in the open pit areas near Mount Platte and monitoring would be carried out at known adit discharge points.

5.6.3 Electron Microprobe (EMP) Analyses

EMP analyses can be used to determine the trace element composition and morphology of the pyrite and other sulfides within the spoils and tailings. Photographs at up to 90,000 times magnification can be obtained, as well as "spot"

analyses of individual grains as small as 1 micron in diameter. The morphology of the pyrite may help to explain why some wastes are more acid generating than others, while the trace element composition could help to explain why arsenic is so immobile. The forms of metals, such as copper, zinc, and lead can also be determined and related to leachability and bioavailability. CDM has an agreement with the University of Colorado to rent their Joel 8600 Superprobe, which has wavelength dispersive spectrometers capable of quantitatively analyzing light elements such as oxygen.

Section 6
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Appendix A
General Geochemistry:
Copper, Zinc, Lead, and Arsenic

Appendix A
General Geochemistry:
Copper, Zinc, Lead, and Arsenic

A1 Copper Geochemistry

Copper exists in oxidation states of 0 (metallic copper), +1, and +2. Only monovalent (Cu^+) and divalent (Cu^{2+}) oxidation states exist in the aqueous environment. At pH values less than 7, Cu^{+2} is the dominant form of divalent copper in solution, while at pH values between 7 and 13, $Cu(OH)_2^0$ predominates. $Cu(OH)_4^{-2}$ is important above a pH of about 13. $Cu(OH)_3^-$ and $Cu(OH)+$ are of minor importance, representing less than 10 percent of the divalent copper at all pH values.
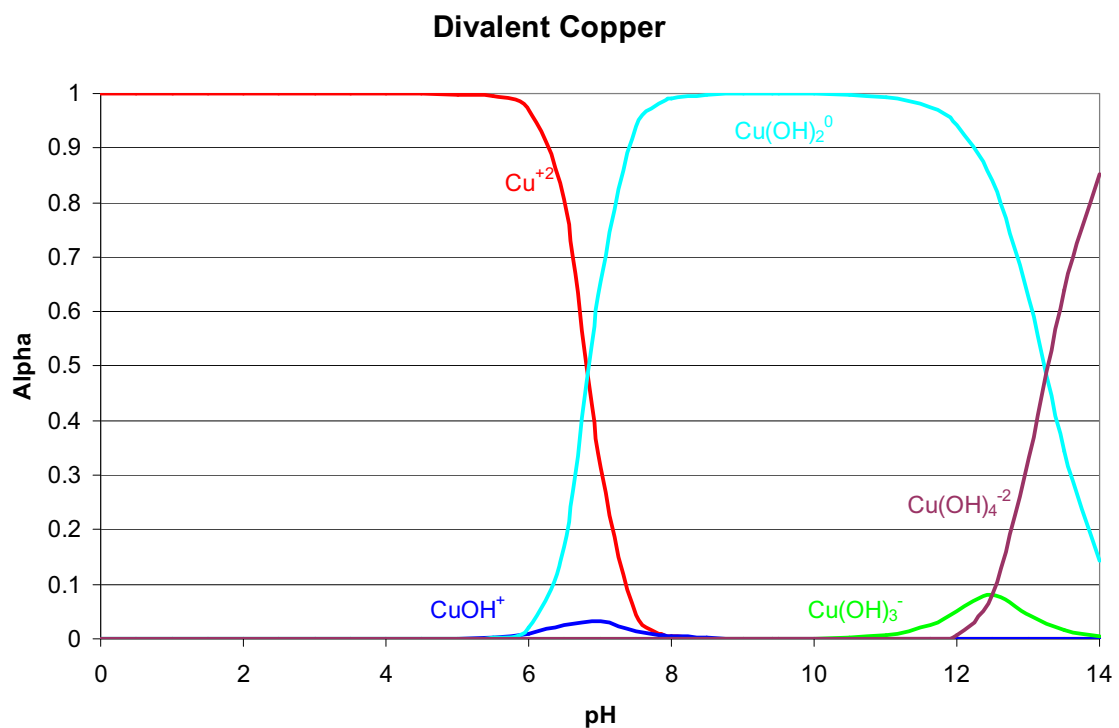
Divalent Copper

Figure A1-1 – Divalent Copper Speciation as a Function of pH
(alpha is the fraction of the total dissolved divalent copper consisting of the given species).

The Eh-pH diagram shown in Figure A1-2 indicates that monovalent copper is present only within a very narrow stability range due to the formation of metallic copper (at Eh < 0.1 volts).
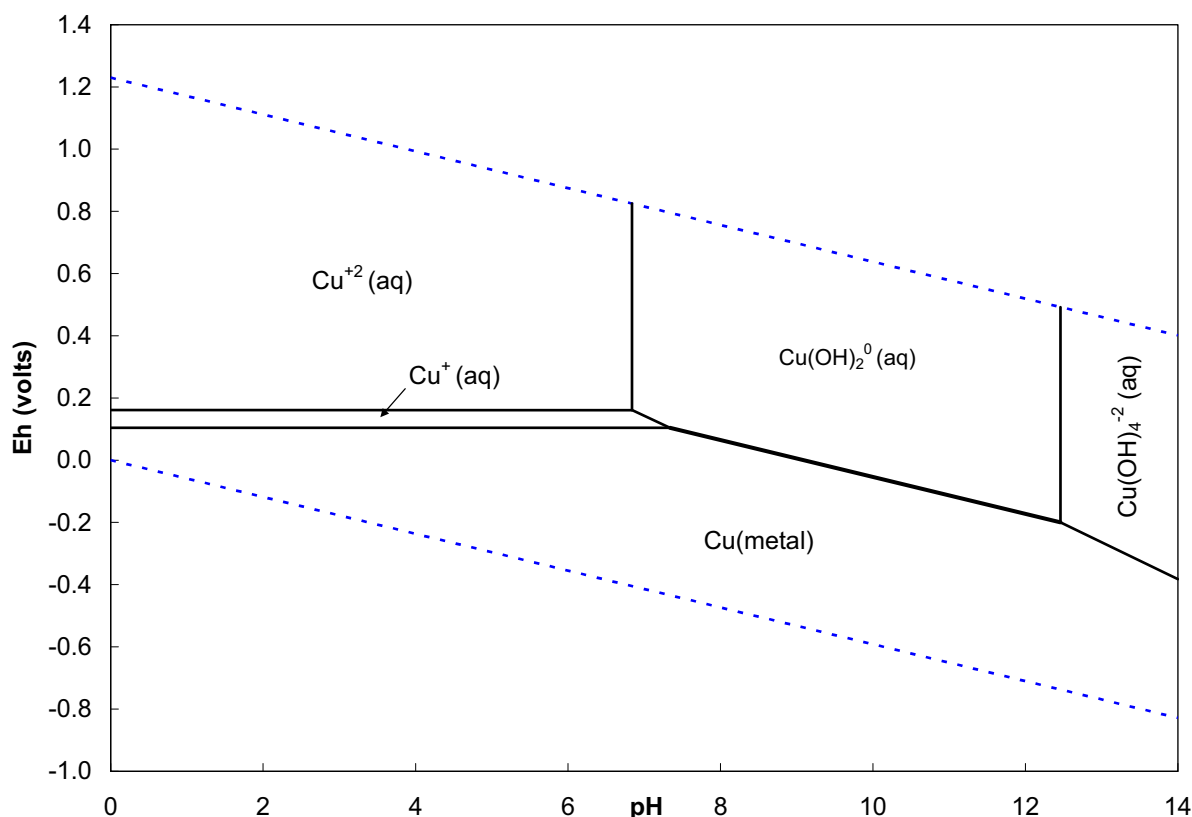
Figure A1-2 - Eh-pH Diagram for the System Cu-O-H at 25°C and 1 atm.
Aqueous Cu activity = 1x10^{-7} M (0.006 mg/L) for equilibrium with Cu(metal).

When total copper concentrations are higher than 0.006 mg/L (the value used to construct Figure 2), the copper metal field expands and completely consumes the monovalent copper field. However, in natural waters other ions are present that can complex Cu^+, such as chloride, which can form important species such as $CuCl^0$, $CuCl_2^-$, and $CuCl_3^{-2}$ which expand the stability field of monovalent copper. Matocha et al. (2005) found that only 28 percent of monovalent copper was present as the free ion (Cu^+) in the presence of as little as 71 mg/L chloride.

In general, divalent copper complexes with sulfate and bicarbonate do not represent a significant fraction of the dissolved copper, except under unusual circumstances, such as within acid rock drainage (sulfate concentrations are typically high) where the copper-sulfate complex ($CuSO_4^0$) can be important.

Copper Pure Phase Minerals

Divalent copper forms hydroxide, hydroxycarbonate, and possibly cupric ferrite ($CuFe_2O_4$) pure phase minerals, while zero-valent copper forms metallic copper. Monovalent copper phases form mainly within a sulfide environment, where minerals such as covellite (Cu_2S) can form.

Table A1-1 Solubility of Copper (II) Hydroxide (Cu(OH)$_2$) vs. pH (Alkalinity = 0 mg/L)

pH (su)	Copper Solubility (mg/L)[1]
4	402,000
5	4,020
6	41
7	1
8	0.6
9	0.6
10	0.6

[1] Calculated using PHREEQC under oxidizing conditions

Copper hydroxide only forms at high pH values, which means the aqueous concentrations of copper can be quite high when the pH is less than 7 (see Table 1). The solubility of copper increases by roughly 100 times for every unit decrease in pH (in the pH range 4-6). However, the correlation is not exact due to the formation of copper hydroxide complexes (see Figure 1). The complexing effect is most noticeable at pH values above 7. In fact, the decrease in copper solubility that would be expected as the pH increases does not occur due to the formation of copper hydroxide complexes.

Lindsay (1979) claimed that cupric ferrite ($CuFe_2O_4$) is a very stable phase and is a likely control for aqueous copper concentrations under oxidizing conditions. However, the results of PHREEQC modeling (shown in Table A1-2) indicate that the predicted concentrations of copper are lower than observed in natural waters and acid mine drainages.

Table A1-2 Solubility of Cupric Ferrite (CuFe$_2$O$_4$) vs. pH (Assuming equilibrium with FeOOH

pH (su)	Copper Solubility (mg/L)[1]
3	0.00001
4	0.000000083

[1] Calculated using PHREEQC under oxidizing conditions

Copper is more likely controlled by an amorphous coprecipitate with ferric hydroxide, as discussed in the next section.

Under high pH and alkaline conditions, hydroxycarbonate phases can form ($Cu_2(OH)_2CO_3$) such as proposed by Carvallaro and McBride (1978). Such a phase is more likely to form within carbonate aquifers and in alkaline soils dominated by calcite or other carbonate minerals.

The control of copper by a pure phase solid will only occur under two circumstances;

1. If a copper phase is released at a site and does not dissolve completely

or,

2. If the soil particles become saturated with adsorbed copper to the point where the solution concentration rises to the solubility limit of a copper phase under the given conditions

Waters in which the dissolved copper concentration is less than the solubility limit of the pure phase copper compounds suggests that aqueous copper concentrations are controlled by either coprecipitation or adsorption.

Copper Coprecipitation

In addition to forming pure compounds, lead can also precipitate as a trace element within other phases, most commonly with iron hydroxide. The general reaction is as follows:

$$2x\ Fe^{+3} + 3\text{-}3x\ Cu^{+2} + 6\ OH^- \rightarrow Fe_{2x}Cu_{3\text{-}3x}(OH)_6\ (s) \tag{A1-1}$$

Where "x" is the fraction of iron in the phase. As a result of reaction (1), copper can coprecipitate from solution as a result of the oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) and/or an increase in the pH. In reality, equation (1) is likely to be much more complex, with other cations such as aluminum (Al^{+3}), and divalent metals (i.e. Pb^{+2}, Zn^{+2}, Ni^{+2}, etc.) substituting for iron, and anions such as arsenate (AsO_4^{-3}), chloride (Cl^-), and phosphate (PO_4^{-3}) substituting for hydroxide. In mine impacted waters where the pH is low, and sulfate concentrations are high (>1,500 mg/L) significant sulfate substitution can occur, resulting in a schwertmannite or jarosite type hydroxysulfate coprecipitate. The phases are typically amorphous (no crystal structure) when first formed, but tend to crystallize (and become less soluble) over time.

Copper Adsorption

Copper adsorbs to solid surfaces due partly to interactions between the positively charged ions and a negatively charged surface. Therefore, copper adsorption tends to be favored for solid materials which are negatively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other cations in solution.

At low pH values, the water and mineral surfaces have higher concentrations of hydronium ion (H_3O^+) which imparts a positive charge to the surface. As the pH increases, the hydronium ion concentration decreases relative to the hydroxide ion (OH^-) concentration in both the water and the solid materials within the water. At a specific threshold pH value called the pH of the zero-point-of-charge (ZPC), the

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surface charge transitions from positive to neutral to negative. Once the surface charge becomes negative, adsorption of the positively charged copper ions become possible. The pH of the ZPC is different for different materials, as shown in Table A1-3.

Table A1-3 pH of the Zero-Point-of-Charge (pH$_{ZPC}$) for Various Minerals[1]

Material	Formula	pH$_{ZPC}$
Magnetite	Fe_3O_4	6.5
Goethite	FeOOH	7.8
Hematite	Fe_2O_3	6.7
Amorphous Ferric hydroxide	$Fe(OH)_3$	8.5
Amorphous Silica	SiO_2	2.0
Manganese Dioxide	$\delta\text{-}MnO_2$	2.8
Montmorillonite Clay	$Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2 \cdot 10\ H_2O$	2.5
Kaolinite Clay	$Al_2Si_2O_5(OH)_4$	4.6

[1] Data from Stumm and Morgan (1981)

The materials with a lower pH$_{ZPC}$ are able to maintain a negative charge at a lower pH than for materials with a higher pH$_{ZPC}$. Of the materials listed in Table A1-3, amorphous silica and montmorillonite clay are the best cation adsorbents at higher pH values (above 2-2.5).

Amorphous ferric hydroxide has a pH$_{zpc}$ of 8.5, which means that for pH values of less than 8.5, the surface charge is positive. Figure A1-1 shows that divalent copper exists predominantly as a positively charged or neutral species below a pH of about 7 (Cu^{+2} or $Cu(OH)_2^0$). Therefore, coulombic-type adsorption (attraction of a charged ion to an oppositely charged surface) of copper onto amorphous ferric hydroxide will not occur to any degree below a pH of 7. Copper tends to adsorb (coulombically) to clay minerals and manganese oxides, which have much lower pH$_{zpc}$ values. However, copper does adsorb to amorphous ferric hydroxide below pH 7 by a process called "specific adsorption" in which the positively charged ions or neutral species attach to specific sites on the surface which are favorable.

In waters high in sulfate, such as acid mine drainage or sea water, the presence of sulfate has been observed to increase the adsorption of copper onto goethite. Balistrieri and Murray (1982) have suggested that sulfate specifically adsorbs to iron hydroxides, resulting in a negative surface charge which allows coulombic adsorption of the positively charged copper ions.

The solid material properties not only control the degree to which copper is adsorbed at a given pH, but also the amount of copper that can be adsorbed before the surface of the solid becomes saturated. The process is described mathematically by the Langmuir Isotherm, which is as follows:

$$C \text{ (solid)} = Kl*Am*C(soln)/(1+Kl*C(soln)) \tag{A1-2}$$

Where,

C(solid) = concentration of copper adsorbed to the solid phase (mg/kg)
C(soln)   = concentration of copper dissolved in the solution phase (mg/L)
Am   = maximum adsorption capacity of the solid (mg/kg)
Kl   = Langmuir adsorption constant

Examples of Langmuir Adsorption Isotherms for three different solid materials are illustrated in Figure A1-3.
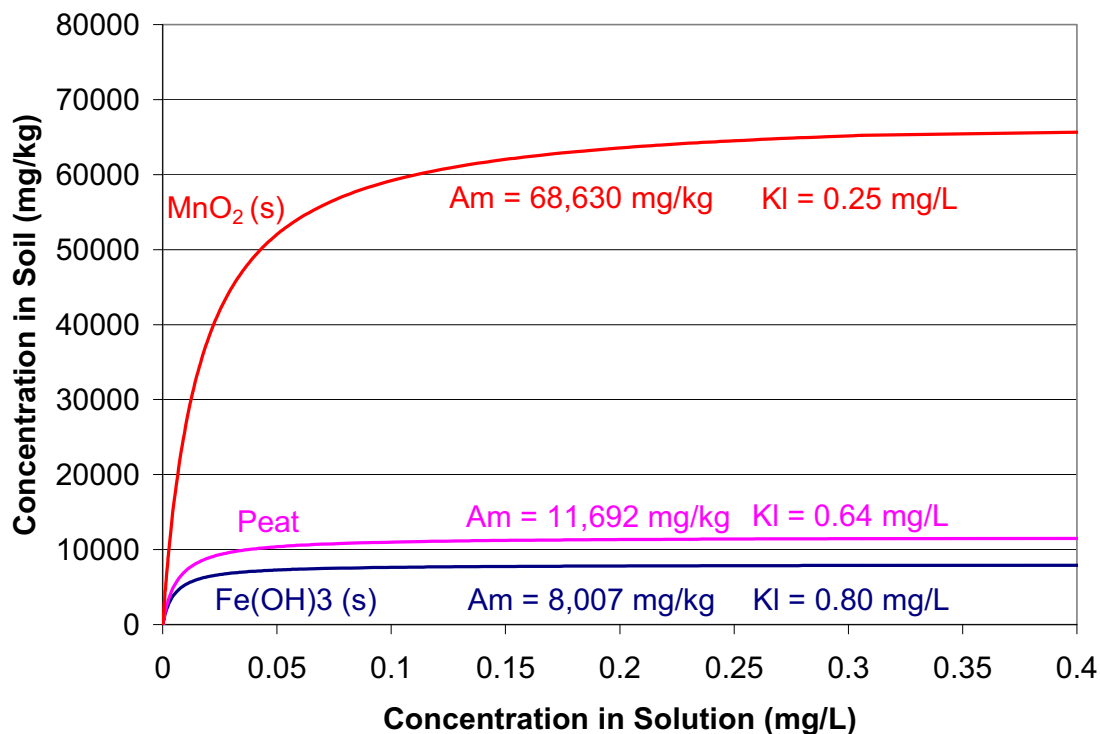
Figure A1-3 Langmuir Isotherms illustrating the copper adsorption capacities of Fe(OH)$_3$(s), peat, and MnO$_2$(s) at a pH of 5.5 su. Langmuir adsorption constants (Kl and Am) are from McLaren and Crawford (1973).

The adsorption of copper as illustrated in Figure A1-3 can be understood by imagining a "clean" soil or sediment which is subjected to waters with increasing copper concentrations (such as a with the expansion of a copper-bearing groundwater plume). As the solution copper concentrations increase, increasingly greater amounts of copper can be "forced" onto the solid surface. The steep part of the curve where soils copper concentration increase rapidly describes the process. As the copper concentrations on the soil continue to increase, a point is eventually reached where the solid surfaces are completely saturated with copper and there is no more capacity for additional copper adsorption. No matter how high the dissolved copper concentrations become, the solid copper concentration remains constant. The flat part of the curve describes the saturation point of the solid. The Langmuir Am constant is the adsorption capacity and determines the level of the flat portion of the curve, while

the Kl constant determines the rate at which Am is reached (the steepness of the initial segment of the curve).

Figure 3 shows that at pH 5.5, organic matter, such as peat, and especially manganese dioxide have much higher copper adsorption capacities than ferric hydroxide. Theoretically, a sample of manganese dioxide or ferric hydroxide could be analyzed, and the concentration of copper could be compared to Am. If the analytical result of the solid is significantly higher than Am, then copper is likely controlled by coprecipitation rather than adsorption. However, in practice, soils and sediments are rarely composed of a single phase, but are instead heterogeneous mixtures of different minerals with varying amounts of iron and manganese oxides and organic matter present. However, the affinity of copper for manganese dioxide and organic matter can be used to evaluate the fate and transport of copper when exposed to soils of varying manganese and organic matter contents.

The presence of other divalent cations, especially calcium, results in decreased adsorption of copper due to competitive for adsorption sites. Cavallaro and McBride (1978) found that copper adsorption onto soil was significantly inhibited by the presence of 40-400 mg/L calcium. However, the presence of lead, zinc, and cadmium had little effect on the adsorption of copper onto iron hydroxide.

Anions, such as chloride can increase copper adsorption onto crystalline ferric hydroxide due to the formation of aqueous chloride complexes.

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A2 Zinc Geochemistry

Zinc exists in oxidation states of 0 (metallic zinc) and +2. Only the divalent (Zn^{2+}) oxidation state exists in the aqueous environment. At pH values less than 8, Zn^{+2} is the dominant form of zinc in solution, while at pH values between 8 and 11, $Zn(OH)_2^0$ predominates. $Zn(OH)_3^-$ and $Zn(OH)_4^{-2}$ are important above a pH of about 11. $Zn(OH)+$ is of minor importance, representing less than 15 percent of the zinc at all pH values.
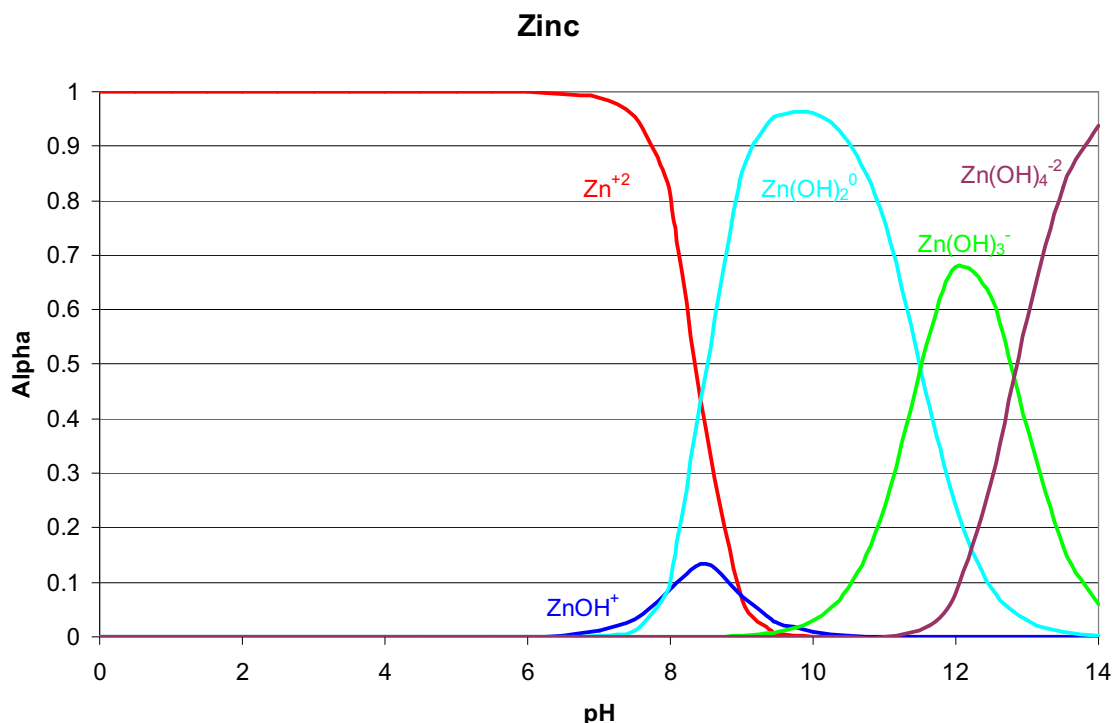
Figure A2-1 Divalent zinc speciation as a function of pH (alpha is the fraction of the total dissolved divalent zinc consisting of the given species).

In natural waters other ions (besides hydroxide) are present that can complex Zn^{+2}, such as sulfate, especially in acid rock drainage (ARD) water. Above a pH of 8.2, zinc carbonate complexes can also be important. Complexes with chloride, fluoride, and bromide, are generally insignificant unless unusually high concentrations of these ions are present in solution.

Zinc Pure Phase Minerals

Zinc forms hydroxide and carbonate pure phase minerals, while zero-valent zinc forms metallic zinc. The solubility of zinc hydroxide at various pH values is shown in Table A2-1.

Table A2-1 Solubility of Zinc (II) Hydroxide (Zn(OH)$_2$) vs. pH (Alkalinity = 0 mg/L)

pH (su)	Zinc Solubility (mg/L)[1]
4	2,670,000,000
5	26,700,000
6	267,000
7	2,700
8	31
9	2.8
10	2.4

[1] Calculated using PHREEQC

Zinc hydroxide only forms at high pH values, which means the aqueous concentrations of zinc can be quite high when the pH is less than 8 or 9 (see Table 1). The solubility of zinc increases by roughly 100 times for every unit decrease in pH (in the pH range 4-7). However, the correlation is not exact due to the formation of zinc hydroxide complexes (see Figure 1). The complexing effect is most noticeable at pH values above 7. In fact, the decrease in zinc solubility that would be expected as the pH increases (between pH 8 and 9 su) does not occur to a significant degree due to the formation of zinc hydroxide complexes.

Under high pH and alkaline conditions, carbonate or hydroxycarbonate phases can form. Such phases are more likely to form within carbonate aquifers and in alkaline soils dominated by calcite or other carbonate minerals.

The control of zinc by a pure phase solid will only occur under two circumstances;

1. If a zinc phase is released at a site and does not dissolve completely

or,

2. If the soil particles become saturated with adsorbed zinc to the point where the solution concentration rises to the solubility limit of a zinc phase under the given conditions

Waters in which the dissolved zinc concentration is less than the solubility limit of the pure phase zinc compounds suggests that aqueous zinc concentrations are controlled by either coprecipitation or adsorption.

Zinc Coprecipitation

In addition to forming pure compounds, lead can also precipitate as a trace element within other phases, most commonly with iron hydroxide. The general reaction is as follows:

$$2x\ Fe^{+3} + 3\text{-}3x\ Zn^{+2} + 6\ OH^- \rightarrow Fe_{2x}Zn_{3\text{-}3x}(OH)_6\ (s) \tag{A2-1}$$

Where "x" is the fraction of iron in the phase. As a result of reaction (1), zinc can coprecipitate from solution as a result of the oxidation of ferrous iron (Fe^{+2}) to ferric

iron (Fe^{+3}) and/or an increase in the pH. In reality, equation (1) is likely to be much more complex, with other cations such as aluminum (Al^{+3}), and divalent metals (i.e. Pb^{+2}, Cu^{+2}, Ni^{+2}, etc.) substituting for iron, and anions such as arsenate (AsO_4^{-3}), chloride (Cl^-), and phosphate (PO_4^{-3}) substituting for hydroxide. In mine impacted waters where the pH is low, and sulfate concentrations are high (>1,500 mg/L) significant sulfate substitution can occur, resulting in a schwertmannite or jarosite type hydroxysulfate coprecipitate. The phases are typically amorphous (no crystal structure) when first formed, but tend to crystallize (and become less soluble) over time.

Zinc Adsorption

Zinc adsorbs to solid surfaces due partly to interactions between the positively charged ions and a negatively charged surface. Therefore, zinc adsorption tends to be favored for solid materials which are negatively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other cations in solution.

At low pH values, the water and mineral surfaces have higher concentrations of hydronium ion (H_3O^+) which imparts a positive charge to the surface. As the pH increases, the hydronium ion concentration decreases relative to the hydroxide ion (OH^-) concentration in both the water and the solid materials within the water. At a specific threshold pH value called the pH of the zero-point-of-charge (ZPC), the surface charge transitions from positive to neutral to negative. Once the surface charge becomes negative, adsorption of the positively charged zinc ions become possible. The pH of the ZPC is different for different materials, as shown in Table 2.

Table A2-2 pH of the Zero-Point-of-Charge (pH$_{ZPC}$) for Various Minerals[1]

Material	Formula	pH$_{ZPC}$
Magnetite	Fe_3O_4	6.5
Goethite	$FeOOH$	7.8
Hematite	Fe_2O_3	6.7
Amorphous Ferric hydroxide	$Fe(OH)_3$	8.5
Amorphous Silica	SiO_2	2.0
Manganese Dioxide	$\delta\text{-}MnO_2$	2.8
Montmorillonite Clay	$Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2 \cdot 10\ H_2O$	2.5
Kaolinite Clay	$Al_2Si_2O_5(OH)_4$	4.6

[1]   Data from Stumm and Morgan (1981)

The materials with a lower pH$_{ZPC}$ are able to maintain a negative charge at a lower pH than for materials with a higher pH$_{ZPC}$. Of the materials listed in Table 2, amorphous silica and montmorillonite clay are the best cation adsorbents at higher pH values (above 2-2.5).

Amorphous ferric hydroxide has a pH$_{zpc}$ of 8.5, which means that for pH values of less than 8.5, the surface charge is positive. Figure 1 shows that divalent zinc exists predominantly as a positively charged or neutral species below a pH of about 7 (Zn^{+2} or $Zn(OH)_2^0$). Therefore, coulombic-type adsorption (attraction of a charged ion to an

oppositely charged surface) of zinc onto amorphous ferric hydroxide will not occur to any degree below a pH of 7. Zinc tends to adsorb to clay minerals and manganese oxides, which have much lower pH_{zpc} values. However, zinc does adsorb to amorphous ferric hydroxide and other phases below pH 7 by a process called "specific adsorption" in which the positively charged ions or neutral species attach to specific sites on the surface which are favorable.

The solid material properties not only control the degree to which zinc is adsorbed at a given pH, but also the amount of zinc that can be adsorbed before the surface of the solid becomes saturated. The process is described mathematically by the Langmuir Isotherm, which is as follows:

$$C \text{ (solid)} = Kl*Am*C(soln)/(1+Kl*C(soln)) \quad\quad\quad (A2-2)$$

Where,

C(solid) = concentration of zinc adsorbed to the solid phase (mg/kg)
C(soln) = concentration of zinc dissolved in the solution phase (mg/L)
Am = maximum adsorption capacity of the solid (mg/kg)
Kl = Langmuir adsorption constant

Examples of Langmuir Adsorption Isotherms for three different solid materials are illustrated in Figure 2.

The adsorption of zinc as illustrated in Figure A2-2 can be understood by imagining a "clean" soil or sediment which is subjected to waters with increasing zinc concentrations (such as a with the expansion of a zinc-bearing groundwater plume). As the solution zinc concentrations increase, increasingly greater amounts of zinc can be "forced" onto the solid surface. The steep part of the curve where soils zinc concentration increase rapidly describes the process. As the zinc concentrations on the soil continue to increase, a point is eventually reached where the solid surfaces are completely saturated with zinc and there is no more capacity for additional zinc adsorption. No matter how high the dissolved zinc concentrations become, the solid zinc concentration remains constant. The flat part of the curve describes the saturation point of the solid. The Langmuir Am constant is the adsorption capacity and determines the level of the flat portion of the curve, while the Kl constant determines the rate at which Am is reached (the steepness of the initial segment of the curve).
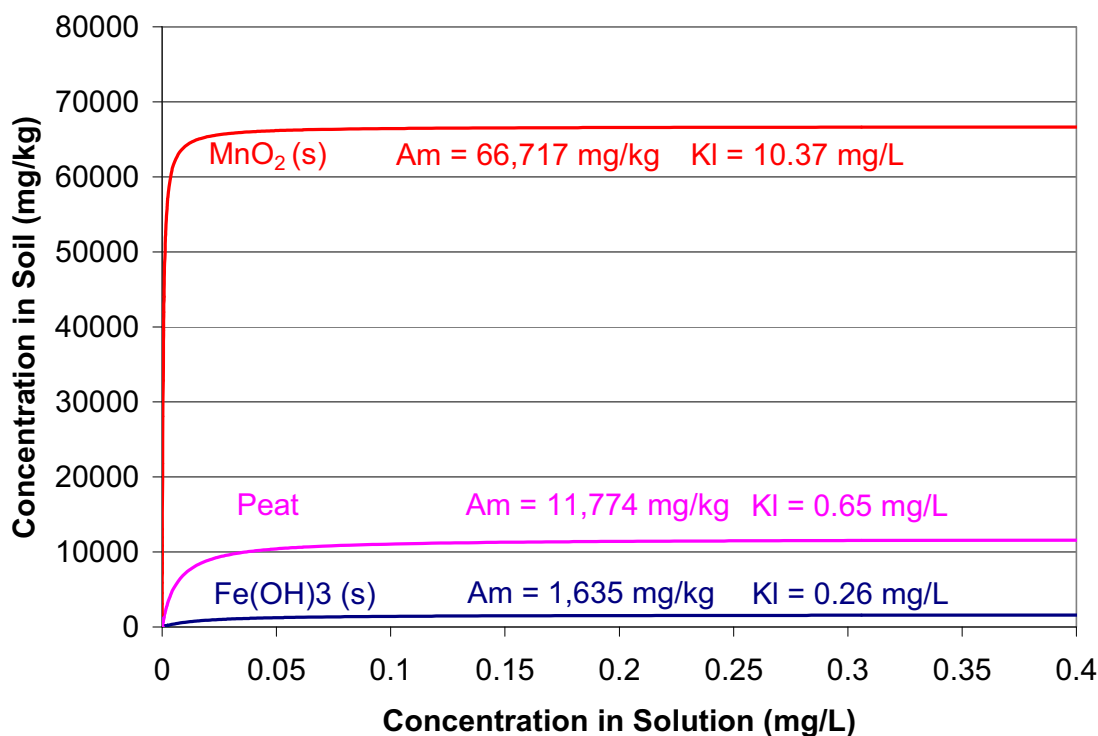
Figure A2-2 Langmuir Isotherms illustrating the zinc adsorption capacities of Fe(OH)$_3$(s), peat, and MnO$_2$(s) at a pH of 5-6 su. Langmuir adsorption constants (Kl and Am) are from Dempsey and Singer (1980) for Fe(OH)$_3$(s), Bunzl et al. (1976) for peat, and McKenzie (1980) for MnO$_2$(s).

Figure A2-3 shows that at pH 5-6, organic matter, such as peat, and especially manganese dioxide have much higher zinc adsorption capacities than ferric hydroxide. Theoretically, a sample of manganese dioxide or ferric hydroxide could be analyzed, and the concentration of zinc could be compared to Am. If the analytical result of the solid is significantly higher than Am, then zinc is likely controlled by coprecipitation rather than adsorption. However, in practice, soils and sediments are rarely composed of a single phase, but are instead heterogeneous mixtures of different minerals with varying amounts of iron and manganese oxides and organic matter present. However, the affinity of zinc for manganese dioxide and organic matter can be used to evaluate the fate and transport of zinc when exposed to soils of varying manganese and organic matter contents.

pH also has a significant effect on the adsorption capacity of zinc, as shown in Table A2-3.

Table A2-3 - Adsorption Capacity of Zinc vs. pH

| pH | Adsorption Capacity (mg/kg) | |
	Goethite (FeOOH)[1]	Manganese Oxides[2]
5	386	-
6	4,448	76,529
7	4,186	104,000
8	-	193,611

[1]   Bolland et al. (1977)
[2]   Dempsey and Singer (1980)

The increase of the adsorption capacity is a function of both the surface charge on the solids (which is negative at higher pH) and on the zinc speciation, as shown in Figure 1.

The presence of other divalent cations, especially calcium, results in decreased adsorption of zinc due to competitive for adsorption sites. Zinc adsorption onto soil is significantly inhibited by the presence of >40 mg/L calcium or magnesium (Shukla et al., 1980). However, the presence of lead, copper, and cadmium had little effect on the adsorption of zinc onto iron hydroxide.

Anions, such as chloride, nitrate, and perchlorate have little affect on zinc adsorption, while adsorption is enhanced by the presence of chromate, selenite, arsenate, and phosphate.

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A3 Lead Geochemistry

Lead exists in oxidation states of 0 (metallic lead), +2, and +4. Only Pb^{2+} exists in the aqueous environment, as Pb^{4+} is outside of the stability range of water. At pH values less than 7.7, Pb^{+2} is the dominant form of lead in solution, while at pH values between 7.7 and 9.4, $PbOH^+$ predominates. $Pb(OH)_2^0$ and $Pb(OH)_3^-$ are only important above a pH of 9.4.
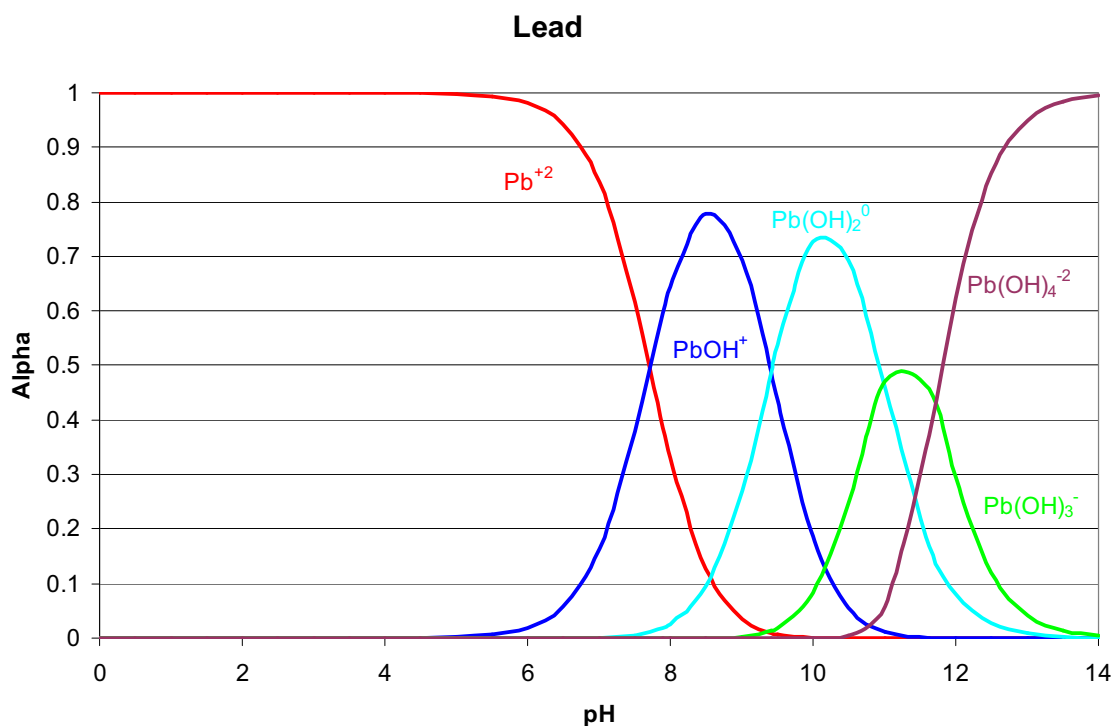
Lead

Figure A3-1 Lead speciation as a function of pH (alpha is the fraction of the total dissolved lead consisting of the given species).

In groundwaters, aqueous lead exists as the uncomplexed ion Pb^{2+} under acidic conditions and as lead –carbonate complexes under alkaline conditions. Within acid rock drainage, where sulfate concentrations are typically high, lead-sulfate complexes are also important.

Lead Pure Phase Minerals

Aqueous lead concentrations can be controlled by pure phase lead minerals, such as lead hydroxide, lead carbonate (cerrusite), and lead phosphates. Lead hydroxide only forms at high pH values, which means the aqueous concentrations of lead can be quite high when the pH is less than 7 (see Table 1). The solubility of lead increases by roughly 100 times for every unit decrease in pH. However, the correlation is not exact due to the formation of lead hydroxide complexes (see Figure 1). The complexing effect is most noticeable at high pH values. For instance the lead solubility at pH 8 is roughly 100 times the solubility at pH 9, but the solubility at pH 9 is only three times the solubility at pH 11.

Table A3-1 Solubility of Lead Hydroxide (Pb(OH)$_2$) vs. pH (Alkalinity = 0 mg/L)

pH (su)	Lead Solubility (mg/L)[1]
4	432,445
5	4,255
6	43
7	0.5
8	0.01
9	0.0009
10	0.0003

[1]   Calculated using PHREEQC

Lead hydroxide is the most likely pure phase control in waters with very low alkalinity and phosphate concentrations. However, when as little as 50 mg/L alkalinity is present, the mineral cerrusite (PbCO$_3$) can form, resulting in much lower lead solubility than for lead hydroxide at the same pH. For example, the solubility of lead at pH 5 is 4,255 mg/L (controlled by lead hydroxide), while in the presence of 50 mg/L alkalinity, the lead solubility is decreased to 8.1 mg/L (control by cerrusite), as shown in Table A3-2.

Table A3-2 – Solubility of Lead Carbonate (PbCO$_3$) vs Alkalinity (pH = 5)

Alkalinity (mg/L as CaCO$_3$)	Lead Solubility (mg/L)[1]
50	8.1
100	5.5
200	4.2
400	3.6
800	3.8

[1]   Calculated using PHREEQC

The presence of even lower concentrations of phosphate can result in the precipitation of lead phosphate, which has even lower lead solubility. At pH 5, in the presence of only 1 mg/L phosphate, the lead solubility is decreased from 4,255 mg/L (for lead hydroxide control) to 1.65 mg/L (due to control by Pb$_3$(PO$_4$)$_2$(s).)

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Table A3-3 Solubility of Lead Phosphate ($Pb_3(PO_4)_2$) vs Phosphate Concentration (pH = 5)

Phosphate (mg/L as P)	Lead Solubility (mg/L) [1]
1	1.65
2	1.04
5	0.57
10	0.36
20	0.23
40	0.14
80	0.09

[1]   Calculated using PHREEQC

The control of lead by a pure phase solid will only occur under two circumstances;

1. If a lead phase is released at a site and does not dissolve completely (such as lead carbonate paint pigment)

or,

2. If the soil particles become saturated with adsorbed lead to the point where the solution concentration rises to the solubility limit of a lead phase under the given conditions

Waters in which the dissolved lead concentration is less than the solubility limit of the pure phase lead compounds suggests that aqueous lead concentrations are controlled by either coprecipitation or adsorption.

Lead Coprecipitation

In addition to forming pure compounds, lead can also precipitate as a trace element within other phases, most commonly with iron hydroxide. The general reaction is as follows:

$$2x\ Fe^{+3} + 3\text{-}3x\ Pb^{+2} + 6\ OH^- \rightarrow Fe_{2x}Pb_{3\text{-}3x}(OH)_6\ (s) \tag{A3-1}$$
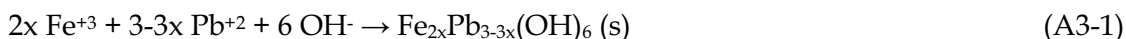
Where "x" is the fraction of iron in the phase. As a result of reaction (1), lead can coprecipitate from solution as a result of the oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) and/or an increase in the pH. In reality, equation (1) is likely to be much more complex, with other cations such as aluminum (Al^{+3}), and divalent metals (i.e. Cu^{+2}, Zn^{+2}, Ni^{+2}, etc.) substituting for iron, and anions such as arsenate (AsO_4^{-3}), chloride (Cl^-), and phosphate (PO_4^{-3}) substituting for hydroxide. In mine impacted waters where the pH is low, and sulfate concentrations are high (>1,500 mg/L) significant sulfate substitution can occur, resulting in a schwertmannite or jarosite type hydroxysulfate coprecipitate. The phases are typically amorphous (no crystal structure) when first formed, but tend to crystallize (and become less soluble) over time.

Lead Adsorption

Lead adsorbs to solid surfaces due partly to interactions between the positively charged ions and a negatively charged surface. Therefore, lead adsorption tends to be favored for solid materials which are negatively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other cations in solution.

At low pH values, the water and mineral surfaces have higher concentrations of hydronium ion (H_3O^+) which imparts a positive charge to the surface. As the pH increases, the hydronium ion concentration decreases relative to the hydroxide ion (OH^-) concentration in both the water and the solid materials within the water. At a specific threshold pH value called the pH of the zero-point-of-charge (ZPC), the surface charge transitions from positive to neutral to negative. Once the surface charge becomes negative, adsorption of the positively charged lead ions become possible. The pH of the ZPC is different for different materials, as shown in Table 4.

Table A3-4 pH of the Zero-Point-of-Charge (pH$_{ZPC}$)for Various Minerals

Material	Formula	pH$_{ZPC}$
Magnetite	Fe_3O_4	6.5
Goethite	$FeOOH$	7.8
Hematite	Fe_2O_3	6.7
Amorphous Ferric hydroxide	$Fe(OH)_3$	8.5
Amorphous Silica	SiO_2	2.0
Montmorillonite Clay	$Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2 \cdot 10\ H_2O$	2.5
Kaolinite Clay	$Al_2Si_2O_5(OH)_4$	4.6

The materials with a lower pH$_{ZPC}$ are able to maintain a negative charge at a lower pH than for materials with a higher pH$_{ZPC}$. Of the materials listed in Table 4, amorphous silica and montmorillonite clay are the best cation adsorbents at higher pH values (above 2-2.5).

Amorphous ferric hydroxide has a pH$_{zpc}$ of 8.5, which means that for pH values of less than 8.5, the surface charge is positive. Figure 1 shows that lead exists predominantly as a positively charged species below a pH of about 9.4 (Pb^{+2} or $Pb(OH)^+$). Therefore, coulombic-type adsorption (attraction of a charged ion to an oppositely charged surface) of lead onto amorphous ferric hydroxide will not occur to any degree below a pH of 8.5. Lead tends to adsorb (coulombically) to clay minerals which have much lower pH$_{zpc}$ values. However, lead does adsorb to amorphous ferric hydroxide below pH 8.5 by a process called "specific adsorption" in which the positively charged ions attach to specific sites on the surface which are favorable.

The solid material properties not only control the degree to which lead is adsorbed at a given pH, but also the amount of lead that can be adsorbed before the surface of the solid becomes saturated. The process is described mathematically by the Langmuir Isotherm, which is as follows:

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C (solid) = Kl*Am*C(soln)/(1+Kl*C(soln)) (A3-2)

Where,

C(solid) = concentration of lead adsorbed to the solid phase (mg/kg)
C(soln) = concentration of lead dissolved in the solution phase (mg/L)
Am = maximum adsorption capacity of the solid (mg/kg)
Kl = Langmuir adsorption constant

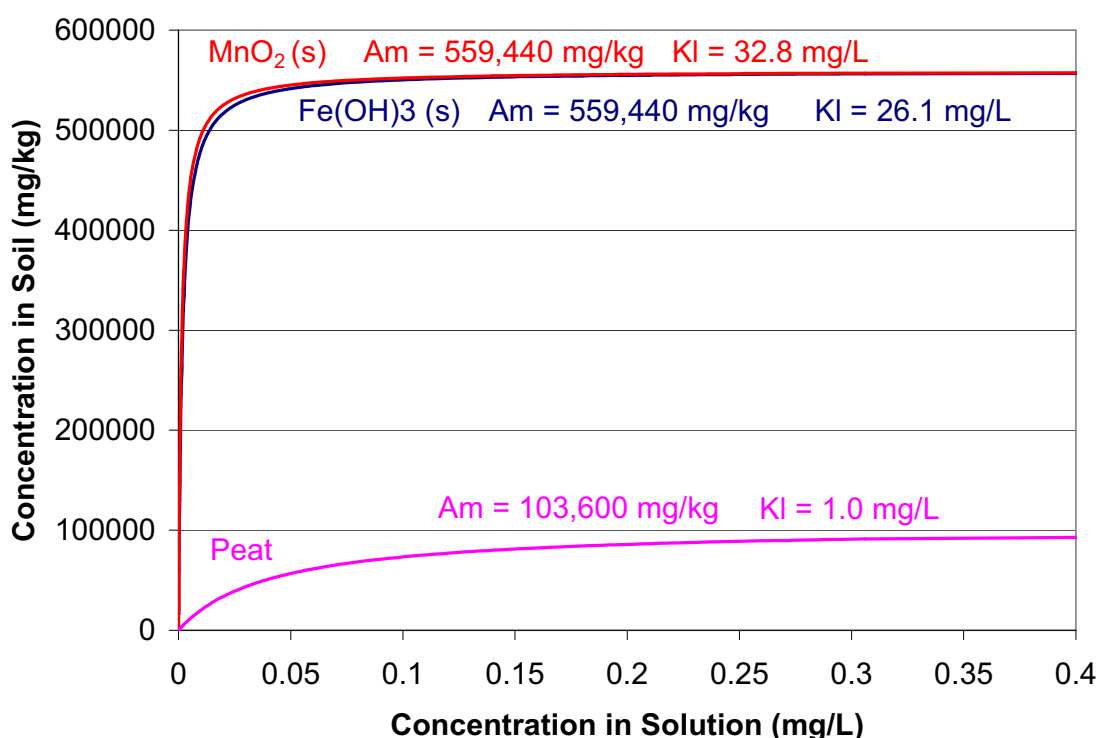Examples of Langmuir Adsorption Isotherms for three different solid materials are illustrated in Figure A3-2.

Figure A3-2 Langmuir Isotherms illustrating the lead adsorption capacities of $Fe(OH)_3(s)$, peat, and $MnO_2(s)$ at a pH of 4-6 su. Langmuir adsorption constants (Kl and Am) are from Gadde and Laitinen (1973) for $Fe(OH)_3(s)$, Bunzl (1974) for peat, and McKenzie (1980)for $MnO_2(s)$.

The adsorption of lead as illustrated in Figure A3-2 can be understood by imagining a "clean" soil or sediment which is subjected to waters with increasing lead concentrations (such as a with the expansion of a lead-bearing groundwater plume). As the solution lead concentrations increase, increasingly greater amounts of lead can be "forced" onto the solid surface. The steep part of the curve where soils lead concentration increase rapidly describes the process. As the lead concentrations on the soil continue to increase, a point is eventually reached where the solid surfaces are completely saturated with lead and there is no more capacity for additional lead adsorption. No matter how high the dissolved lead concentrations become, the solid

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lead concentration remains constant. The flat part of the curve describes the saturation point of the solid. The Langmuir Am constant is the adsorption capacity and determines the level of the flat portion of the curve, while the Kl constant determines the rate at which Am is reached (the steepness of the initial segment of the curve).

Figure A3-2 shows that at pH 4-6, iron hydroxide and manganese dioxide have much higher lead adsorption capacities than organic matter such as peat. Theoretically, a sample of manganese dioxide or ferric hydroxide could be analyzed, and the concentration of lead could be compared to Am. If the analytical result of the solid is significantly higher than Am, then lead is likely controlled by coprecipitation rather than adsorption. However, in practice, soils and sediments are rarely composed of a single phase, but are instead heterogeneous mixtures of different minerals with varying amounts of iron and manganese oxides and organic matter present. However, the affinity of lead for manganese dioxide and organic matter can be used to evaluate the fate and transport of lead when exposed to soils of varying manganese and organic matter contents.

pH also has a significant effect on the adsorption capacity of lead. Due to the surface charge changes that occur as the pH increases (becomes negative at high pH) and the speciation changes (Figure A3-1), the lead adsorption capacity of solids tends to increase with increasing pH.

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A4 Arsenic Geochemistry

Arsenic occurs in two oxidation states in natural waters, +3 (arsenite) and +5 (arsenite). As(+5) exists predominantly as a negatively charged ion (anion) above a pH of about 2. As(+5) is predominantly monovalent (charge of -1) over the pH range of 2 to 7 ($H_2AsO_4^-$), divalent from pH 7 to 11.5 ($HAsO_4^{2-}$) and trivalent at pH values above 11.5 (AsO_4^{3-}), as shown in Figure A4-1.
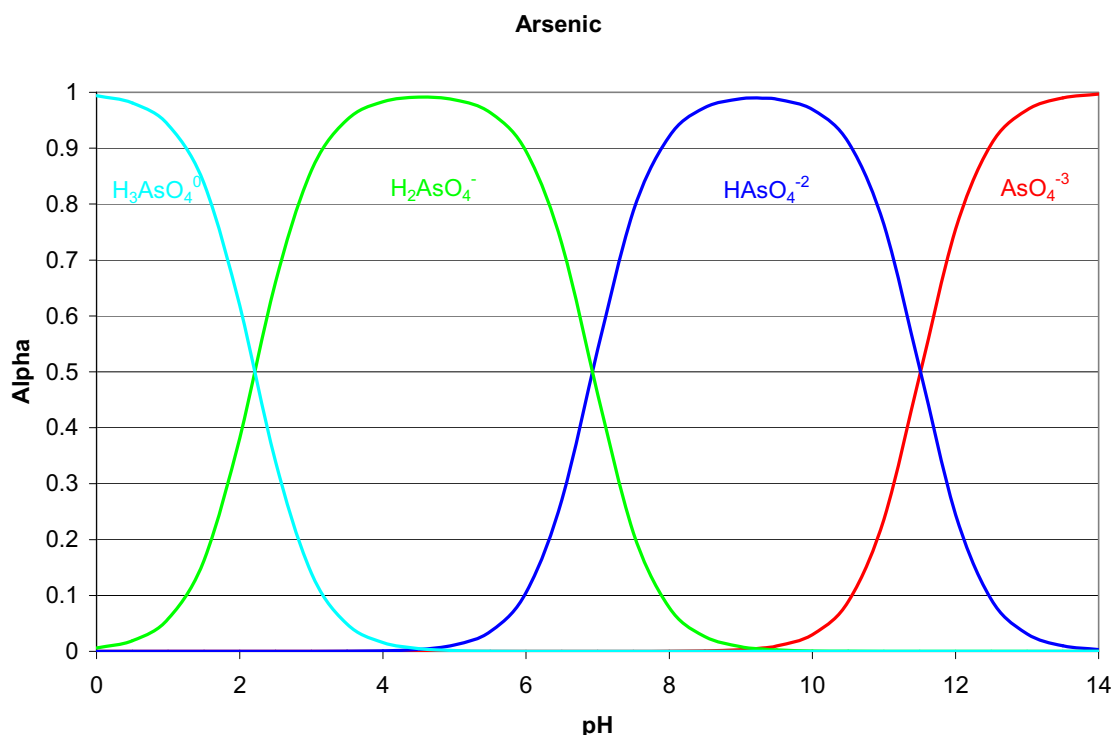
Arsenic

Figure A4-1 Arsenate speciation as a function of pH (alpha is the fraction of the total dissolved arsenate consisting of the given species).

The aqueous arsenate and arsenite species distribution with Eh and pH are shown in Figure A4-2.

As(+3) is predominantly a neutral species ($H_3AsO_3^0$) below a pH of about 9. $H_2AsO_3^-$ and $HAsO_3^{-2}$ do not become important until the pH exceeds 9 su, which is higher than observed in the vast majority of natural waters.
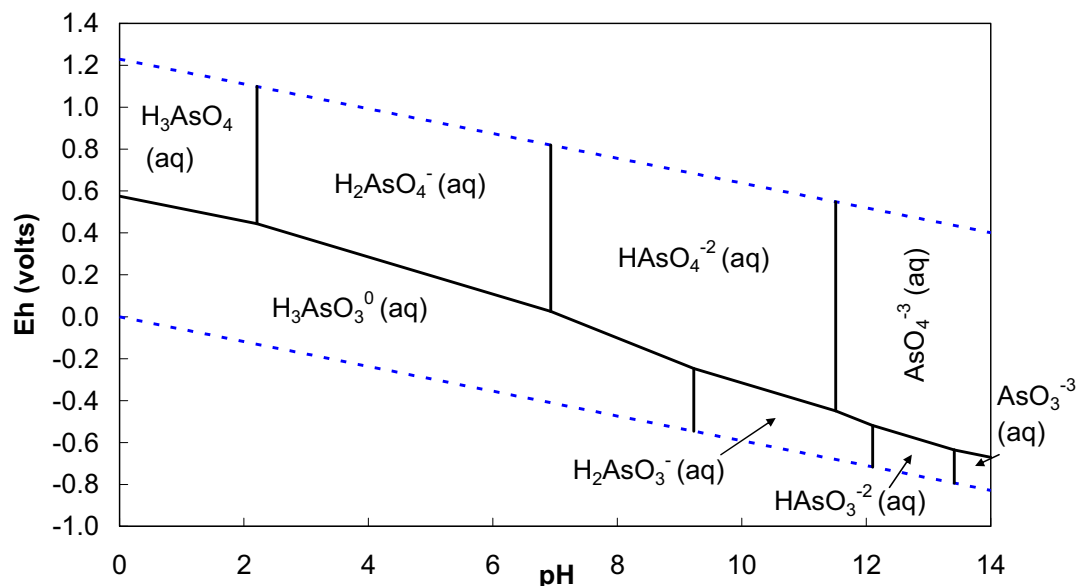
Figure A4-2 Eh-pH diagram for the system As-O-H at 25º C and 1 atm.

Arsenic Pure Phase Minerals

Pure phase arsenic minerals such as orpiment (As_2S_3), realgar (AsS), and arsenopyrite (FeAsS) occur mainly in ore deposits formed from hydrothermal fluids within the Earth's crust. A few pure phase arsenic minerals occur under low temperature and low pressure conditions at the Earth's surface, such as scorodite ($FeAsO_4 \cdot 2H_2O$ at low pH), and arsenic sulfides (under reducing conditions). However, the vast majority of pure phase arsenic minerals are too soluble to be present in soils that are in contact with water.

Arsenic Solid-Solution Phases

Arsenic forms solid-solution phases with ferric hydroxide and iron hydroxysulfates such as jarosite ($HFe_3(OH)_6(SO_4)_2$) and schwertmannite ($Fe_8O_8(OH)_6SO_4$) and with amorphous silica. Arsenate, like silicate, has a tetrahedral form (a central atom coordinated with four oxygen atoms) which may facilitate the incorporation of arsenate into amorphous silica.

Amorphous phases such as ferric hydroxide or schwertmanite tend to substitute hydroxide or sulfate for arsenate. A reaction to form an iron-arsenic solid-solution is as follows:

$$Fe^{+3} + xAsO_4^{-3} + (3-3x) \, OH^- \rightarrow [FeAsO_4 \, 2H_2O]_x[Fe(OH)_3]_{1-x} \tag{A4-1}$$

The amount of substitution of arsenic into ferric hydroxide is determined by the pH of the solution (more arsenic substitution occurs at lower pH values) and the

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concentration of arsenic in solution (higher arsenic concentrations result in more substitution).

Arsenic Adsorption

Arsenic adsorbs to solid surfaces due partly to interactions between the negatively charged ions and a positively charged surface. Therefore, arsenic adsorption tends to be favored for solid materials which are positively charged. The surface charge of the material depends on the type of solid, the pH of the water, and the concentration of other anions in solution.

At low pH values, the water and mineral surfaces have higher concentrations of hydronium ion (H_3O^+) which imparts a positive charge to the surface. As the pH increases, the hydronium ion concentration decreases relative to the hydroxide ion (OH^-) concentration in both the water and the solid materials within the water. At a specific threshold pH value called the pH of the zero-point-of-charge (ZPC), the surface charge transitions from positive to neutral to negative. Once the surface charge becomes negative, adsorption of the negatively charged arsenate ions become less prevalent. The pH of the ZPC is different for different materials, as shown in Table A4-1.

Table A4-1 pH of the Zero-Point-of-Charge (pH_{ZPC}) for Various Minerals[1]

Material	Formula	pH_{ZPC}
Magnetite	Fe_3O_4	6.5
Goethite	$FeOOH$	7.8
Hematite	Fe_2O_3	6.7
Amorphous Ferric hydroxide	$Fe(OH)_3$	8.5
Aluminum Hydroxide	$\gamma\text{-AlOOH}$	8.2
Aluminum Hydroxide	$\overline{A}\text{-Al(OH)}_3$	5.0
Amorphous Silica	SiO_2	2.0
Manganese Dioxide	$\delta\text{-MnO}_2$	2.8
Montmorillonite Clay	$Na_{0.2}Ca_{0.1}Al_2Si_4O_{10}(OH)_2 \cdot 10\ H_2O$	2.5
Kaolinite Clay	$Al_2Si_2O_5(OH)_4$	4.6

[1]. Data from Stumm and Morgan (1981)

The materials with a higher pH_{ZPC} are able to maintain a positive charge at a higher pH than for materials with a lower pH_{ZPC}. Of the materials listed in Table 3-1, amorphous ferric hydroxide is the best anion adsorbent at higher pH values (below 8.5).

Under typical Eh/pH conditions, As(+3) is a neutral ion and does not adsorb well to negatively or positively charged surfaces. Therefore, As(+3) is roughly 4-10 times more mobile than As(+5) (Duel and Swoboda, 1972). In addition, As(+3) is about 60 times more toxic to humans than arsenate (Houslow, 1980).

Arsenic has a strong affinity for iron phases and minerals. Strong correlations between arsenic and iron have been found in soils (Woolson et al., 1971; Duel and Swoboda 1972); in ores (Shnyukov, 1963); within ferrihydrite impurities in phosphate

pebbles (Stow, 1969); and in sediments impacted by arsenic-containing groundwaters (Whiting, 1992).

The solid material properties not only control the degree to which arsenic is adsorbed at a given pH, but also the amount of arsenic that can be adsorbed before the surface of the solid becomes saturated. The process is described mathematically by the Langmuir Isotherm, which is as follows:

$$C \text{ (solid)} = Kl*Am*C(\text{soln})/(1+Kl*C(\text{soln})) \tag{A4-2}$$

Where,

C(solid)	=	concentration of arsenic adsorbed to the solid phase (mg/kg)
C(soln)	=	concentration of arsenic dissolved in the solution phase (mg/L)
Am	=	maximum adsorption capacity of the solid (mg/kg)
Kl	=	Langmuir adsorption constant

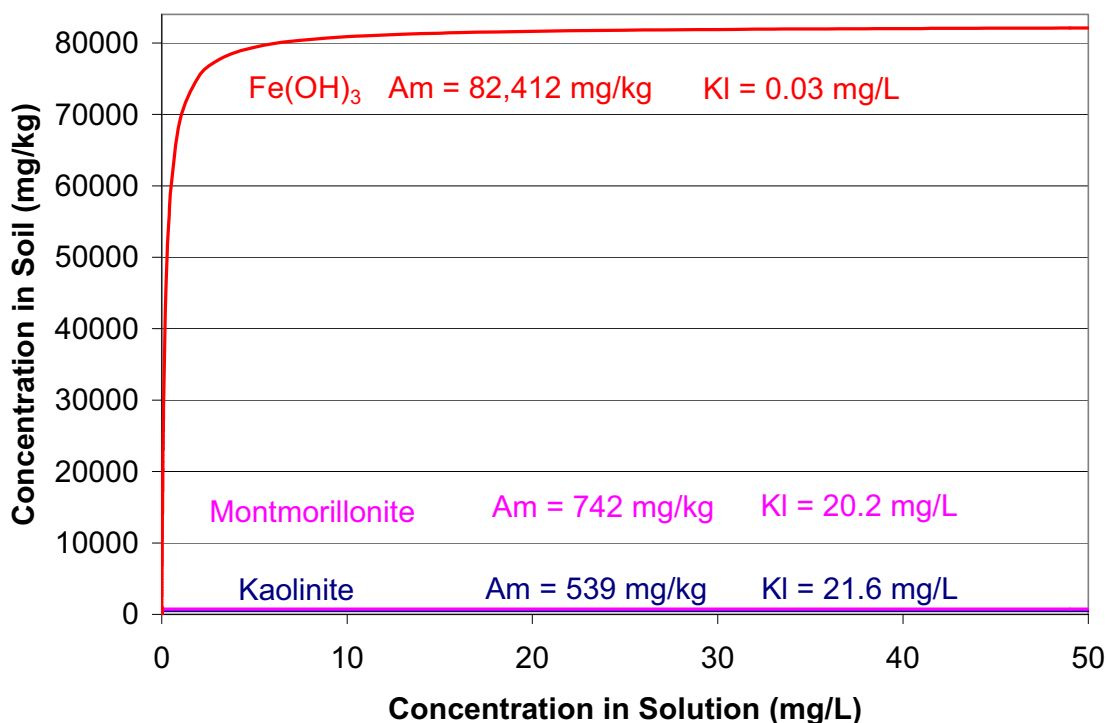Examples of Langmuir Adsorption Isotherms for three different solid materials are illustrated in Figure 3.

Figure A4-3 Langmuir Isotherms illustrating arsenate adsorption capacities of Fe(OH)₃(s), kaolinite, and montmorillonite at a pH of 5 su. Langmuir adsorption constants (Kl and Am) are from Pierce and Moore (1982) for Fe(OH)₃(s) and Frost and Griffin (1977) for kaolinite and montmorillonite.

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The adsorption of arsenate as illustrated in Figure A4-3 can be understood by imagining a "clean" soil or sediment which is subjected to waters with increasing arsenate concentrations (such as a with the expansion of an arsenate-bearing groundwater plume). As the solution arsenate concentrations increase, increasingly greater amounts of arsenate can be "forced" onto the solid surface. The steep part of the curve where soils arsenate concentration increase rapidly describes the process. As the arsenate concentrations on the soil continue to increase, a point is eventually reached where the solid surfaces are completely saturated with arsenate and there is no more capacity for additional arsenate adsorption. No matter how high the dissolved arsenate concentrations become, the solid arsenate concentration remains constant. The flat part of the curve describes the saturation point of the solid. The Langmuir Am constant is the adsorption capacity and determines the level of the flat portion of the curve, while the Kl constant determines the rate at which Am is reached (the steepness of the initial segment of the curve).

Figure A4-3 shows that at pH 5, iron hydroxide has a much higher arsenate adsorption capacity than montmorillonite or kaolinite clays. Theoretically, a sample of ferric hydroxide could be analyzed, and the concentration of arsenic could be compared to Am. If the analytical result of the solid is significantly higher than Am, then arsenate is likely controlled by coprecipitation rather than adsorption. However, in practice, soils and sediments are rarely composed of a single phase, but are instead heterogeneous mixtures of different minerals with varying amounts of iron hydroxide present. However, the affinity of arsenate for iron minerals such as iron hydroxide can be used to evaluate the fate and transport of arsenate when exposed to soils of varying iron contents.

pH also has a significant effect on the adsorption capacity of arsenic, as shown in Table A4-2.

Table A4-2 Adsorption Capacity of Arsenate and Arsenite vs. pH

| pH | Arsenate Adsorption Capacity (mg/kg) | | Arsenite Adsorption Capacity (mg/kg) |
	$Fe(OH)_3$ (s)[1]	$Al(OH)_3$ (s)[2]	$Fe(OH)_3$ (s)[1]
5	82,412	119,872	34,688
6	63,682	110,732	37,685
7	34,014	88,331	38,434
8	16,932	62,783	36,561
9	10,189	37,535	31,242

[1] Pierce and Moore (1982)
[2] Anderson et al. (1976)

The pH dependence is due to the speciation of arsenic and the surface charge of the solid at different pH values. Arsenate is a negatively charged ion (anion) at pH values greater than about 2 (Figure A4-1), while the aluminum and iron hydroxides tend to be positively charged. However, as the pH increases, the surfaces of the solids become less positive and the arsenate species become increasingly negative resulting in fewer

adsorption sites. Arsenite, being a neutral species below pH 9 (Figure A4-2), is relatively insensitive to changes in pH.

Phosphate competes with arsenate for adsorption sites resulting in less arsenate adsorption and greater mobility. Other ions such as chloride, sulfate, and nitrate have little or no effect on arsenic adsorption.

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