Investigating soil arsenic concentrations across Bendigo

Technical report

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EPA acknowledges Aboriginal people as the first peoples and Traditional custodians of the land and water on which we live, work, and depend. We pay respect to Aboriginal Elders past and present and recognise the continuing connection to, and aspirations for Country.

Contents

1 Background to the report

1.1 Project Overview

Bendigo's gold mining operations in the 1800s and early 1900s generated mine wastes that are still part of its environment today. These mine wastes can have high levels of arsenic resulting from the mining processes used. EPA Victoria is undertaking a program to better understand the nature and extent of arsenic in soil in the Central Victoria gold mining areas. As a part of the program, this project aimed to establish ambient background soil arsenic concentrations across the City of Greater Bendigo using surface and subsurface soil data. A soil survey was undertaken to establish a regional ambient background level and help inform future policy directions.

1.2 Purpose and structure of report

These findings provide EPA, Environmental Auditors, and contaminated land consultants with further information to support assessment of arsenic mine tailings in the Goldfields Regions. The information contained in this report will be useful for other parties involved or interested in contaminated land management, including:

- landowners and managers
- planning or responsible authorities and other statutory authorities
- Djaara, in their aspirations and goals for country
- community.

2 Background to arsenic in the Bendigo area

2.1 Geology of the Bendigo Region

The bedrock geology of the Bendigo area predominantly comprises alternating layers of slates, siltstones and sandstones, with occasional very thin beds of limestone associated with tightly folded Ordovician marine sedimentary rocks of the Castlemaine Group. The thickness of these layers varies, but is often less than a centimetre. Gold-bearing quartz veins are extensively intruded into the Ordovician bedrock, in association with a parallel series of about 40 north-south anticlines over a width of approximately 8km. The minerals pyrite and arsenopyrite are abundantly present within these reef systems, being a favourable indicator for the presence of gold (Wilkinson, 1977).

2.2 Historical gold mining as a source of arsenic in Bendigo

Gold was first discovered in Victoria in the early 1850s, with more than 2,500,000 kg of gold mined to date. Approximately 40% was mined from primary lode deposits, and 60% from alluvial (placer) deposits (Smith et al., 2003). Initially, gold was easily recovered from alluvial deposits using physical separation methods such as hydraulic sluicing. Once alluvial deposits were exhausted, attention was turned to the primary lode

deposits in the form of auriferous pyrites (gold incorporated in mineral grains of pyrite) (Rae, 2001).

Recovering gold from pyrite (FeS2) requires additional processing. Roasting is used to oxidise sulfur in the pyrite, leaving behind gold ore mixed with iron rich gangue (Rae 2001). The roasted ore was then crushed, and gold was recovered through density separation methods or through amalgamation with mercury. In some instances, crushing was performed before roasting, with mining companies sending crushed ore to centralised roasting and recovering plants (Rae, 2001). Bendigo was a major centre for processing auriferous pyrites, reportedly receiving pyritic sands from all over Australia (Lawrence and Davies, 2020).

In Victoria's gold deposits, arsenic primarily occurs as a solid in pyrite (FeS2), thought to substitute sulfide and is present as arsenopyrite (FeAsS) (Thomas et al, 2011). When historical gold processing methods were used on arsenic-bearing pyrite and arsenopyrite (for example. crushing, grinding, milling, sulfide concentration, roasting) the arsenic was often concentrated in the iron oxide tailings. High arsenic concentrations are found in sulfidic phases of primary ores in gold mining regions (up to 5 w/w%) and its associated waste materials (up to 40.5 w/w%) (Craw and Bowell, 2014; Haffert and Craw, 2008; Majzlan et al., 2014).

Historic management practices of the solid wastes produced by the Victorian Goldfields included stockpiling, deposition in low lying areas, and burial, as well as reuse as infill material in earthworks. These practices have resulted in legacy contaminated sites across the region (Hinwood et al., 1998; Smith et al., 2003).

2.3 Background levels

The EP Act 2017, in relation to contaminated land, defines the default background level to be the 'naturally occurring concentration'. The terms 'naturally occurring concentration' or 'natural background' is used commonly to describe 'background levels' reflecting natural geological (geogenic) processes that have not been influenced to any measurable extent by anthropogenic activity (Reimann and Garrett, 2005). Mikkonen (2018) summarised various literature and definitions of background levels, and surmised that even in remote areas, surface soils are not free of anthropogenic influence and do not represent 'natural background' as such.

Mikkonen et al (2018) noted that the term 'ambient background' has been introduced to account for the presence of low-level contaminant concentrations entering the environment from diffuse anthropogenic sources. The EP Act 2017 enables EPA to account for the ambient background contamination by allowing EPA to set background level(s) to reflect historic land use. Where EPA sets a background level for a contaminant in a defined area, this takes precedence over any default background level (that is, the naturally occurring concentration).

In Bendigo, the presence of natural geogenic sources of arsenic - as well as diffuse inputs from historical mining activity - makes distinguishing natural background from anthropogenic inputs challenging.

3 Purpose and objectives of the study

3.1 Purpose

The purpose of this study was to establish an ambient background level for arsenic in surface soils (0.0-0.05 m) across the Bendigo region.

3.2 Objectives of study

To address the purpose of the study, the following was undertaken:

- Collect soil samples representative of ambient background concentrations in Greater Bendigo.
- Quantification of arsenic in the collected soil samples.
- Statistical analysis and interpretation of results using geographic information systems.
- Derivation of an ambient background level, considering geogenic and diffuse inputs of arsenic.
- Benchmarking of the derived level against Australian and international values.

4 Methods

4.1 Study boundary

For the purposes of this study, the Assessment Region was defined spatially by the boundary of the Greater City of Bendigo local government area (LGA), covering approximately 3,000 km^2 (Appendix A Figure 1). The Assessment Region was chosen in consultation with EPA Policy and Regulation Branch, whereby an LGA is a preferred boundary for use in legislative instruments, such as the Classification of Arsenic-Contaminated Waste from the City of Greater Bendigo (Victorian Government Gazette No. S307, 2021).

Based on historical mining records, most of the mining activity in the assessment region was clustered in and around the Bendigo township in a roughly north-south corridor approximately 16 km wide and 24 km long (Appendix A, Figure 2).

4.2 Sampling design

A grid-based sampling pattern was applied to the whole Great Bendigo City Assessment Region. The objective of the study was to derive an ambient background concentration, and grid-based designs are considered suitable for this purpose. Within each spatial grid square, a sampling site on public land was identified. We avoided sample collection at sites known to be (or thought likely to be) influenced by arsenic point sources, including mining waste sites. Avoiding known anthropogenically contaminated sites was important, as such sites are not likely representative of ambient background conditions. This design provided a straightforward and relatively unbiased method and approach for designating sample locations that ensured uniform coverage across the Assessment Region. At the same time, the design allowed some flexibility to select exact sampling locations in alignment with in-field observations, access or safety considerations.

Limitations of the adopted sampling program include insufficient sampling density to identify and delineate hot-spots or source sites, some likely human bias in adjusting exact sampling locations, and that the location of public land is likely subject to some historical biases (that is, partitioning of public and private land in the township was probably not done randomly). However, we consider these limitations to be relatively minor, and they should not confound the final assessment of arsenic background levels.

Sampling density was based on available time and budget, while allowing for sufficient samples to perform required statistical assessments. As historical mining activity in the Assessment Region was largely confined to the Bendigo township, we anticipated that surface soil arsenic concentrations in this central corridor would be more variable (and potentially overall higher) than the surrounding Assessment Region soils. Therefore, the Assessment Region was stratified into two distinct study areas, termed Study Area 1 and Study Area 2. Different sampling grid densities were applied to the two areas (Appendix

A, Figure 3). This was because higher sampling intensity is typically needed to characterise landscapes with greater variability (that is, the central township required a more dense grid to achieve reliable arsenic characterisation).

Study Area 1

Study Area 1 comprises approximately 384 km^2, encompassing the central township of Bendigo and its immediate surrounds. The shape of Study Area 1 is a north-south rectangle, with a width of 16 km and length of 24 km. This defined area covers the corridor of more intense historic mining activity.

A 2 km × 2 km grid was applied to Study Area 1, with one sample collected per grid cell. The object was to collect in the centre-point of the cell, or as close to it as possible.

Study Area 2

Study Area 2 covers approximately 2,600 km^2, comprising the remainder of the Assessment Region. It is bounded by the City of Greater Bendigo LGA limits. Study Area 2 was anticipated to be less impacted by historic mining activity than Study Area 1. This is due to the relatively sparse occurrence of any historical mining recording in this area. Study Area 2 soil data should therefore be more reflective of regional background conditions.

A 4 km × 4 km grid was applied to Study Area 2, with one sample collected per cell. As per above, the object was to take a sample in the centre-point of each cell, or as close to it as possible.

Justification for sampling differences between the two Study Areas

A lower sampling density was adopted for Study Area 2 in comparison to Study Area 1 for the following reasons:

- There was expected to be less variability in arsenic concentrations compared to Study Area 1, given that this area was not subject to significant mining activity.
- The spatial area to be covered in Study Area 2 is far greater than in Study Area 1, and with limited resources, greater focus was placed on Study Area 1 where the most contaminated soils were anticipated to be present.

4.3 On-site assessment and sample collection

To avoid taking samples from substantially comminated or anthropogenically altered soils, a field scientist at each pre-designated sampling location visually assessed the surrounds to identify:

- signs of mining activity (infrastructure, mullock heaps etc)
- the presence imported fill soils
- the presence of other possible point contamination sources, including other industrial activities.

If any of the above were identified, the sampling location was adjusted to be >20 m from the potentially confounding site of human activity. If the sampling location could not be moved away from areas potentially influenced by anthropogenic mining activity, this information was recorded in field notes and photos for interrogation following sample analysis.

Surface soil (0-5 cm depth) samples were collected using a hand trowel. Subsurface samples were collected by digging a shallow pit using a hand trowel or shovel. In each test pit, samples were collected at 0.5 m below ground level, or the maximum depth able to be dug before refusal on rock was encountered.

At each location, GPS coordinates, time/date, site description, sampler's name, photos and additional comments were recorded in Avenza Maps™ (Avenza Systems Inc.). Samples were sealed securely in a labelled ziplock bag and submitted in batches to University of South Australia for concentration analysis of arsenic and other major and minor trace elements. Samples were analysed within 3 months of sampling. Trowels used for soil sampling were triple-rinsed between sampling locations to avoid cross-contamination.

4.4 Laboratory analytical methods

Laboratory analysis was conducted at the Future Industries Institute, University of South Australia. Pseudo-total elemental concentration was measured in all samples using aqua-regia digestion. Elemental concentrations in the aqua-regia digests were determined by Triple Quad Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Agilent Technologies Incorporated).

For pseudo-total elemental concentration, aqua-regia soil digestion method 3051A (USEPA, 2007) was used. Samples were oven-dried and sieved to two particle size fractions, <2mm and <250 µm. The < 2 mm and < 250 µm soil particle size fractions were weighed, with a subsample comprising 0.5 g placed in teflon digestion tubes. Inside a fume hood, 5 mL of aqua-regia [3:1 v/v 37% hydrochloric acid (HCl) : 70% nitric acid (HNO^3)] was pumped into digestion tubes and left overnight to pre-digest the samples (Kastury et al., 2021). Samples were digested with a Mars6 microwave (CEM) using US

EPA method 3051A (US EPA 2007). The digestion method requires that the acidified sample temperature increases to 175 ˚C over 10 minutes, holds temperature 175 ˚C for 10 minutes, then cools for 20 minutes. For quality assurance and quality control purposes, one standard reference material from the National Institute of Standards and Technology (NIST) 2710a Montana 1 soil, and one reagent blank was analysed every 38 samples. A duplicate sample was analysed every 10th sample.

Following digestion, the supernatant was decanted into 50 mL centrifuge tubes and diluted up to 50 mL using Milli-Q water, then syringe-filtered (0.45 µm, cellulose acetate) to separate undigested solids from the solution containing dissolved elements. The digested samples were stored at room temperature until analysis. Quantification of pseudo-total elemental concentrations was conducted using US EPA method 6010D for ICP-OES and 6020B for ICP-MS. For quality assurance and quality control purposes, a spiked sample (spiked at a final concentration of 400 and 500 µg/kg of arsenic) and two Continuous Check Verifications (CCV) (10 and 100 µg/kg of arsenic) were used every 20 samples (USEPA, 2018).

A summary of quality assurance and quality control samples is provided below. Tabulated results are provided in Appendix B Table B1-B5.

The standard reference material, NIST SRM 2710a is certified to contain 1540 mg/kg arsenic. Average recovery of arsenic was 93% (n=14), ranging from 86 – 106%, giving a high level of confidence to the preciseness of the laboratory method used. A total of 29 laboratory duplicate samples were tested at a rate of 9% total sampling locations. Average relative percent difference was 1%, giving a high level of confidence in analytical repeatability of the primary result. To test the reproducibility of field sampling, arsenic was measured in the field at 257 locations using pXRF instrumentation. Mean difference in arsenic concentrations between laboratory arsenic results compared with field pXRF results was 3.5 mg/kg, with a strong correlation observed in linear regression analysis. The results of the pXRF analysis will be reported elsewhere, but are used here in place of laboratory analysed field duplicates and triplicates.

Continuous check verifications (CCV) of 10 ppb and 100 ppb were run at a rate of 8% total sampling locations. For the 10 ppb CCV (n=34), a mean 10.23 ppb was reported, with an average percent deviation of 2.31 % from 10 ppb. For the 100 ppb CCV (n=34), a mean of 102.31 ppb was reported, with an average percent deviation of 2.31 % from 100 ppb. Spiked samples were tested a rate of 8% total sampling locations, with an average recovery of 98.52%. Reagent blanks had arsenic concentration of <0.01 mg/kg (n = 16).

4.5 Statistical and data analytical methods

Analytical and field data were inputted in to ProUCL 5.1 (USEPA, 2016) for statistical analysis. Although exact sample collection sites were adjusted spatially to avoid identifiable point sources of arsenic, additional statistical analyses were undertaken to further reduce the potential for the ambient background dataset to be influenced by point-source outlier concentration values. Specifically, the following outlier removal process was performed: Statistical outliers were identified as being results greater than the third quartile plus 1.5 times the interquartile range (Q3 + (1.5 x IQR)) (Palmer et al., 2021).

Where a statistical outlier was identified, further investigation was undertaken to inform a decision about whether to exclude the result from the ambient background dataset. This investigation included review of field notes/photos and aerial imagery to identify the potential for the result to have been influenced by mining waste or other anthropogenic industrial activity.

After removal of suspect outlier data, summary statistics and percentiles were calculated.

A two-way Wilcoxon-Mann-Whitney test was used to assess differences in medians between Study Area 1 and Study Area 2. This test is appropriate for non-normally distributed data.

Georeferenced data were inputted into ArcMap (ArcGIS 10.0) to prepare various maps and figures.

5 Results and discussion

5.1 Soil sampling

In total, 263 samples were collected from across the Assessment Region, comprising 107 samples across Study Area 1 and 156 across Study Area 2. Due to geographic and access constraints, there were several locations which were adjusted away from the centroid of the grid cell or could not be collected at all (for example, samples could not be retrieved from in or around water bodies like Lake Eppalock, in the west of the Assessment Region).

5.2 Results (outliers included)

In the <2 mm size fractions, arsenic was detected in all samples analysed in the Assessment Region. Concentrations ranged from 1 mg/kg to 2,632 mg/kg (Table 1, Appendix A, Figure 4, and Appendix B, Table B1). The highest soil arsenic concentration (2,632 mg/kg) was reported in the west of the Study Area 2, near the town of Fosterville, in a sample that was later discovered to be mining sand. This data point was excluded from the ambient background dataset as per the methods in Section 5.5.

	Study Area 1 – Central Bendigo	**Study Area 2 – Broader Bendigo**
Sample count	107	156
Minimum arsenic concentration (mg/kg)	1	1
Maximum arsenic concentration (mg/kg)	516	2632
Mean arsenic concentration (mg/kg)	37	35
Geometric Mean arsenic concentration (mg/kg)	17	7
Standard deviation (mg/kg)	72	238
Standard error of the mean	7	19
Coefficient of variation	2	7

Table 1: Summary statistics of the surface soil samples raw dataset including outliers.

5.3 Outlier identification and removal

Whilst the sampling approach aimed to avoid mining waste or areas directly or likely to be directly affected by mining activity (Section 5.2, above), inadvertent collection of samples directly influenced by mining activity or other point sources appears to have occurred. This is not surprising given the scale of mining activity in the region, but it nevertheless highlights the importance of identifying and assessing outliers to reduce the likelihood of such results influencing the estimated ambient background concentrations. A summary of statistical outliers and parameters used to identify these outliers is provided in Table 2. Each statistical outlier was assessed following the approach described in Section **Error! Reference source not found.**. Details of the assessment are provided in Appendix C.

Value	**Study Area 1 – Central Bendigo**	**Study Area 2 – Broader Bendigo**
Lower quartile (Q1) (mg/kg)	9	4
Median (Q2) (mg/kg)	15	6
Upper quartile (Q3) (mg/kg)	26	8
Interquartile range (IQR=Q3 Q1) (mg/kg)	17	4
Statistical outlier upper threshold (Q3+1.5xIQR) (mg/kg)	52	14
Count of outliers	15	10
Total samples following removal of outliers	107	156

Table 2: Dataset parameters used to identify statistical outliers in each study area of all surface soil samples.

5.4 Influence of particle size on arsenic concentration

Total arsenic concentrations measured in the two particle size fractions (<2 mm and <250 µm) are displayed (Figure 1). Arsenic concentration in the <2 mm indicates bulk soil composition, while the finer <250 µm fraction is relevant for human health risk assessment. The <250 µm fraction is the more likely to stick to hands and be incidentally ingested by children < 5 years of age (age class with pre-disposition for hand to mouth behaviour), or adhere to home gardened produce, or be carried on wind and deposited on eating surfaces. The proportion of arsenic in the finer fraction was slightly higher in Study Area 1, compared to Study Area 2, which is likely due to enrichment from anthropogenic sources (Luo et al., 2011) including fine grained mine waste (Martin et al., 2016). This source of anthropogenic contamination this has not been confirmed in this study. Characterisation of arsenic forms in the different size fractions could further inform the sources.

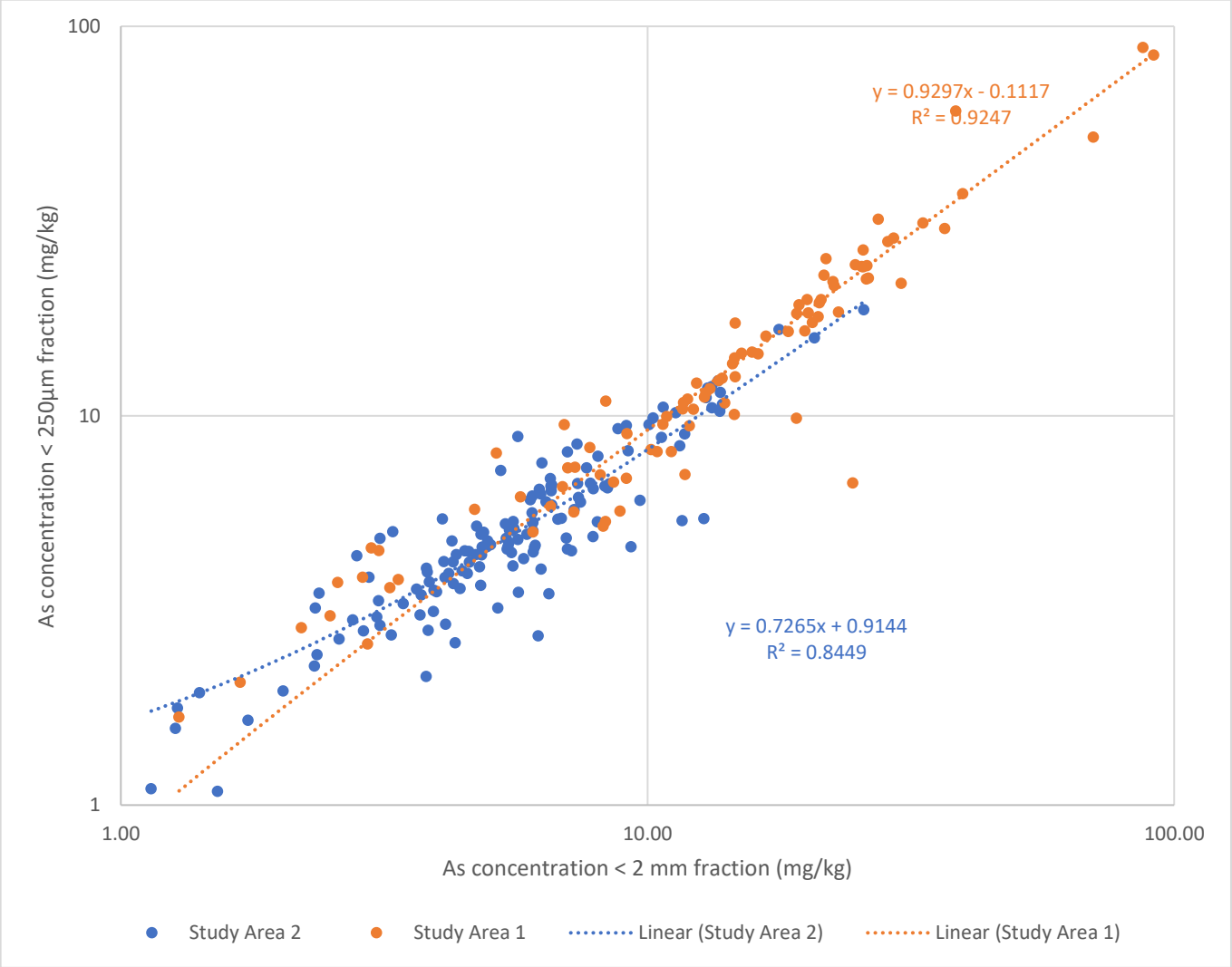

Figure 1: Comparison of arsenic concentration in the <2 mm and <250 µm size fractions includes both surface and subsurface soils with outliers removed. Note that the data are plotted on log-log axes.

5.5 Influence of depth on arsenic concentration

Extraction and crushing of arsenic rich ore in Bendigo resulted in many legacy contaminated sites. These may act as ongoing sources of arsenic entering topsoil across the broader environment, via wind and/or hydrological processes. It is hypothesised that higher concentrations of arsenic in surface soils relative to subsoils at point source impacted sites and sites in Study Area 1 are indicative of anthropogenic inputs of arsenic in surface soil.

Corresponding surface and subsoil samples were collected at 19 locations across the Assessment Region. Subsoils were sampled at 0.3 m (n = 6) and 0.5 m (n = 13) depth, depending on the maximum depth able to be dug before refusal was encountered. Table 3 below summarises data obtained across different depths for Study Area 1 and Study Area 2.

	Study Area 1 – Central Bendigo		**Study Area 2 – Broader Bendigo**	
	Surface Soil	**Subsurface Soil**	**Surface soil**	**Subsurface soil**
Total samples	12	12	7	7
Minimum As concentration (mg/kg)	2	1	3	3
Median As concentration (mg/kg)	9	7	6	5
Maximum As concentration (mg/kg)	29	14	11	11
Mean As concentration (mg/kg)	12	7	6	6
Standard error (mg/kg)	3	6	1	1

Table 3: Summary statistics of arsenic concentrations based only on co-located samples at the surface (0-5 cm) and subsurface (30-50 cm) depth in the <2mm fraction, outliers are excluded.

In Study Area 1, the mean topsoil arsenic concentration was 12 ± 3 mg/kg, compared to 7 ± 1 mg/kg in subsurface soils, though no statistically significant difference was observed ($P>0.05$). The mean arsenic concentration in subsurface soils from Study Area 1 (7 ± 1 mg/kg) was very close to those measured in Study Area 2 (6 ± 2 mg/kg). Moreover, the mean surface soil arsenic concentrations in Study Area 2 (6 ± 2 mg/kg) was also highly similar to subsurface soils from Study Area 2. This suggests that there were no clearly discernible arsenic concentrations entering the surface soils from diffuse inputs associated with mining sources in these twelve sampling sites. If surface soils were receiving diffuse arsenic, the expectation would be that surface soils would have higher overall concentrations than the subsurface soils.

5.6 Ambient Background Dataset

Summary statistics for the datasets after outlier verification and removal are presented (Table 4). These refined datasets will be subsequently referred to as the 'ambient background datasets'. The <2mm grain size fraction has been used an ambient background level, as this is the fraction measured during contaminated site assessments that follow the National Environmental Protection (Assessment of Site Contamination) Measure (NEPC, 2013).

Concentrations of arsenic were generally higher in Study Area 1 than in Study Area 2 in the ambient background dataset as displayed in Table 4. A two-way Wilcoxon-Mann-Whitney test following outlier removal indicated a significant difference in the mean arsenic concentrations ($w = 10{,}854$, $P < 0.001$) between the two study areas. This indicates that it is appropriate to treat the Study Areas as individual populations.

	Study Area 1 – Central Bendigo	**Study Area 2 – Broader Bendigo**
Sample count	92	146
Count of outliers removed	15	10
Minimum As concentration (mg/kg)	1	1
Median As concentration (mg/kg)	14	6
Maximum As concentration (mg/kg)	91	26
Mean As concentration (mg/kg)	18	6
Standard deviation (mg/kg)	15	4
Standard error around the mean (mg/kg)	2	0.3

Table 4: Summary of ambient background datasets, <2mm grain size.

The distributions of the datasets for both study areas did not meet assumptions of normality (Shapiro-Wilk's test of normality). As such, the estimated upper threshold background level used the 95%tile (Palmer et al., 2021). The values obtained were 40 mg/kg and 14 mg/kg for Study Area 1 and Study Area 2, respectively. Note that the value of 40 mg/kg is not suitable for use as a background ambient threshold, because the central Bendigo Study Area 1 is known to be heavily affected by point source historic gold mining.

However, the 95 percentile of ambient background arsenic for Study Area 2 (14 mg/kg) is consistent with previously reported estimates of natural background arsenic, both in Vicotria and elsewhere. Reimann and Garrett, (2005) reported that median arsenic concentrations in undisturbed soils across 14 different studies around the world were typically <30 mg/kg. A recent study by Palmer et al.(2021) proposed an upper threshold for geochemical background of 15 mg/kg (upper inner fence n=1490) in the Yellowknife gold mining region in Canada. In Australia, (Reimann and de Caritat, 2017) proposed a continent-wide geochemical background threshold of 16.8 mg/kg based on the upper inner fence of a Tukey box-plot (n=1313) of the National Geochemical Survey of Australia dataset. In Stawell Victoria (a gold mining town), Noble et al. (2010) measured a maximum regional background of 16.4 mg/kg (n=8) in surface soils within 15 km of the

town. The upper inner fence is equal to the third quartile (75th percentile) plus 1.5 times the interquartile range. The upper thresholds estimated in this study do not represent geochemical background, rather they are likely to include some diffuse anthropogenic inputs. Nevertheless, the concentrations are consistent with the values reported in the National Geochemical Survey of Australia dataset, indicating that diffuse point sources have not substantively altered geogenic background in Study Area 2.

Unsurprisingly, given the known history of intensive gold mining activity in Study Area 1, the upper thresholds for ambient background thresholds were higher than Study Area 2. Anthropogenic influences on the ambient background level for Study Area 1 are also supported by the presence of lower arsenic concentrations in subsurface soils compared to surface soils.

Given the likelihood that the level derived for Study Area 1 is elevated due to point source historical mining, it is recommended that the 95th percentile of the ambient background dataset for Study Area 2 (14 mg/kg) be adopted as an ambient background level for the Assessment Region. This 14 mg/kg value also corresponds to the maximum arsenic concentration observed in subsurface soils, and the median surface soil arsenic concentration in Study Area 1.

5.7 Contaminated land implications

As set out in Section 35 of the EP Act 2017, and further clarified in EPA Publication 1940, with respect to arsenic in soil, land is considered contaminated where the concentration exceeds background levels ***and*** creates a risk of harm to human health or the environment. With respect to the term 'creates a risk of harm', EPA Publication 1940 describes this expression to be akin to the word 'hazard' – that is, presence of a chemical substance or waste that has an inherent characteristic capable of causing harm. For the purposes of Section 35 of the EP Act, Publication 1940 suggests that the lowest of default ecological investigation level (EIL) and health investigation level (HIL) set out in the National Environment Protection (Assessment of Site Contamination) 1999 (as amended 2013) be used as thresholds for 'creates a risk of harm' when determining the status of contaminated land at a site. With respect to arsenic, the default HIL-A is 100 mg/kg and the EIL is 40 mg/kg.

In both cases neither threshold is reached in respect of the ambient background concentrations derived in this study. The maximum concentration of arsenic in the ambient background dataset is 91 mg/kg, below the HIL-A value of 100 mg/kg, which used as a threshold concentration for creating a risk of harm to human health. The HIL-A is also used to inform the need to notify EPA of contaminated land in low density residential land use settings. Importantly, based on the data collected in this study, the ambient background concentrations of arsenic in soil across the City of Greater Bendigo are unlikely to attract a duty to notify of contaminated land, even in residential land use settings because the concentrations are below HIL-A. As such, the ambient background level based on the results of this study will not have any effect on the

thresholds for which land is considered to be contaminated in the region, nor on the duty to notify notification thresholds. The outliers excluded from the dataset have not been considered here, and future work is required to assess the significance of point source mining waste sites.

With respect to risk of harm to the environment, 5% (95th percentile = 40 mg/kg) of the ambient background dataset for Study Area 1 exceeded the 40 mg/kg EIL value. This EIL value corresponds to 99% species protection levels and is applicable to areas of ecological significance including national parks and designated conservation areas. The observed exceedances of this value are consistent with historic mining activities in the area. Further assessment should be undertaken to determine if the exceedances occur in areas of ecological significance to assess whether or not the 99% species protection levels are applicable.

6 Summary and Recommendations

6.1 Ambient background level in surface soils

Based on the results of the soil survey and associated statistical analysis, the ambient background concentrations of arsenic in surface and subsurface soils soil across the City of Greater Bendigo local government area did not exceed a maximum of 91 mg/kg (n = 238). Instances of moderately elevated concentrations (maximum concentration of 91 mg/kg) were observed in surface soils in and around the Bendigo township (Study Area 1) compared to Study Area 2, likely owing to increased incidences of point source historical mining activity, urbanisation and other industrial activity in that area. Nevertheless, the median total arsenic concentration (14 mg/kg) was markedly below the NEPM HIL A value for residential land use (100 mg/kg), below which a risk of harm to human health is not considered to be created.

Arsenic concentrations in subsurface soils in Study Area 1 were consistent with those measured in surface and subsurface soils in Study Area 2. Therefore, adopting an ambient background level based on surface soil concentrations in Study Area 1 will likely overestimate subsurface concentrations. Across the broader local government area (Study Area 2), ambient background concentrations of arsenic in surface soil were consistent with geochemical background and ambient background concentrations reported for Victoria and Australia (Reimann and de Caritat, 2017, Mikkonen et al., 2017).

The 95th percentile of the ambient background surface soil (< 2mm) dataset in Study Area 2 (14 mg/kg) is deemed to be a suitable value to be used as an upper threshold for ambient background across the whole of the City of Greater Bendigo local government area. This is also equivalent to the median concentration of the ambient background dataset (15 mg/kg, <2mm) collected from Study Area 1 and corresponds with the maximum subsurface arsenic concentrations (< 2mm) in Study Area 1.

6.2 Assessing other parts of Central Victoria

This work focussed on understanding the arsenic soil concentrations across the City of Greater Bendigo local government area. Future assessments of ambient background could be undertaken using the above approach in other regions and towns where historical gold mining and ore processing has occurred. EPA Victoria has recently acquired pXRF analysis capabilities, which will enable efficient and effective analysis of ambient background soil concentrations for arsenic amongst other trace elements.

6.3 Assessing the significance of point source/mine waste sites

This study focussed on characterising soil arsenic concentrations in the ambient environment of Greater Bendigo, and by design excluded point source mine waste sites

in the area. The significance of discrete mine waste sites requires further study. This could include:

- The identification and mapping of mine waste sites across the Assessment Region.
- Characterisation of mine wastes with respect to arsenic bioavailability. Application of this information in guidance may provide further clarification about contaminated land duties.
- Impact of contaminated mine wastes on residential environments adjacent to known point sources.

Further work is currently being undertaken by EPA Science to better understand the location of mine waste sites, with a focus on those containing grey sands to better understand total and bioavailable arsenic concentrations.

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Appendix A – Figures

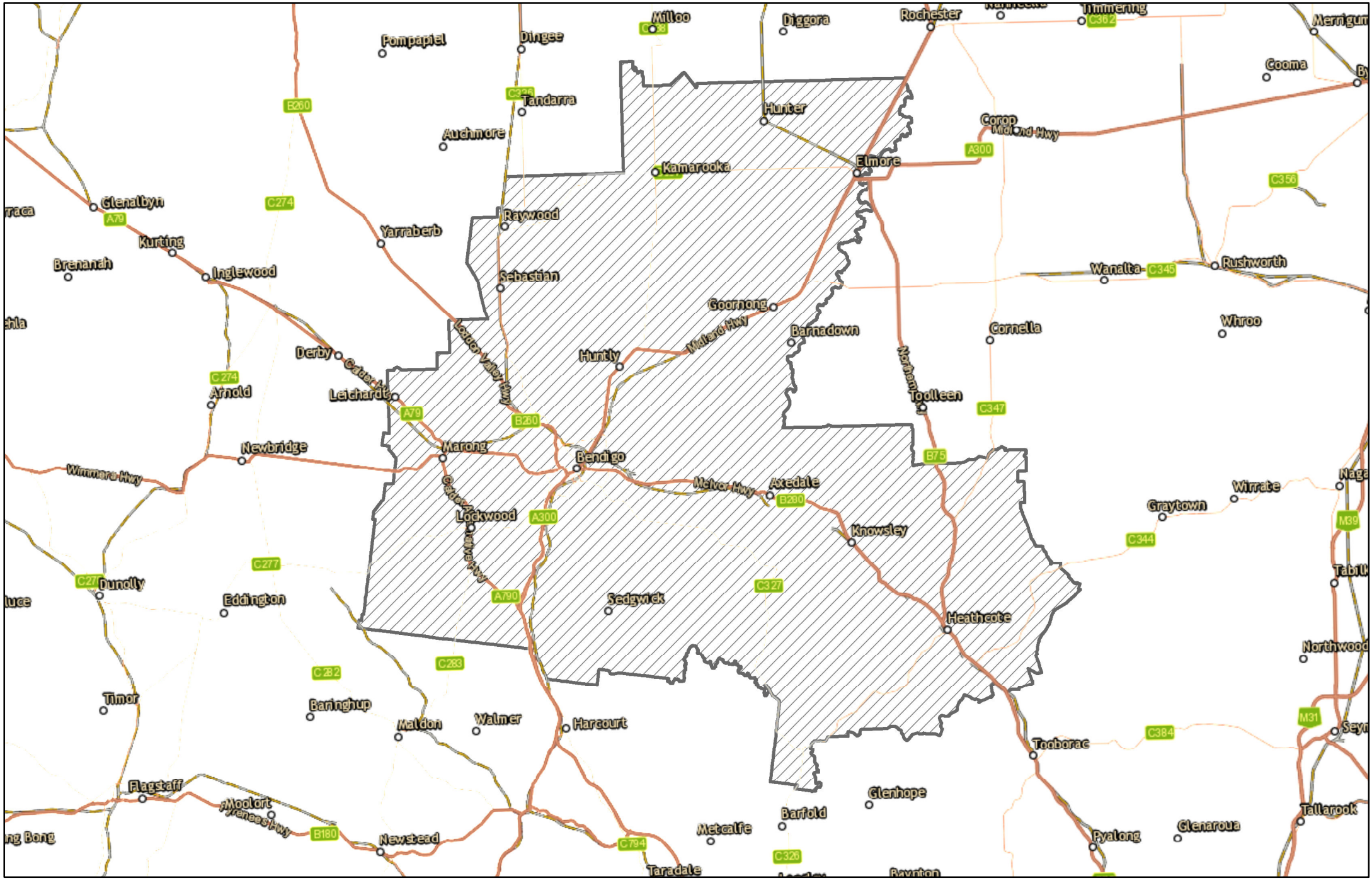


FIGURE 1
Assessment Region

Legend

Assessment Region

0 2.5 5 10 Km

Data Sources:
Assessment Region (EPA Victoria 2022)
Basemap (ESRI)

N

EPA VICTORIA

Map Printed On: 16/02/2022

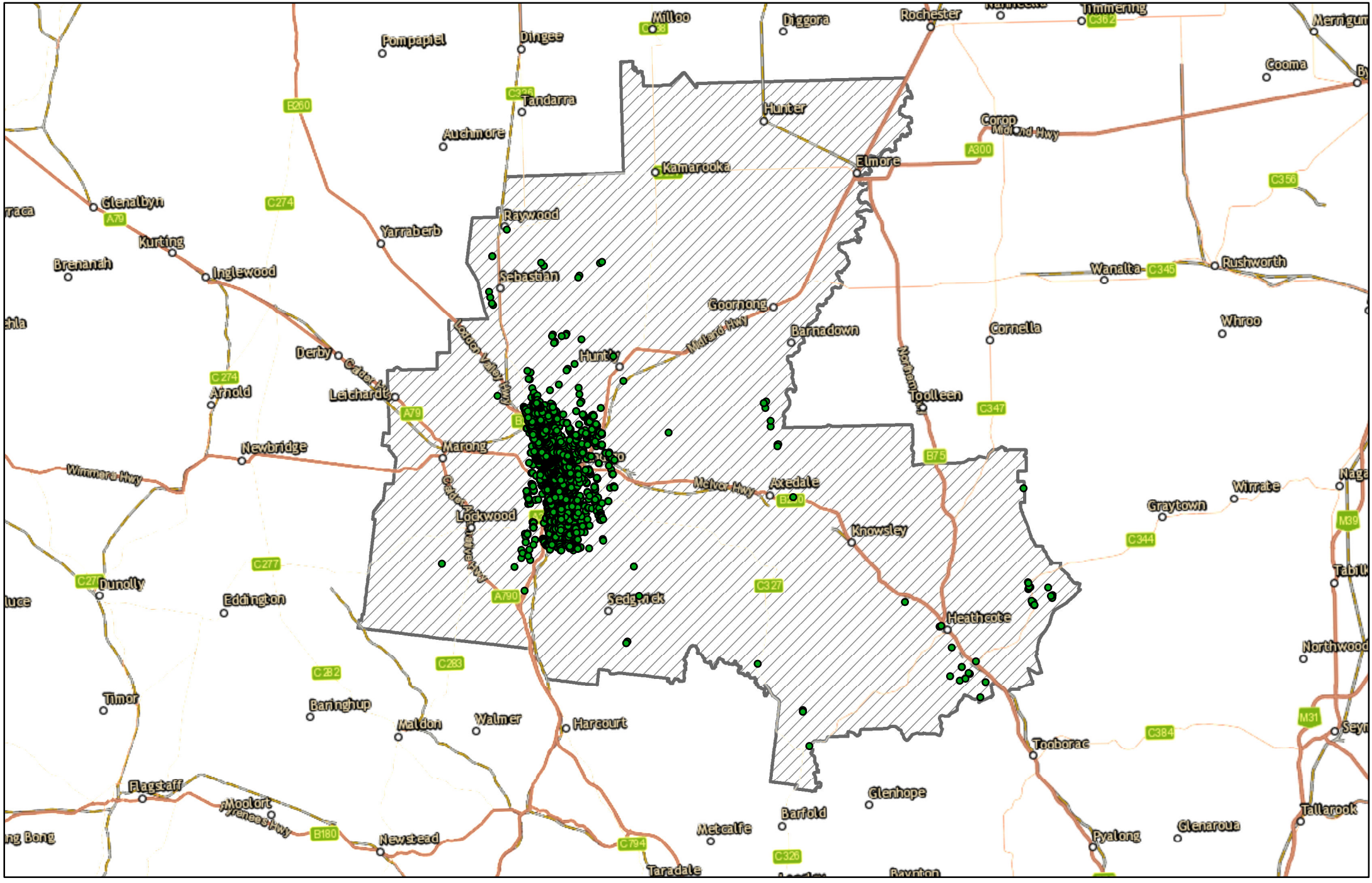


FIGURE 2
Historical mining activity

Legend

- Historical mining activity records
- Assessment Region

0 2.5 5 10 Km

Data Sources:
Study areas (EPA Victoria 2022)
Basemap (ESRI)
Historical Mining Activity
(Department of Jobs, Precincts and Regions, 2022)

N

EPA VICTORIA

Map Printed On: 16/02/2022

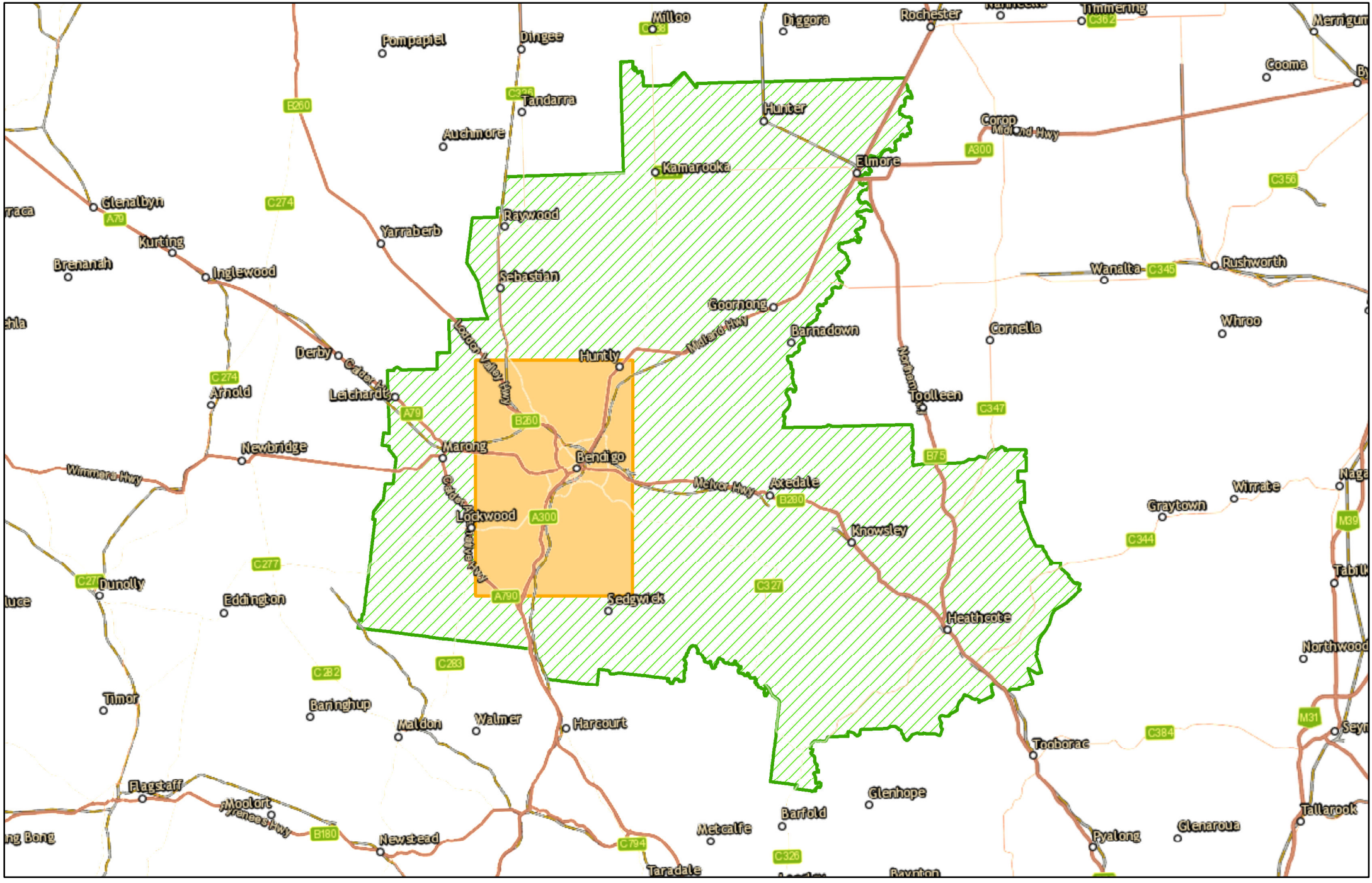


FIGURE 3
Study Area Overview

Legend

Study Area 1

Study Area 2

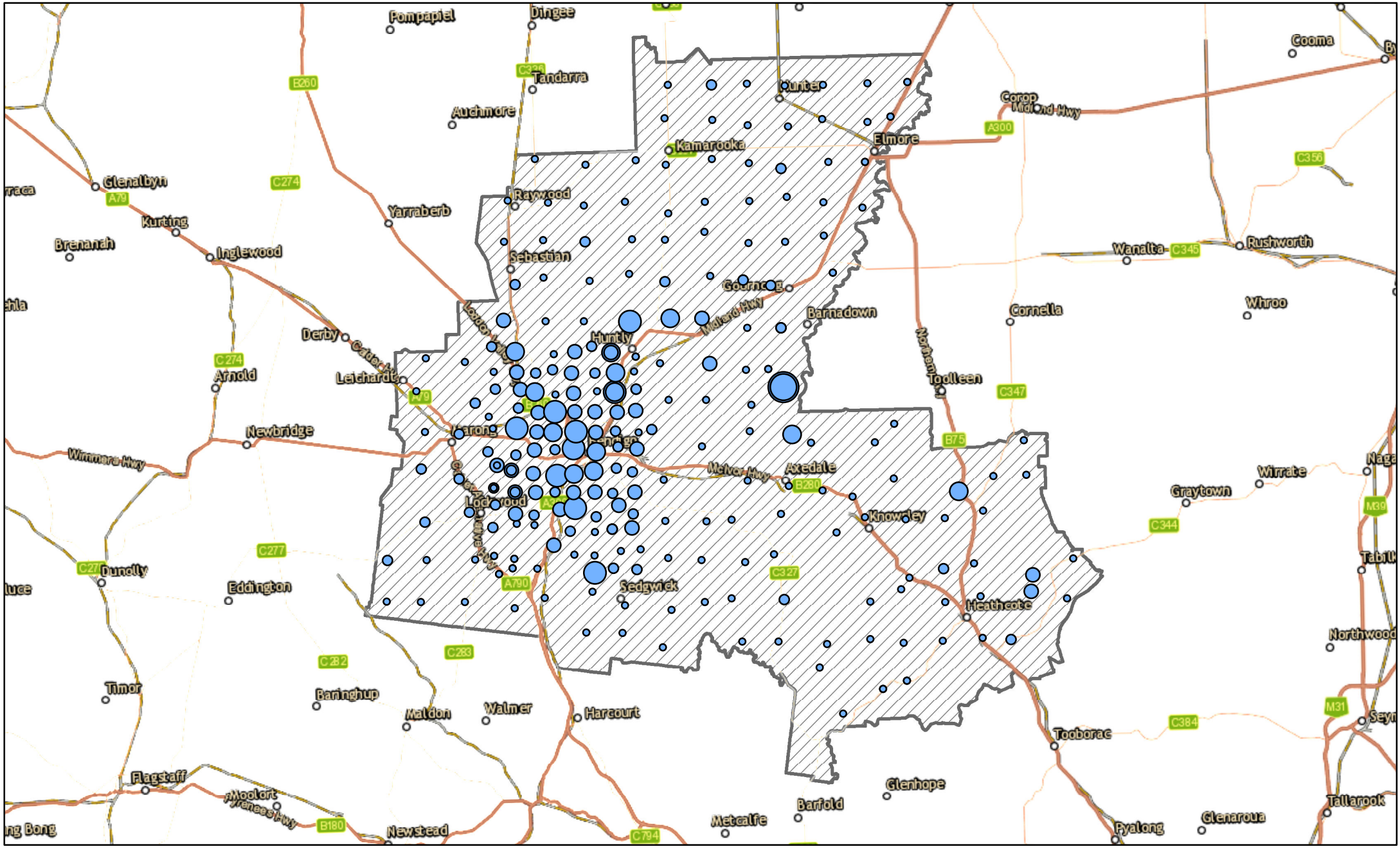
0 2.5 5 10 Km

Data Sources:
Study areas (EPA Victoria 2022)
Basemap (ESRI)

N

EPA VICTORIA

Map Printed On: 16/02/2022



Legend

Arsenic concentration (mg/kg)

- 1 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 1000
- 1000 - 1500
- 1500 - 2632

0 2.5 5 10 Km

N

Data Sources:
Assessment Region (EPA Victoria 2022)
Basemap (ESRI)

EPA VICTORIA

Map Printed On: 16/02/2022

FIGURE 4
Arsenic Results

Appendix B – Data tables

Location ID	Study Area	Latitude	Longitude	Depth (m bgl)	LOD mg/kg	As <2 mm (mg/kg)	As < 250 µm (mg/kg)
B001	Study Area 1	-36.864730	144.177573	0.00 - 0.05	0.01	2.88	3.85
B001	Study Area 1	-36.864730	144.177573	0.40 - 0.50	0.01	1.29	1.68
B003	Study Area 1	-36.861175	144.263942	0.00 - 0.05	0.01	7.25	5.66
B004	Study Area 1	-36.866078	144.285047	0.00 - 0.05	0.01	146.94	107.68
B005	Study Area 1	-36.862397	144.306088	0.00 - 0.05	0.01	10.71	9.49
B006	Study Area 1	-36.864164	144.332160	0.00 - 0.05	0.01	10.88	9.95
B007	Study Area 1	-36.848221	144.172478	0.00 - 0.05	0.01	2.50	3.06
B007	Study Area 1	-36.848221	144.172478	0.40 - 0.50	0.01	1.69	2.07
B008	Study Area 1	-36.851362	144.195069	0.00 - 0.05	0.01	5.17	8.01
B008	Study Area 1	-36.851362	144.195069	0.40 - 0.50	0.01	2.58	3.73
B010	Study Area 1	-36.840116	144.239746	0.00 - 0.05	0.01	21.08	17.95
B011	Study Area 1	-36.849057	144.262513	0.00 - 0.05	0.01	6.90	6.56
B012	Study Area 1	-36.850555	144.285191	0.00 - 0.05	0.01	8.62	6.75
B013	Study Area 1	-36.847147	144.314680	0.00 - 0.05	0.01	8.13	7.05
B014	Study Area 1	-36.846146	144.336935	0.00 - 0.05	0.01	8.24	5.20
B015	Study Area 1	-36.822738	144.171985	0.00 - 0.05	0.01	19.17	9.84
B016	Study Area 1	-36.819928	144.198825	0.00 - 0.05	0.01	6.96	9.47
B017	Study Area 1	-36.821667	144.218683	0.00 - 0.05	0.01	6.06	5.02
B018	Study Area 1	-36.828809	144.244771	0.00 - 0.05	0.01	14.50	13.58
B019	Study Area 1	-36.827876	144.258624	0.00 - 0.05	0.01	14.64	14.06
B020	Study Area 1	-36.829322	144.286363	0.00 - 0.05	0.01	9.12	6.90
B021	Study Area 1	-36.827260	144.305620	0.00 - 0.05	0.01	18.51	16.43
B021	Study Area 1	-36.827260	144.305620	0.20 - 0.30	0.01	11.11	8.07
B022	Study Area 1	-36.826508	144.327852	0.00 - 0.05	0.01	20.58	17.33
B023	Study Area 1	-36.802465	144.175832	0.00 - 0.05	0.01	12.01	9.41
B024	Study Area 1	-36.810885	144.198162	0.00 - 0.05	0.01	24.83	24.37
B025	Study Area 1	-36.812525	144.218824	0.00 - 0.05	0.01	11.66	10.40
B026	Study Area 1	-36.808050	144.247968	0.00 - 0.05	0.01	21.20	19.46
B027	Study Area 1	-36.807279	144.264810	0.00 - 0.05	0.01	516.05	384.16
B028	Study Area 1	-36.815603	144.288390	0.00 - 0.05	0.01	19.20	18.28
B029	Study Area 1	-36.805808	144.313881	0.00 - 0.05	0.01	36.67	30.21
B030	Study Area 1	-36.813875	144.329965	0.00 - 0.05	0.01	16.78	16.00
B031	Study Area 1	-36.787130	144.174325	0.00 - 0.05	0.01	13.65	12.29
B031	Study Area 1	-36.787130	144.174325	0.20 - 0.30	0.01	6.55	5.84
B032	Study Area 1	-36.791226	144.198070	0.00 - 0.05	0.01	21.36	19.84
B032	Study Area 1	-36.791226	144.198070	0.20 - 0.30	0.01	12.23	10.37
B033	Study Area 1	-36.792334	144.221253	0.00 - 0.05	0.01	22.50	22.07
B034	Study Area 1	-36.792273	144.242851	0.00 - 0.05	0.01	14.68	12.58
B035	Study Area 1	-36.793089	144.263507	0.00 - 0.05	0.01	39.67	37.10
B036	Study Area 1	-36.793304	144.287635	0.00 - 0.05	0.01	26.06	22.43
B037	Study Area 1	-36.795015	144.307575	0.00 - 0.05	0.01	13.14	11.73
B038	Study Area 1	-36.794317	144.332420	0.00 - 0.05	0.01	25.53	24.15
B039	Study Area 1	-36.766625	144.178787	0.00 - 0.05	0.01	20.11	19.86
B039	Study Area 1	-36.766625	144.178787	0.20 - 0.30	0.01	9.14	8.98
B040	Study Area 1	-36.771563	144.194796	0.00 - 0.05	0.01	29.36	28.57
B040	Study Area 1	-36.771563	144.194796	0.20 - 0.30	0.01	12.40	12.12
B041	Study Area 1	-36.775050	144.219293	0.00 - 0.05	0.01	26.11	24.27
B042	Study Area 1	-36.777662	144.245570	0.00 - 0.05	0.01	122.61	236.11

Location ID	Study Area	Latitude	Longitude	Depth (m bgl)	LOD mg/kg	As <2 mm (mg/kg)	As < 250 µm (mg/kg)
B043	Study Area 1	-36.776714	144.264881	0.00 - 0.05	0.01	89.49	87.87
B044	Study Area 1	-36.774404	144.287046	0.00 - 0.05	0.01	87.27	97.53
B045	Study Area 1	-36.772322	144.312338	0.00 - 0.05	0.01	14.02	10.77
B046	Study Area 1	-36.776082	144.330189	0.00 - 0.05	0.01	14.62	10.06
B047	Study Area 1	-36.754207	144.169335	0.00 - 0.05	0.01	10.43	8.07
B048	Study Area 1	-36.758008	144.200528	0.00 - 0.05	0.01	16.22	14.40
B049	Study Area 1	-36.754058	144.221237	0.00 - 0.05	0.01	25.70	24.11
B050	Study Area 1	-36.754271	144.244427	0.00 - 0.05	0.01	14.67	17.28
B051	Study Area 1	-36.753532	144.265133	0.00 - 0.05	0.01	413.93	439.41
B052	Study Area 1	-36.757298	144.290281	0.00 - 0.05	0.01	87.29	88.21
B053	Study Area 1	-36.753179	144.314769	0.00 - 0.05	0.01	12.83	11.15
B054	Study Area 1	-36.755414	144.336099	0.00 - 0.05	0.01	21.84	25.27
B055	Study Area 1	-36.733715	144.175325	0.00 - 0.05	0.01	7.05	7.34
B056	Study Area 1	-36.734088	144.202298	0.00 - 0.05	0.01	137.40	122.84
B057	Study Area 1	-36.737759	144.224645	0.00 - 0.05	0.01	30.34	21.84
B058	Study Area 1	-36.738453	144.242590	0.00 - 0.05	0.01	91.42	84.30
B059	Study Area 1	-36.738477	144.268523	0.00 - 0.05	0.01	279.07	429.22
B060	Study Area 1	-36.739852	144.290625	0.00 - 0.05	0.01	38.51	60.56
B061	Study Area 1	-36.738927	144.312323	0.00 - 0.05	0.01	15.09	14.44
B062	Study Area 1	-36.740851	144.338163	0.00 - 0.05	0.01	7.77	8.28
B063	Study Area 1	-36.722718	144.171121	0.00 - 0.05	0.01	5.74	6.18
B064	Study Area 1	-36.715945	144.204614	0.00 - 0.05	0.01	19.39	19.24
B065	Study Area 1	-36.720256	144.226684	0.00 - 0.05	0.01	28.59	27.97
B066	Study Area 1	-36.720239	144.245430	0.00 - 0.05	0.01	143.19	243.23
B067	Study Area 1	-36.720755	144.267800	0.00 - 0.05	0.01	27.43	31.91
B068	Study Area 1	-36.721266	144.290171	0.00 - 0.05	0.01	33.36	31.22
B069	Study Area 1	-36.722247	144.314888	0.00 - 0.05	0.01	21.63	22.93
B070	Study Area 1	-36.720928	144.335929	0.00 - 0.05	0.01	24.54	6.71
B071	Study Area 1	-36.698318	144.179649	0.00 - 0.05	0.01	15.80	14.55
B072	Study Area 1	-36.699407	144.207754	0.00 - 0.05	0.01	20.21	18.35
B073	Study Area 1	-36.701710	144.223708	0.00 - 0.05	0.01	70.23	51.85
B074	Study Area 1	-36.704485	144.246664	0.00 - 0.05	0.01	8.34	10.88
B075	Study Area 1	-36.703838	144.266683	0.00 - 0.05	0.01	25.67	26.60
B076	Study Area 1	-36.702794	144.293300	0.00 - 0.05	0.01	3.24	3.61
B077	Study Area 1	-36.703937	144.312988	0.00 - 0.05	0.01	110.92	128.89
B077	Study Area 1	-36.703937	144.312988	0.40 - 0.50	0.01	84.02	136.55
B078	Study Area 1	-36.701958	144.336686	0.00 - 0.05	0.01	19.90	16.49
B078	Study Area 1	-36.701958	144.336686	0.40 - 0.50	0.01	13.87	12.48
B079	Study Area 1	-36.682723	144.178352	0.00 - 0.05	0.01	7.28	7.36
B080	Study Area 1	-36.683704	144.203983	0.00 - 0.05	0.01	22.63	21.55
B081	Study Area 1	-36.684980	144.225028	0.00 - 0.05	0.01	11.93	11.02
B082	Study Area 1	-36.682326	144.244233	0.00 - 0.05	0.01	10.16	8.17
B083	Study Area 1	-36.685848	144.265288	0.00 - 0.05	0.01	26.27	22.54
B084	Study Area 1	-36.686469	144.291581	0.00 - 0.05	0.01	11.71	10.79
B085	Study Area 1	-36.686310	144.314194	0.00 - 0.05	0.01	63.39	72.47
B086	Study Area 1	-36.685948	144.335040	0.00 - 0.05	0.01	2.94	2.59
B087	Study Area 1	-36.659801	144.176676	0.40 - 0.50	0.01	8.32	5.34
B087	Study Area 1	-36.659801	144.176676	0.00 - 0.05	0.01	12.91	11.45

Location ID	Study Area	Latitude	Longitude	Depth (m bgl)	LOD mg/kg	As <2 mm (mg/kg)	As < 250 µm (mg/kg)
B088	Study Area 1	-36.665169	144.202650	0.00 - 0.05	0.01	66.96	61.47
B090	Study Area 1	-36.668089	144.246055	0.00 - 0.05	0.01	8.87	5.69
B091	Study Area 1	-36.666727	144.269713	0.00 - 0.05	0.01	23.04	18.42
B092	Study Area 1	-36.662187	144.288498	0.00 - 0.05	0.01	11.79	7.05
B093	Study Area 1	-36.668380	144.309955	0.00 - 0.05	0.01	64.72	50.01
B093	Study Area 1	-36.668380	144.309955	0.40 - 0.50	0.01	43.13	51.89
B094	Study Area 1	-36.672572	144.337445	0.00 - 0.05	0.01	3.36	3.79
B094	Study Area 1	-36.672572	144.337445	0.20 - 0.30	0.01	4.70	5.75
B095	Study Area 1	-36.859820	144.193171	0.00 - 0.05	0.01	2.20	2.85
B095	Study Area 1	-36.859820	144.193171	0.40 - 0.50	0.01	3.09	4.50
B096	Study Area 1	-36.860936	144.220568	0.00 - 0.05	0.01	2.99	4.57
G002	Study Area 2	-36.998897	144.559207	0.00 - 0.05	0.01	6.07	4.46
G004	Study Area 2	-36.956906	144.534207	0.00 - 0.05	0.01	3.11	4.84
G005	Study Area 2	-36.977656	144.604439	0.00 - 0.05	0.01	5.52	4.44
G005	Study Area 2	-36.977656	144.604439	0.40 - 0.50	0.01	3.70	3.07
G006	Study Area 2	-36.886416	144.050652	0.00 - 0.05	0.01	2.34	3.20
G007	Study Area 2	-36.970668	144.631588	0.00 - 0.05	0.01	6.56	6.59
G009	Study Area 2	-36.970668	144.631588	0.00 - 0.05	0.01	5.27	7.23
G010	Study Area 2	-36.919647	144.273558	0.00 - 0.05	0.01	2.96	3.85
G011	Study Area 2	-36.921008	144.313817	0.00 - 0.05	0.01	5.20	3.20
G012	Study Area 2	-36.934649	144.359009	0.00 - 0.05	0.01	6.31	7.55
G013	Study Area 2	-36.931476	144.448145	0.00 - 0.05	0.01	6.76	5.42
G014	Study Area 2	-36.932385	144.488890	0.00 - 0.05	0.01	5.67	8.84
G015	Study Area 2	-36.935856	144.542872	0.00 - 0.05	0.01	7.18	4.49
G016	Study Area 2	-36.932178	144.591806	0.00 - 0.05	0.01	4.28	3.70
G017	Study Area 2	-36.936263	144.628949	0.00 - 0.05	0.01	8.79	9.26
G018	Study Area 2	-36.935400	144.672822	0.00 - 0.05	0.01	6.57	6.41
G019	Study Area 2	-36.933616	144.717950	0.00 - 0.05	0.01	12.93	11.11
G020	Study Area 2	-36.935734	144.749704	0.00 - 0.05	0.01	3.29	5.03
G021	Study Area 2	-36.887721	144.089131	0.00 - 0.05	0.01	4.20	3.93
G022	Study Area 2	-36.888931	144.138407	0.00 - 0.05	0.01	2.81	4.36
G023	Study Area 2	-36.895663	144.193917	0.00 - 0.05	0.01	1.28	1.77
G024	Study Area 2	-36.887223	144.227966	0.00 - 0.05	0.01	4.08	5.43
G025	Study Area 2	-36.883196	144.281859	0.00 - 0.05	0.01	6.42	6.01
G026	Study Area 2	-36.896009	144.317562	0.00 - 0.05	0.01	3.98	3.52
G027	Study Area 2	-36.901153	144.369711	0.00 - 0.05	0.01	7.89	6.48
G028	Study Area 2	-36.895110	144.407456	0.00 - 0.05	0.01	4.80	4.09
G029	Study Area 2	-36.892366	144.437219	0.00 - 0.05	0.01	5.58	5.13
G030	Study Area 2	-36.894694	144.496328	0.00 - 0.05	0.01	13.88	10.69
G032	Study Area 2	-36.898628	144.592925	0.00 - 0.05	0.01	4.32	2.61
G033	Study Area 2	-36.888276	144.627843	0.00 - 0.05	0.01	5.55	4.11
G034	Study Area 2	-36.900681	144.676583	0.00 - 0.05	0.01	2.33	2.27
G035	Study Area 2	-36.896113	144.716674	0.00 - 0.05	0.01	1.53	1.08
G036	Study Area 2	-36.893023	144.773317	0.00 - 0.05	0.01	36.16	16.38
G037	Study Area 2	-36.899917	144.813485	0.00 - 0.05	0.01	1.74	1.65
G038	Study Area 2	-36.849493	144.053191	0.00 - 0.05	0.01	10.07	9.47
G039	Study Area 2	-36.849918	144.096790	0.00 - 0.05	0.01	4.50	4.49
G040	Study Area 2	-36.851171	144.151308	0.00 - 0.05	0.01	1.41	1.94

Location ID	Study Area	Latitude	Longitude	Depth (m bgl)	LOD mg/kg	As <2 mm (mg/kg)	As < 250 µm (mg/kg)
G041	Study Area 2	-36.854532	144.367361	0.00 - 0.05	0.01	4.34	4.40
G042	Study Area 2	-36.857235	144.404721	0.00 - 0.05	0.01	5.46	4.72
G043	Study Area 2	-36.860058	144.453502	0.00 - 0.05	0.01	3.44	3.29
G044	Study Area 2	-36.853948	144.486299	0.00 - 0.05	0.01	6.28	4.03
G047	Study Area 2	-36.877844	144.637408	0.00 - 0.05	0.01	2.03	1.96
G048	Study Area 2	-36.870676	144.675656	0.00 - 0.05	0.01	11.64	5.37
G049	Study Area 2	-36.866535	144.710291	0.00 - 0.05	0.01	2.60	2.67
G050	Study Area 2	-36.878060	144.775941	0.00 - 0.05	0.01	37.04	25.65
G051	Study Area 2	-36.864094	144.821389	0.00 - 0.05	0.01	3.80	2.14
G053	Study Area 2	-36.815818	144.096301	0.00 - 0.05	0.01	11.51	8.36
G054	Study Area 2	-36.808366	144.146443	0.00 - 0.05	0.01	13.24	11.86
G055	Study Area 2	-36.821129	144.365671	0.00 - 0.05	0.01	4.26	4.76
G056	Study Area 2	-36.822460	144.411682	0.00 - 0.05	0.01	5.69	3.51
G057	Study Area 2	-36.821814	144.439875	0.00 - 0.05	0.01	6.05	5.30
G058	Study Area 2	-36.817507	144.495380	0.00 - 0.05	0.01	4.11	4.22
G059	Study Area 2	-36.835607	144.557109	0.00 - 0.05	0.01	8.31	6.59
G060	Study Area 2	-36.822694	144.589334	0.00 - 0.05	0.01	4.13	3.83
G061	Study Area 2	-36.825227	144.634654	0.00 - 0.05	0.01	3.83	2.81
G062	Study Area 2	-36.825129	144.678436	0.00 - 0.05	0.01	5.90	4.95
G063	Study Area 2	-36.819078	144.721487	0.00 - 0.05	0.01	3.72	3.46
G065	Study Area 2	-36.768057	144.094178	0.00 - 0.05	0.01	17.77	16.62
G066	Study Area 2	-36.777843	144.135848	0.00 - 0.05	0.01	13.01	11.77
G067	Study Area 2	-36.783884	144.364921	0.00 - 0.05	0.01	6.59	6.63
G069	Study Area 2	-36.786823	144.458753	0.00 - 0.05	0.01	7.46	5.99
G070	Study Area 2	-36.792754	144.504757	0.00 - 0.05	0.01	5.58	5.10
G071	Study Area 2	-36.797408	144.542665	0.00 - 0.05	0.01	2.36	2.43
G072	Study Area 2	-36.803678	144.576129	0.00 - 0.05	0.01	4.55	3.93
G073	Study Area 2	-36.788511	144.622591	0.00 - 0.05	0.01	4.14	2.91
G074	Study Area 2	-36.801232	144.695025	0.00 - 0.05	0.01	54.68	19.37
G075	Study Area 2	-36.788456	144.734274	0.00 - 0.05	0.01	4.45	3.99
G076	Study Area 2	-36.787806	144.771023	0.00 - 0.05	0.01	2.38	3.50
G077	Study Area 2	-36.734938	144.099382	0.00 - 0.05	0.01	7.35	8.44
G078	Study Area 2	-36.737789	144.137660	0.00 - 0.05	0.01	10.25	9.85
G079	Study Area 2	-36.738697	144.353064	0.00 - 0.05	0.01	11.77	8.97
G080	Study Area 2	-36.754844	144.408615	0.00 - 0.05	0.01	3.09	3.35
G081	Study Area 2	-36.742363	144.462825	0.00 - 0.05	0.01	7.37	6.69
G082	Study Area 2	-36.746372	144.510017	0.00 - 0.05	0.01	61.14	50.15
G083	Study Area 2	-36.754367	144.530862	0.00 - 0.05	0.01	4.85	4.60
G084	Study Area 2	-36.755345	144.602522	0.00 - 0.05	0.01	7.01	4.84
G085	Study Area 2	-36.739080	144.624273	0.00 - 0.05	0.01	5.41	4.54
G086	Study Area 2	-36.756799	144.768894	0.00 - 0.05	0.01	1.14	1.10
G087	Study Area 2	-36.697782	144.090908	0.00 - 0.05	0.01	6.04	5.62
G088	Study Area 2	-36.710437	144.156602	0.00 - 0.05	0.01	15.54	14.51
G089	Study Area 2	-36.712410	144.372694	0.00 - 0.05	0.01	5.37	5.27
G090	Study Area 2	-36.713090	144.414570	0.00 - 0.05	0.01	9.68	6.05
G091	Study Area 2	-36.718605	144.465042	0.00 - 0.05	0.01	7.89	4.89
G092	Study Area 2	-36.703699	144.501846	0.00 - 0.05	0.01	2632.14	2562.69
G092	Study Area 2	-36.703699	144.501846	0.40 - 0.50	0.01	1409.89	1106.24

Location ID	Study Area	Latitude	Longitude	Depth (m bgl)	LOD mg/kg	As <2 mm (mg/kg)	As < 250 µm (mg/kg)
G093	Study Area 2	-36.668595	144.102831	0.00 - 0.05	0.01	2.76	2.99
G094	Study Area 2	-36.672846	144.146435	0.00 - 0.05	0.01	5.44	4.61
G095	Study Area 2	-36.679228	144.364363	0.00 - 0.05	0.01	7.26	5.73
G096	Study Area 2	-36.680569	144.419835	0.00 - 0.05	0.01	20.76	15.83
G097	Study Area 2	-36.687124	144.460316	0.00 - 0.05	0.01	6.59	5.90
G098	Study Area 2	-36.686749	144.485404	0.00 - 0.05	0.01	5.99	6.08
G098	Study Area 2	-36.686749	144.485404	0.40 - 0.50	0.01	6.87	5.44
G100	Study Area 2	-36.636632	144.191068	0.00 - 0.05	0.01	25.75	18.68
G101	Study Area 2	-36.638555	144.237831	0.00 - 0.05	0.01	9.12	9.43
G102	Study Area 2	-36.639355	144.280621	0.00 - 0.05	0.01	4.83	4.95
G103	Study Area 2	-36.640972	144.332211	0.00 - 0.05	0.01	148.98	236.68
G104	Study Area 2	-36.638910	144.377118	0.00 - 0.05	0.01	63.48	59.43
G105	Study Area 2	-36.639850	144.412493	0.00 - 0.05	0.01	20.51	15.35
G106	Study Area 2	-36.649335	144.462782	0.00 - 0.05	0.01	6.06	5.06
G107	Study Area 2	-36.649996	144.500461	0.00 - 0.05	0.01	11.32	10.16
G107	Study Area 2	-36.649996	144.500461	0.40 - 0.50	0.01	10.63	8.78
G108	Study Area 2	-36.604479	144.205164	0.00 - 0.05	0.01	13.62	12.27
G109	Study Area 2	-36.599064	144.236835	0.00 - 0.05	0.01	5.47	5.08
G110	Study Area 2	-36.603012	144.288285	0.00 - 0.05	0.01	6.20	2.72
G111	Study Area 2	-36.597799	144.332548	0.00 - 0.05	0.01	4.41	3.60
G112	Study Area 2	-36.605954	144.372460	0.00 - 0.05	0.01	12.80	5.44
G113	Study Area 2	-36.601773	144.423070	0.00 - 0.05	0.01	3.92	3.14
G114	Study Area 2	-36.606232	144.459966	0.00 - 0.05	0.01	19.27	16.50
G115	Study Area 2	-36.611644	144.490535	0.00 - 0.05	0.01	10.71	10.51
G116	Study Area 2	-36.601777	144.560375	0.00 - 0.05	0.01	4.89	5.01
G116	Study Area 2	-36.601777	144.560375	0.40 - 0.50	0.01	4.74	5.20
G117	Study Area 2	-36.565944	144.193855	0.00 - 0.05	0.01	9.31	4.60
G118	Study Area 2	-36.565211	144.237579	0.00 - 0.05	0.01	8.46	6.68
G119	Study Area 2	-36.567929	144.284369	0.00 - 0.05	0.01	13.72	10.25
G120	Study Area 2	-36.566754	144.336851	0.00 - 0.05	0.01	6.50	3.49
G121	Study Area 2	-36.568155	144.373868	0.00 - 0.05	0.01	1.27	1.57
G122	Study Area 2	-36.561958	144.417876	0.00 - 0.05	0.01	7.05	4.54
G123	Study Area 2	-36.572896	144.466722	0.00 - 0.05	0.01	8.03	5.34
G124	Study Area 2	-36.572810	144.507666	0.00 - 0.05	0.01	8.40	6.51
G125	Study Area 2	-36.568167	144.551084	0.00 - 0.05	0.01	3.80	4.05
G127	Study Area 2	-36.528708	144.199227	0.00 - 0.05	0.01	9.19	8.12
G128	Study Area 2	-36.531649	144.244601	0.00 - 0.05	0.01	7.05	8.07
G129	Study Area 2	-36.535258	144.284127	0.00 - 0.05	0.01	4.58	4.48
G130	Study Area 2	-36.532918	144.330264	0.00 - 0.05	0.01	5.67	4.80
G131	Study Area 2	-36.544499	144.378276	0.00 - 0.05	0.01	5.39	4.84
G132	Study Area 2	-36.534884	144.419539	0.00 - 0.05	0.01	3.93	3.56
G133	Study Area 2	-36.535139	144.469176	0.00 - 0.05	0.01	4.97	4.77
G134	Study Area 2	-36.532341	144.510964	0.00 - 0.05	0.01	6.06	5.32
G135	Study Area 2	-36.537977	144.551809	0.00 - 0.05	0.01	4.84	4.39
G136	Study Area 2	-36.543613	144.594971	0.00 - 0.05	0.01	6.23	6.47
G137	Study Area 2	-36.492117	144.231036	0.00 - 0.05	0.01	6.05	6.22
G138	Study Area 2	-36.498586	144.287162	0.00 - 0.05	0.01	7.39	6.16
G139	Study Area 2	-36.495956	144.343630	0.00 - 0.05	0.01	6.12	4.64

Location ID	Study Area	Latitude	Longitude	Depth (m bgl)	LOD mg/kg	As <2 mm (mg/kg)	As < 250 µm (mg/kg)
G140	Study Area 2	-36.500695	144.376635	0.00 - 0.05	0.01	3.86	3.74
G141	Study Area 2	-36.496688	144.428202	0.00 - 0.05	0.01	4.28	4.21
G142	Study Area 2	-36.500977	144.469512	0.00 - 0.05	0.01	4.95	4.60
G143	Study Area 2	-36.506731	144.505290	0.00 - 0.05	0.01	13.75	11.47
G144	Study Area 2	-36.502019	144.558145	0.00 - 0.05	0.01	2.89	2.80
G145	Study Area 2	-36.502588	144.599229	0.00 - 0.05	0.01	7.79	6.70
G145	Study Area 2	-36.502588	144.599229	0.40 - 0.50	0.01	6.54	6.88
G146	Study Area 2	-36.458855	144.376714	0.00 - 0.05	0.01	4.59	4.20
G147	Study Area 2	-36.461473	144.430169	0.00 - 0.05	0.01	8.05	7.85
G148	Study Area 2	-36.466809	144.469337	0.00 - 0.05	0.01	3.82	3.96
G149	Study Area 2	-36.469020	144.514149	0.00 - 0.05	0.01	5.82	4.29
G150	Study Area 2	-36.463237	144.552730	0.00 - 0.05	0.01	7.66	7.34
G151	Study Area 2	-36.466759	144.602892	0.00 - 0.05	0.01	3.64	3.58
G152	Study Area 2	-36.462427	144.628863	0.00 - 0.05	0.01	4.72	4.40
G152	Study Area 2	-36.462427	144.628863	0.40 - 0.50	0.01	4.82	3.66
G153	Study Area 2	-36.428929	144.381379	0.00 - 0.05	0.01	5.04	4.65
G154	Study Area 2	-36.429957	144.430244	0.00 - 0.05	0.01	13.26	10.46
G155	Study Area 2	-36.429466	144.469723	0.00 - 0.05	0.01	5.56	5.34
G156	Study Area 2	-36.432190	144.511746	0.00 - 0.05	0.01	6.10	4.59
G157	Study Area 2	-36.432423	144.554350	0.00 - 0.05	0.01	6.27	6.28
G158	Study Area 2	-36.432036	144.604121	0.00 - 0.05	0.01	3.10	2.89
G159	Study Area 2	-36.431554	144.648705	0.00 - 0.05	0.01	3.06	3.04
G159	Study Area 2	-36.431554	144.648705	0.40 - 0.50	0.01	3.26	2.73

Calculation of recovery of As from digestion						
NIST SRM 2710a	ICP-MS	Mass (g)	Dilution factor	As (mg/kg)	Certified As value in SRM (mg/kg)	Recovery (%)
SRM1	143.418	0.1006	9940.357853	1425.626243	1540	92.6
SRM2	139.938	0.1005	9950.248756	1392.417910	1540	90.4
SRM3	164.489	0.1008	9920.634921	1631.835317	1540	106.0
SRM4	148.173	0.1008	9920.634921	1469.970238	1540	95.5
SRM5	145.251	0.1002	9980.039920	1449.610778	1540	94.1
SRM6	133.566	0.1007	9930.486594	1326.375372	1540	86.1
SRM7	149.900	0.1007	9930.486594	1488.579940	1540	96.7
SRM8	147.416	0.1008	9920.634921	1462.460317	1540	95.0
SRM9	128.420	0.1007	9930.486594	1275.273088	1540	82.8
SRM10	151.595	0.1002	9980.039920	1512.924152	1540	98.2
SRM11	142.382	0.1008	9920.634921	1412.519841	1540	91.7
SRM12	141.186	0.1004	9960.159363	1406.235060	1540	91.3
SRM13	147.225	0.1008	9920.634921	1460.565476	1540	94.8
SRM14	138.773	0.1002	9980.039920	1384.960080	1540	89.9
Average recovery (%)						93.2

Calculation of average deviation between duplicates			Difference between duplicates (ppb)
	blank 12	0.006	<LOD
	blank 12 dup	0.020	
	SRM7	149.900	4.627
	SRM7 dup	145.273	
G009	13	53.106	1.781
< 2mm	13 dup	54.887	
G018	32	65.934	1.145
< 2mm	32 dup	64.789	
G026	51	40.014	-0.878
< 2mm	51 dup	40.892	
G035	70	363.403	-5.271
< 2mm	70 dup	358.132	
G047	89	20.455	0.106
< 2mm	89 dup	20.349	
G057	108	60.539	-2.294
< 2mm	108 dup	62.833	
G067	127	66.326	-1.629
< 2mm	127 dup	64.697	
G077	146	73.551	1.685
< 2mm	146 dup	71.866	
G086	165	11.477	0.132
< 2mm	165 dup	11.345	
G094	184 dup	53.184	1.291
< 2mm	184	54.475	
G103	203 x 10	149.216	-6.937
< 2mm	203 x 10 dup	156.153	
G111	222	44.433	0.499
< 2mm	222 dup	43.934	
G119	241	137.834	1.919
< 2mm	241 dup	139.753	
G128	259	81.049	2.013
< 250um	259 dup	79.036	
G137	278	62.243	-1.870
< 250um	278 dup	64.113	
G145b	297	69.240	3.860
< 250um	297 dup	65.380	
G153	316	46.634	2.155
< 250um	316 dup	44.479	
B001_0.	334	12.941	3.982
5 <	335	16.923	
B010	354	180.358	-1.065
< 250um	354 dup	181.423	
B019	373	141.672	3.281
< 250um	373 dup	138.391	
B027	392 x 10	386.538	17.099
< 250um	392 x10 dup	369.439	

Calculation of average deviation between duplicates			Difference between duplicates (ppb)
B034 < 250um	411	125.951	1.353
	411 dup	127.304	
B041 < 250um	430	244.551	-1.726
	430 dup	246.277	
B050 < 250um	449	173.791	3.044
	449 dup	170.747	
B059 < 250um	468 x10	431.798	-1.713
	468 x 10 dup	433.511	
B068 < 250um	487	313.777	-8.369
	487 dup	322.146	
B077 < 250um	506 x10	129.402	-1.329
	506 x10 dup	128.073	
B084 < 250um	525	108.187	3.534
	525 dup	104.653	
B093_0.5 <	544	503.911	3.764
	544 dup	500.147	
Average deviation between duplicates			**0.806**

Deviations from 10 ppb continuous check verifications (CCV)	
10ppb CCV multi element	11.286
10ppb CCV multi element	12.009
10ppb CCV multi element	12.361
10ppb CCV multi element	10.329
10ppb CCV multi element	11.387
10ppb CCV multi element	10.219
10ppb CCV multi element	9.662
10ppb CCV multi element	9.373
10ppb CCV multi element	9.199
10ppb CCV multi element	9.349
10ppb CCV multi element	9.327
10ppb CCV multi element	10.168
10ppb CCV multi element	8.977
10ppb CCV multi element	9.658
10ppb CCV multi element	9.060
10ppb CCV multi element	10.189
10ppb CCV multi element	9.976
10ppb CCV multi element	10.038
10ppb CCV multi element	10.206
10ppb CCV multi element	9.691
10ppb CCV multi element	9.798
10ppb CCV multi element	12.508
10ppb CCV multi element	10.376
10ppb CCV multi element	9.898
10ppb CCV multi element	9.957
10ppb CCV multi element	10.249
10ppb CCV multi element	10.300
10ppb CCV multi element	9.770
10ppb CCV multi element	9.903
10ppb CCV multi element	11.840
10ppb CCV multi element	10.871
10ppb CCV multi element	10.285
10ppb CCV multi element	9.849
10ppb CCV multi element	9.795
Mean of 10 ppb CCV	**10.231**
Deviation from 10 ppb (%)	**2.313**

Deviations from 100 ppb continuous check verifications (CCV)	
100ppb CCV multi element	100.833
100ppb CCV multi element	108.035
100ppb CCV multi element	106.938
100ppb CCV multi element	107.077
100ppb CCV multi element	103.243
100ppb CCV multi element	101.695
100ppb CCV multi element	97.924
100ppb CCV multi element	102.574
100ppb CCV multi element	99.298
100ppb CCV multi element	101.392
100ppb CCV multi element	101.232
100ppb CCV multi element	100.760
100ppb CCV multi element	99.417
100ppb CCV multi element	96.584
100ppb CCV multi element	97.212
100ppb CCV multi element	104.292
100ppb CCV multi element	103.706
100ppb CCV multi element	106.136
100ppb CCV multi element	103.315
100ppb CCV multi element	102.853
100ppb CCV multi element	103.273
100ppb CCV multi element	105.505
100ppb CCV multi element	100.137
100ppb CCV multi element	101.820
100ppb CCV multi element	97.085
100ppb CCV multi element	105.003
100ppb CCV multi element	102.933
100ppb CCV multi element	100.574
100ppb CCV multi element	100.633
100ppb CCV multi element	101.970
100ppb CCV multi element	101.548
100ppb CCV multi element	110.854
100ppb CCV multi element	101.710
100ppb CCV multi element	101.053
Mean of 100 ppb CCV	**102.312**
Deviation from 100 ppb (%)	**2.312**

Calculation of As spike recovery				Difference between spiked and unspiked (ppb)	As recovery (%)
	blank	Target	6.601	361.082	90.271
	spike blank 3	400ppb	367.683		
G012	20	Target	63.584	396.734	99.184
< 2mm	spike 20	400ppb	460.318		
G006	40	Target	32.283	502.955	100.591
< 250um	Spike 40 x100	500ppb	535.238		
G030	60	Target	139.347	418.106	83.621
< 2mm	Spike 60 x100	500ppb	557.453		
G040	80	Target	19.427	487.677	121.919
< 250um	Spike 80	400ppb	507.104		
G053	100	Target	116.007	411.155	102.789
< 2mm	spike 100	400ppb	527.162		
G062	120	Target	49.835	465.938	116.485
< 250um	spike 120	400ppb	515.773		
G074	140	Target	548.007	-34.346	-8.587
< 2mm	Spike 140	400ppb	513.661		
G083	160	Target	46.310	484.056	121.014
< 250um	Spike 160	400ppb	530.366		
G092b	180 x 20	Target	707.626	-85.645	-21.411
< 2mm	Spike 180	400ppb	621.981		
G101	200	Target	94.456	436.644	109.161
< 250um	spike 200	400ppb	531.100		
G110	220	Target	62.138	475.037	118.759
< 2mm	Spike 220	400ppb	537.175		
G118	240	Target	67.297	432.053	108.013
< 250um	Spike 240	400ppb	499.350		
G129	260	Target	45.960	456.804	114.201
< 2mm	Spike 260	400ppb	502.764		
G138	280	Target	61.868	457.027	114.257
< 250um	Spike 280	400ppb	518.895		
G147	300	Target	81.119	455.253	113.813
< 2mm	Spike 300	400ppb	536.372		
G155	320	Target	53.573	396.997	99.249
< 250um	Spike 320	400ppb	450.570		
B005	340	Target	107.391	472.812	118.203
< 2mm	Spike 340	400ppb	580.203		
B013	360	Target	69.912	495.254	123.814
< 2mm	Spike 360	400ppb	565.166		
B021_0.	380	Target	80.174	474.864	118.716
3 <	Spike 380	400ppb	555.038		
B031	400	Target	137.119	410.562	102.641
< 2mm	Spike 400	400ppb	547.681		
B038	420	Target	243.307	317.772	79.443
< 250um	Spike 420	400ppb	561.079		

Calculation of As spike recovery				Difference between spiked and unspiked (ppb)	As recovery (%)
B046	440	Target	147.205	390.461	97.615
< 2mm	Spike 440	400ppb	537.666		
B055	460	Target	73.587	493.497	123.374
< 250um	Spike 460	400ppb	567.084		
B065	480	Target	286.510	244.762	61.191
< 2mm	Spike 480	400ppb	531.272		
B074	500	Target	109.306	495.188	123.797
< 250um	Spike 500	400ppb	604.494		
B082	520	Target	101.884	511.871	127.968
< 2mm	Spike 520	400ppb	613.755		
Average recovery of spiked As (%)					**98.522**

Appendix C – Outlier assessment

Location ID	Depth	Latitude	Longitude	Arsenic (mg/kg) (< 2mm)	Comment	Decision
G036	0.00 - 0.05	-36.893023	144.773317	36	Review of aerial imagery indicated that this location was in close proximity to Costerfield mine.	exclude
G050	0.00 - 0.05	-36.878060	144.775941	37	Review of aerial imagery indicated that this location was in close proximity to Costerfield mine.	exclude
G065	0.00 - 0.05	-36.768057	144.094178	18	Review of this location did not identify any discernible potential influences from point sources	include
G074	0.00 - 0.05	-36.801232	144.695025	55	This location was collected immediately adjacent and down gradient of intensive horticulture wine growing activity.	exclude
G082	0.00 - 0.05	-36.746372	144.510017	61	Review of site and aerial photographs identified a pile of mining waste approximately 50 m upgradient of this location.	exclude
G088	0.00 - 0.05	-36.710437	144.156602	16	Review of this location did not identify any discernible potential influences from point sources	include
G092	0.00 - 0.05	-36.703699	144.501846	2632	Review of aerial imagery indicated that this location was in close proximity to Fosterville Mine. The soil texture was reported as a fine grained grey sand, indicative of mining waste.	exclude
G092	0.40 - 0.50	-36.703699	144.501846	1410	Review of aerial imagery indicated that this location was in close proximity to Fosterville Mine. The soil texture was reported as a fine grained grey sand, indicative of mining waste.	exclude
G096	0.00 - 0.05	-36.680569	144.419835	21	Review of this location did not identify any discernible potential influences from point sources	include
G100	0.00 - 0.05	-36.636632	144.191068	26	Review of this location did not identify any discernible potential influences from point sources	include
G103	0.00 - 0.05	-36.640972	144.332211	149	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude
G104	0.00 - 0.05	-36.638910	144.377118	63	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude
G105	0.00 - 0.05	-36.639850	144.412493	21	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude
G114	0.00 - 0.05	-36.606232	144.459966	19	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude
B004	0.00 - 0.05	-36.866078	144.285047	147	Review of field notes and images from this location identified alluvial diggings in the immediate area.	exclude
B027	0.00 - 0.05	-36.807279	144.264810	516	Review of field notes and images from this location identified alluvial diggings in the immediate area.	exclude
B042	0.00 - 0.05	-36.777662	144.245570	123	Review of aerial imagery indentified the likely presence of mining waste to the immediate north of this location.	exclude
B043	0.00 - 0.05	-36.776714	144.264881	89	Review of aerial imagery identified visible signs of mine tailings located approximately 50 m south of this location.	exclude
B044	0.00 - 0.05	-36.774404	144.287046	87	Review of field photos and notes identified Bendigo Creek immediately adjacent. There were also signs of mining wastes at the surface surrounding this location.	exclude
B051	0.00 - 0.05	-36.753532	144.265133	414	Review of aerial imagery identified visible signs of mining waste and disturbed soils. Virginia Hill mine is approxiamtely 150 m south west.	exclude
B052	0.00 - 0.05	-36.757298	144.290281	87	Review of this location did not identify any discernible potential influences from point sources	include
B056	0.00 - 0.05	-36.734088	144.202298	137	Sample was collected in base of ephemeral creek which was dry. There were signs of mining sands recorded in field notes.	exclude
B059	0.00 - 0.05	-36.738477	144.268523	279	Review of aerial imagery identified likely grey sands site approximately 50 m west	exclude
B066	0.00 - 0.05	-36.720239	144.245430	143	Review of field photos and aerial imagery identified likely grey sands approximately 50 m west	exclude
B073	0.00 - 0.05	-36.701710	144.223708	70	Review of this location did not identify any discernible potential influences from point sources	include
B077	0.00 - 0.05	-36.703937	144.312988	111	Field notes indicated material was a fine grained sand, likely indicative of mining waste sand	exclude
B077	0.40 - 0.50	-36.703937	144.312988	84	Field notes indicated material was a fine grained sand, likely indicative of mining waste sand	exclude
B085	0.00 - 0.05	-36.686310	144.314194	63	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude
B088	0.00 - 0.05	-36.665169	144.202650	67	adjacent Myers Creek. Signs of mining sands were observed in creek channel.	exclude
B093	0.00 - 0.05	-36.668380	144.309955	65	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude
B093	0.40 - 0.50	-36.668380	144.309955	43	Field notes indicated this location was adjacent Bendigo Creek in a low-lying area. This stretch of Bendigo Creek is known to be impacted by mining waste.	exclude

Accessibility

Contact us if you need this information in an accessible format such as large print or audio.

Please telephone **1300 372 842** or email **contact@epa.vic.gov.au**

Interpreter assistance

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