Appendix D

Potential Impact on European Honey Bees and Local Honey Production

REGIS RESOURCES LTD



McPhillamys Gold Project – Potential Impact on European Honey Bees and Local Honey Production

Prepared for: Regis Resources Pty Ltd

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EnRiskS

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Limitations

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It is prepared in accordance with the scope of work and for the purpose outlined in the Section 1 of this report.

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Glossary of Terms and Abbreviations

ADI	Acceptable Daily Intake
ANZECC	Australia and New Zealand Environment and Conservation Council
AT	Averaging Time
BGL	Below ground level
BW	Body weight
CF	Unit conversion factor
ED	Exposure duration
EF	Exposure frequency
EPA	Environment Protection Authority
ET	Exposure time
HI	Hazard Index
HIL	Health investigation level
HQ	Hazard Quotient
HHERA	Human Health and Ecological Risk Assessment
LOR	Limit of Reporting
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
RfC	Reference Concentration
RfD	Reference Dose
RME	Reasonable maximum exposure
TC	Tolerable Concentration
TDI	Tolerable Daily Intake
TDS	Total dissolved solids
TRV	Toxicity Reference Value
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

Executive Summary

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Regis Resources Pty Ltd (Regis) to undertake a review of the potential for impacts on bees of the proposed McPhillamys Gold Project near Blayney in New South Wales.

The environmental impact statement (EIS) for the development of this gold mine near Blayney, NSW was on public exhibition in mid 2019. One question that arose in consultations and in the submissions on the EIS is whether there is potential for the mine to have impacts on the local bee industry, both from dust blown from the mine site directly onto the plants the bees visit as well as indirectly when they drink water that may be impacted by dust from the site or water in the tailings storage facility.

This assessment has been designed to evaluate whether the mine could have impacts on bees via dust or water. The assessment has used the outcomes of the air quality impact assessment in regard to dust deposition from the proposed mine to characterise exposure of bees from dust and information from the geochemical assessment to estimate exposure via water in the tailings storage facility.

Reviews of the scientific literature in regard to:

- metal levels in honey, nectar, pollen and/or bees generally worldwide and around specific locations where metal contamination is known to be present
- metal concentrations that might cause impacts on the survival and health of bees

have been undertaken and are included in this assessment.

The assessment has found the following:

- concentrations of metals in soil due to deposition of dust are estimated to be below soil quality guidelines that are protective for soil organisms that live in or on the soil for their entire lifecycles
- concentrations of metals in water due to deposition of dust are estimated to be below water quality guidelines that are protective for aquatic organisms that live in the affected water for their entire lifecycles
- concentrations of metals that may get into nectar or pollen in plants around the proposed mine are all estimated to be below concentrations that might indicate effects on the survival or health of the bees could occur
- concentrations of metals or cyanide that may be present in water in the tailings storage facility tailings storage facility are all estimated to be below concentrations that might indicate effects on the survival or health of the bees could occur
- concentrations of metals that could be present in honey are within or below the general levels reported for honey worldwide

Consequently, it is not expected that there will be any adverse impacts on the bee industry from metals in dust or from water in the tailings storage facility at the proposed mine.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Regis Resources Pty Ltd (Regis) to undertake a review of the potential for impacts of the proposed McPhillamys Gold Project near Blayney in New South Wales on the local honey industry.

The environmental impact statement (EIS) for the development of this gold mine near Blayney, NSW was on public exhibition in mid 2019. One issue identified during the public submission process was whether there is potential for the mine to have impacts on the local bee industry, both from dust blown from the mine site directly onto the plants the bees visit as well as indirectly when they drink water that may be impacted by dust from the site and/or water from onsite water storages, including the Tailings Storage Facility.

This assessment has been undertaken to provide an evaluation of this issue. The assessment includes a review of the scientific literature regarding what levels of metals may have impacts on bees.

1.2 Objectives

The overall objectives of this review are:

- Review air quality impact assessment to understand nature of dust, how deposition was calculated and other relevant information.
- Prioritise metals for consideration based on amount in dust and potential toxicity (likely to be arsenic, copper, manganese and lead).
- Characterise exposure to the bees by adapting the APVMA insect pollinator road map (risk assessment procedures used in pesticide assessment) as appropriate.
    - Exposure will include consideration of potential for uptake via:
        - Direct exposure to dust on the plants
        - Uptake of metals into the plants and then the flowers (nectar and pollen) which the bees consume
        - Uptake from water impacted by dust
        - Uptake from water in tailings and other mine water sources
- Identify and evaluate ecotoxicity studies on the impacts of metals on bees
- Undertake risk assessment for the bees based on comparing exposure to effects concentrations.

The assessment will not address risks to human health although there will be a qualitative discussion on the potential impacts on honey quality. It is noted that the information on this aspect appears limited.

1.3 Approach and scope of works

The methodology adopted for the risk assessment will be in accordance with the relevant National protocols/ guidelines including:

- enHealth (2012a) Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012b);

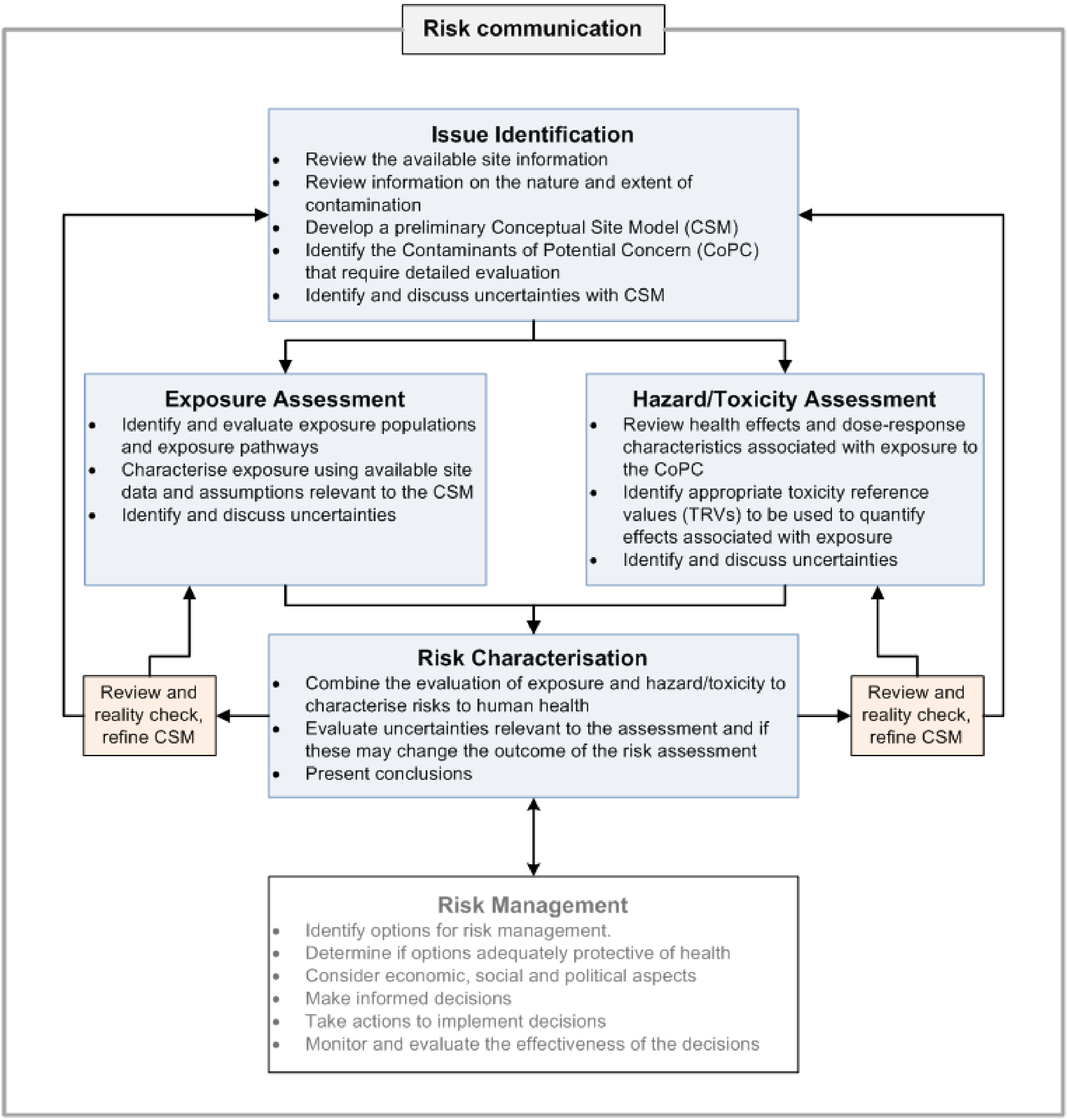
- enHealth (2012b) Australian Exposure Factor Guide (enHealth 2012a); and
- ASC NEPM (1999 amended 2013) National Environmental Protection Measure – Assessment of Site Contamination including:
  - Schedule B1 Investigation Levels for Soil and Groundwater (NEPC 1999 amended 2013c)
  - Schedule B4 Guideline on Site-Specific Health Risk Assessment Methodology (NEPC 1999 amended 2013a)
  - Schedule B5 Guideline on Ecological Risk Assessment (NEPC 1999 amended 2013b)
- APVMA (2015) Roadmap for insect pollinator risk assessment in Australia (APVMA 2015)
- EPHC (2009) Environmental risk assessment guidance manual for agricultural and veterinary chemicals (EPHC 2009a)
- APVMA (2019) APVMA risk assessment manual – environment (APVMA 2019)
- USEPA (2014) Guidance for assessing pesticide risks to bees (USEPA 2014)
- EFSA (2013) Guidance on the risk assessment of plant protection products on bees (*Apis mellifera*, Bombus spp. and solitary bees) (EFSA 2014)

In addition, protocols and guidelines developed by international agencies such as the USEPA and the WHO have been used (and referenced) to provide supplementary guidance where required consistent with current industry best practice.

Following this guidance, the review has been undertaken to include the following:

- A description of the proposed mining project (**Section 2**);
- Background information on chemicals and metals, in particular, in the world around us (**Section 3**);
- A description of the lifecycle of bees and how they may be exposed (**Section 4**);
- A description of the various foods collected by bees and products consumed by bees, how metals in dust could move into those materials and measured levels of metals in honey, nectar, pollen and bees from general studies of bees and honey worldwide and specific studies of metals levels in such materials around known areas of contamination (**Section 5**);
- Review of literature investigating the effects of metals on bee survival and health (**Section 6**):
- Characterisation of exposures and risks of metals from dust and in water from the proposed mine on bees in the local area including honey quality (**Section 7**);
- Consideration of the uncertainties in the assessment presented (**Section 8**);
- Conclusions of the review (**Section 9**).

The overall approach is outlined in the following figure (modified from enHealth 2012):



Section 2. McPhillamys Gold Project – Summary

2.1 Project location

The project is located in the Central Tablelands region of NSW, approximately 8 km to the north-east of Blayney, 20 km to the west of Bathurst and 27 km to the south-east of Orange (refer to **Figure 2.1**). The project is mostly located within the Blayney local government area (LGA) with a small proportion extending into the Cabonne LGA, and the Bathurst LGA located to the east. The pipeline runs through the LGAs of Lithgow, Bathurst and Blayney.

The project involves two key components, as shown on **Figure 1**:

- The mine site where the ore will be extracted and processed (referred to as the mine development); and
- An associated water pipeline (referred to as the pipeline development) which is a 90 km long pipeline, transferring surplus water from Centennial Coal's Angus Place Colliery (Angus Place) and Springvale Coal Services operations (SCSO), and Energy Australia's Mount Piper Power Station (MPPS) near Lithgow, to the mine.

The mine project area is zoned RU1 Primary Production and is surrounded by a variety of land uses – including honey production. The predominant land use in the area is agriculture which includes rural residential properties, with other uses that include forestry and natural areas.

The pipeline corridor alignment is predominantly used for agriculture, with mostly cleared, open paddocks used for sheep and cattle grazing.

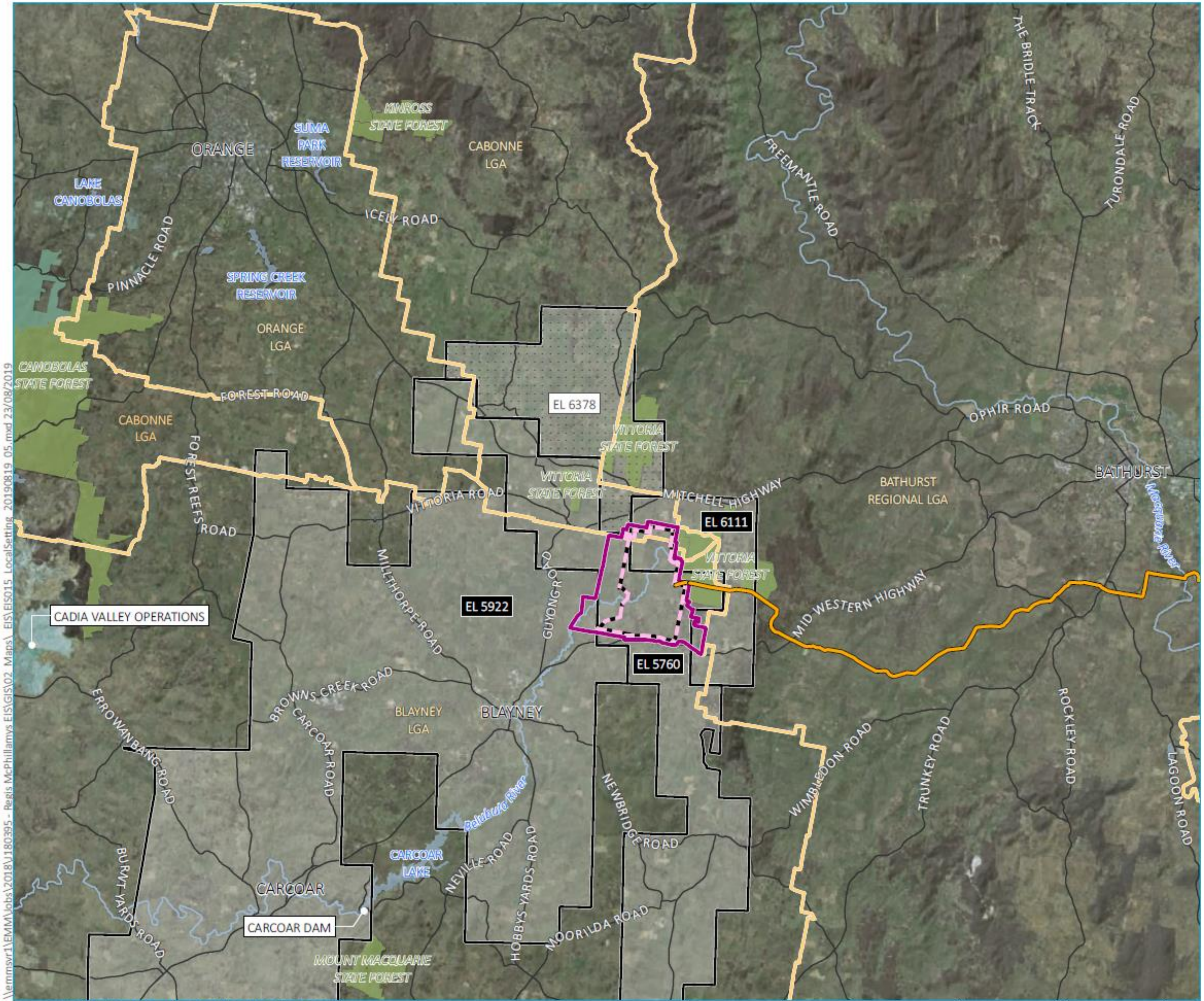
The mine site is the area for consideration in this assessment for the potential for impacting bees.

2.2 Project overview

The following provides an overview of the key components of the project (refer to the EIS (EMM 2019) for full details):

- Development and operation of an open cut gold mine, comprising approximately one to two years of construction, approximately 10 years of mining and processing and a closure period (including the final rehabilitation phase) of approximately three to four years, noting there may be some overlap of these phases. The total project life for which approval is sought is 15 years.
- Development and operation of a single circular open cut mine with a maximum diameter at the surface of approximately 1050 metres (m) and a final depth of approximately 460 m, developed by conventional open cut mining methods encompassing drill, blast, load and haul operations. Up to 8.5 million tonnes per annum (Mtpa) of ore will be extracted during the life of the project.
- Construction and use of a conventional carbon-in-leach processing plant with an approximate processing rate of 7 Mtpa to produce approximately 200 000 ounces, and up to 25 000 ounces per annum of product gold. The processing facility will comprise a run-of-mine (ROM) pad and crushing, grinding, gravity leaching, gold recovery, tailing thickening, cyanide destruction and tailings management circuits. Product gold will be taken off-site to customers via road transport.

- Placement of waste rock into a waste rock emplacement which will include encapsulation of materials with the potential to produce a low pH leachate. A portion of the waste rock emplacement will be constructed and rehabilitated early in the project life to act as an amenity bund.
- Construction and use of an engineered tailings storage facility to store tailings material.
- Construction and operation of associated mine infrastructure including:
  - Administration buildings
  - Workshop and stores facilities, including associated plant parking, laydown and hardstand areas, vehicle washdown facilities and fuel and lubricant storage;
  - Internal road network;
  - Explosives magazine and ammonium nitrate emulsion (ANE) storage;
  - Topsoil, subsoil and capping stockpiles;
  - Ancillary facilities, including fences, access roads, car parking areas and communications infrastructure; and
  - On-site laboratory.
- Establishment and use of a site access road and intersection with the Mid Western Highway.
- Construction and operation of water management infrastructure, including raw water storage dam, clean water and process water diversions and storages, and sediment control infrastructure.
- A peak construction workforce of approximately 710 full-time equivalent (FTE) workers. During operations, an average workforce of around 260 FTE employees will be required, peaking at approximately 320 FTEs in around 4 years
- Construction and operation of a water supply pipeline approximately 90 km long from Centennial's Angus Place and SCSO; and Energy Australia's MPPS operations near Lithgow to the mine development project area. The pipeline development will include approximately four pumping station facilities, a pressure reducing system and communication system. Approximately 13 ML/day (and up to a maximum of 15.6 ML/day) will be transferred for mining and processing operations.
- Installation and use of environmental management and monitoring equipment.
- Progressive rehabilitation throughout the mine life. At the end of mining, mine infrastructure will be decommissioned, and disturbed areas will be rehabilitated to integrate with natural landforms as far as practicable. The final landform, apart from the final void, will support land uses similar to current land uses or land uses consistent with land use strategies of the Blayney and Cabonne LGAs.



KEY

Project application area

- Mine development project area (2,513.47 ha)
- Mining lease application area (1,812.99 ha) (Note: boundary offset for clarity)
- Pipeline corridor

Existing environment

- Main road
- Named watercourse
- Named waterbody
- NPWS reserve
- State forest
- Local government area

Exploration lease boundaries (of interest)

- Held by LFB Resources NL (Regis)
- Held by others

Figure 1

Local setting of the mine development

McPhillamys Gold Project
Environmental impact statement

Source: EMM (2019); Regis Resources (2019); DFSI (2017); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

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Section 3. Background Information – Metals

3.1 Presence of chemicals and exposure to chemicals in everyday life

The fundamental building blocks for the entire planet are chemical substances. Whether it is the water we drink, the air we breathe, the food we eat, the ground we walk on, the houses we live in, the things we have inside our houses or workplaces or what we are made of, everything is made of chemicals – elements and compounds which are combinations of different elements.

Some chemical substances are essential for life (humans, animals or plants) – like water, oxygen and nutrients. Other chemical substances are naturally occurring, but they can kill us – like spider and snake venoms. The same applies to the chemical substances we make – some are quite benign and some are quite toxic.

A range of chemical substances are used to manufacture things we use every day like food, clothes, computers, kitchen appliances, cars, houses, roads, trains, planes, hair dyes, beauty products, toothpaste, shampoo and many other things.

Metals are one group of naturally occurring chemicals. They are present in the earth's crust and are widely distributed in soil, sediments, surface waters and groundwater.

This means the idea of "chemical free" is problematic. Instead the focus in chemicals management is to work out how much of a chemical people or the environment could be exposed to and whether effects are likely from such exposure.

3.2 Hazard vs Risk

Governments have established a range of legal requirements about how chemicals are approved for use, handling, transport and disposal as well as what to do in emergency situations so that chemicals are managed well. Such requirements include consideration of the characteristics of the chemical substances, how much will be used, how they might be released into the environment and a range of other matters.

In Australia, assessments are undertaken by NICNAS for industrial chemicals (National Industrial Chemicals Notification and Assessment Scheme); APVMA (Australian Pesticides and Veterinary Medicines Authority) for pesticides; TGA (Therapeutic Goods Administration) for human medicines; and FSANZ (Food Standards Australia and New Zealand) for food additives or contaminants in foods.

The potential for a chemical to have effects on people, plants or animals is assessed using toxicity tests. Such tests expose relevant organisms or parts of organisms to a chemical and determine at what concentration damage appears to occur.

These tests provide information on the hazard posed by chemical – the amount of a chemical that would cause a noticeable effect. Hazard is one of the characteristics of a chemical used in some parts of chemicals management. Hazard is used by the Globally Harmonised System of Classification and Labelling of Chemicals (GHS) which is a single internationally agreed system of classifying and labelling chemicals, particularly in regard to occupational use, emergency management and transport. The GHS has been put together under the auspices of the UN.

Environmental protection and other aspects of chemicals management are more usually based on a measure of risk rather than hazard. Risk combines a consideration of the hazard of a chemical (as found in the toxicity tests) and the potential for exposure given the proposed use or situation. This means a chemical can be extremely hazardous but will pose a low or negligible risk if exposure to people or ecological systems cannot occur (e.g. if it is used only within a reaction vessel at a manufacturing facility). This also means a less hazardous chemical can pose a more elevated risk if exposure is widespread and/or high.

Consequently, assessing the potential risk posed by a chemical and the need for management actions requires detailed consideration of a complex range of factors. Assessing risk is what has been undertaken in this report.

3.3 Environmental Fate of Chemicals

Assessing risk requires detailed consideration of how much of a chemical can reach a place where people or ecosystems can be exposed.

This includes consideration of where and how a chemical is used along with whether or not it can escape into the environment and then what happens to the chemical when it is released into the environment.

Issues for consideration of exposure in relation to the fate of a chemical in the environment include:

- Will the chemical end up in soil, water, air, sediments or in organisms
- Is the chemical persistent
- Is the chemical bioaccumulative
- Can the chemical be broken down by chemical processes (hydrolysis, photolysis)
- Can the chemical be broken down by microbial processes (aerobic/anaerobic)
- Does the chemical leach to groundwater
- Is the chemical volatile
- What mix of chemicals is present in the environment and does that change the fate of a particular chemical

As noted in the Commonwealth risk assessment manuals for industrial chemicals and agricultural chemicals, an exposure assessment needs to:

- Estimate how much will be released into the environment
- Consider the environmental fate of the chemical (mobility, degradation, drift, accumulation, form, persistence etc)
- Determine how much of the chemical will end up in environmental compartments where people or organisms can be exposed (e.g. soil, water, air etc) (EPHC 2009a, 2009b).

3.4 Metals – general

As noted above, metals are one group of naturally occurring chemicals. They are present in the earth's crust and are widely distributed in soil, sediments, surface waters and groundwater.

Metals are elements so they cannot be broken down into component parts. Some of the characteristics of chemicals listed above, don't apply to elements in the same way as they do to compounds – which are combinations of elements. For example, metals or elements are not described as persistent but it is not because they are short lived but rather it is because they cannot ever be broken down, so they are essentially infinitely persistent.

Ore bodies are locations where one or more minerals (metal containing compounds) have accumulated over geological time and so have higher (often much higher) levels of some metals than other locations. The metals in these ore bodies are usually in a form that doesn't move easily due to weathering, however, some does move into the environment in the area so highly mineralised geology will lead to higher levels of the relevant metals in the environment around such locations. When such ore bodies are mined, more dust etc containing the metals can be blown around into the environment around such activities. This means that people or the environment may be exposed to somewhat higher levels than normal.

3.5 Metals – foods

Food Standards Australia and New Zealand set guidelines for metals in foods as part of the Food Standards Code (https://www.foodstandards.gov.au/code/Pages/default.aspx).

For a range of metals, the guidance notes that it is unlikely levels could reach concentrations in foods that would cause human health effects. For these metals, FSANZ provides generally expected levels that indicate appropriate food production and management practices. These generally expected levels are provided for antimony (in meat), arsenic (in meat), copper (in meat, seafood, nuts, wheat), mercury (in meat), selenium (in seafood and meat) and zinc (in meat and seafood) (FSANZ 2001).

For other metals, the Food Standards Code contains maximum levels that are permitted in a range of foods. Maximum levels are provided for arsenic (in seafood, grains and salt), cadmium (in a range of food types), lead (in a range of food types), mercury (in seafood and salt) and tin (in canned foods) (FSANZ 2016, 2017).

Guidelines for metals in honey are not provided in the Code.

International guidance about the characteristics of honey is available in a Codex Alimentarius Standard for Honey (CXS 12-1981) which was first published in 1981 and was most recently updated in 2019 (Codex Alimentarius 2019). This standard is voluntary and was developed by the UN Food and Agriculture Organisation and the World Health Organisation. It does not contain guidelines for metals but indicates recommended levels for parameters like moisture content and content of the various sugars. It also notes that levels of heavy metals should not pose a hazard to human health and that levels of pesticides should not exceed maximum residue limits (also known as tolerances) set out in other relevant guidance.

Section 4. Lifecycle of Bees

4.1 General

The University of Purdue Agricultural Extension Services provide a summary of the complex life of honey bees which has been used here to provide an understanding of how bees interact with their environment and have the potential to interact with dust from the proposed mine (Whitford et al. 2017).

This summary document includes a description of the process used by the US Environmental Protection Agency when assessing the potential for bees to be impacted by pesticides used in agriculture. The development of test methods to assess the sensitivity of bees has been targeted at assessing pesticides as these are the main types of chemicals that could have a widespread impact on bees given how they are used – which includes spraying directly onto plants while they are flowering. The methods for assessing potential for effects can be adapted for use in this assessment for metals rather than pesticides (Whitford et al. 2017).

4.2 Bee Lifecycle

A hive contains the following different types of bees:

- Queen bee
- Drones – male bees
- Worker bees – sterile female bees (Whitford et al. 2017)

There is a single queen bee, several hundred to a thousand drones and thousands of worker bees in any hive.

Each type of bee starts as an egg then becomes a larva (there are 5 stages of larval development as the larva grows) then it forms a pupa and finally becomes an adult bee. Eggs take about 3 days to hatch. Larval bees exist for 5-6 days depending on the type of bee. The pupal stage can take between 7 and 14 days (Whitford et al. 2017).

The queen bee and the drones have limited tasks to perform, however, the worker bees have numerous roles and they move through these roles as they age. Worker bees can nurse and feed the eggs, larvae and pupae, clean up around the hive, guard the hive from bees from other hives as well as other insects, clear out dead and sick bees from the hive, fan air movement through the hive, receive nectar and pollen from forager bees to place in the combs and, finally, forage for nectar, water, tree resin/sap (propolis) and pollen to feed the hive. During the busy time of the year, worker bees live for about 6 weeks while over winter they can live for months. **Figure 2** shows these activities in more detail (Whitford et al. 2017).

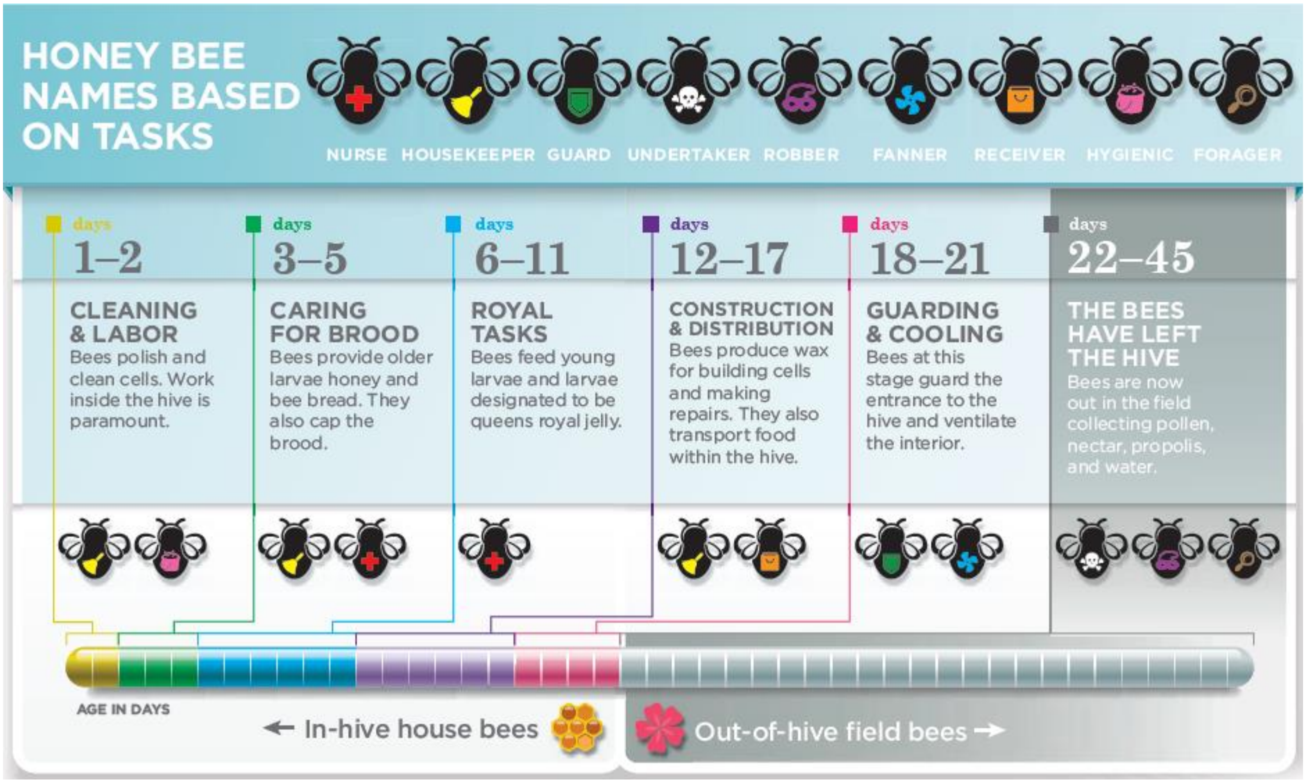


Figure 2: Activities undertaken by worker bees (Whitford et al. 2017)

Foraging is undertaken by the older worker bees – from about 3 weeks old. Different species of bee forage over different distances from the hive but the most common species – the European honey bee – forages over about 7 km^2 (Whitford et al. 2017).

Section 5. Bee Products and Metals

5.1 Honey, Pollen, Wax, Propolis

5.1.1 Honey

Honey is formed by bees through collection of nectar from flowers. The nectar contains a high proportion of water (60-80%) so one of the differences between nectar and honey is the removal of water once the nectar is moved into the hive. Honey usually has less than 20% water (Whitford et al. 2017).

In addition, bees cause sucrose (two glucose molecules joined together) and other more complex sugars within the nectar to break down into glucose and fructose through an enzyme they add to the nectar while it is in their honey stomachs. The worker bees who take nectar from the foraging bees to place into cells in the honeycomb also add other enzymes into the nectar as they store it in a cell. These enzymes (such as glucose oxidase) help to stabilise the honey so it doesn't degrade over time (Whitford et al. 2017).

Figure 3 shows the steps in the process.

Honey is stored within the hive to provide food at times when there are few flowers around or during rain. It is also used to sustain the hive through winter (Whitford et al. 2017).

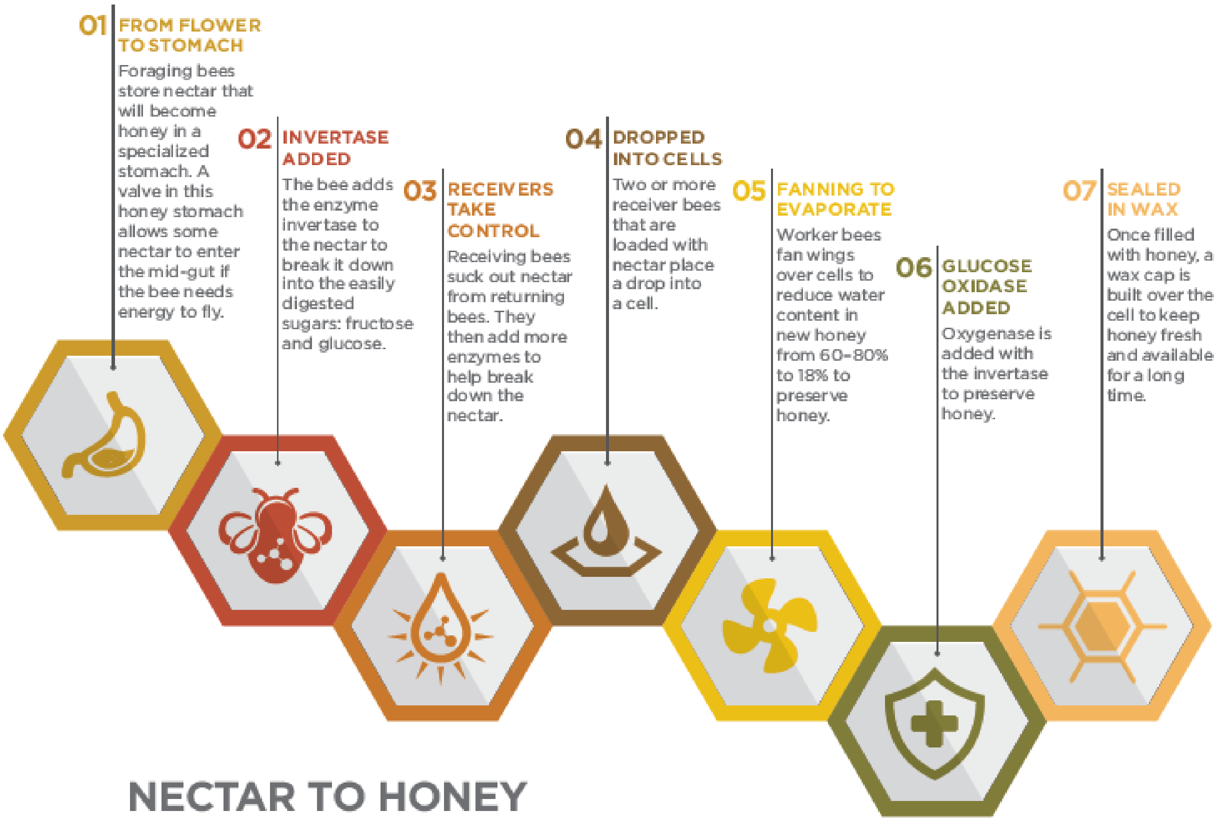


Figure 3: Honey production (Whitford et al. 2017)

5.1.2 Pollen

Pollen from plants is used by bees as their main source of amino acids/proteins. Bees collect pollen as it clings to them via electrostatic attraction when they land but also as the bees brush pollen into a type of basket on their hind legs. They brush off pollen from their bodies and move it into these baskets until they are full (Whitford et al. 2017).

Bees eat pollen and it is also turned into royal jelly by nurse bees. To produce royal jelly, they consume the pollen and digest it. The digested protein is then excreted through glands on their heads as royal jelly. Older larvae get fed royal jelly and honey while the queen bee is fed only royal jelly throughout her life (Whitford et al. 2017).

Pollen is stored within the hive to provide food at times when there are few flowers around or during rain. It is also used to sustain the hive through winter (Whitford et al. 2017).

5.1.3 Wax and Propolis

Propolis is resin from plants that is used as a glue within the hives. It is mixed with wax to help form the combs. It also helps control microorganisms within the hive (Whitford et al. 2017).

Wax is secreted by the bees and formed into the cells that make up the honeycomb. It is an energy intensive exercise so the bees need to eat a lot to keep up the ability to make the wax (Whitford et al. 2017).

5.1.4 Water

Bees need water for a range of purposes including:

- Maintain relevant moisture content of the bees themselves
- Addition to secretions produced by the bees including wax, royal jelly etc
- Dilution of honey prior to feeding to larvae
- Maintenance of temperature in the hive – both to cool the hive or heat the hive depending on the environmental conditions (Ostwald et al. 2016)

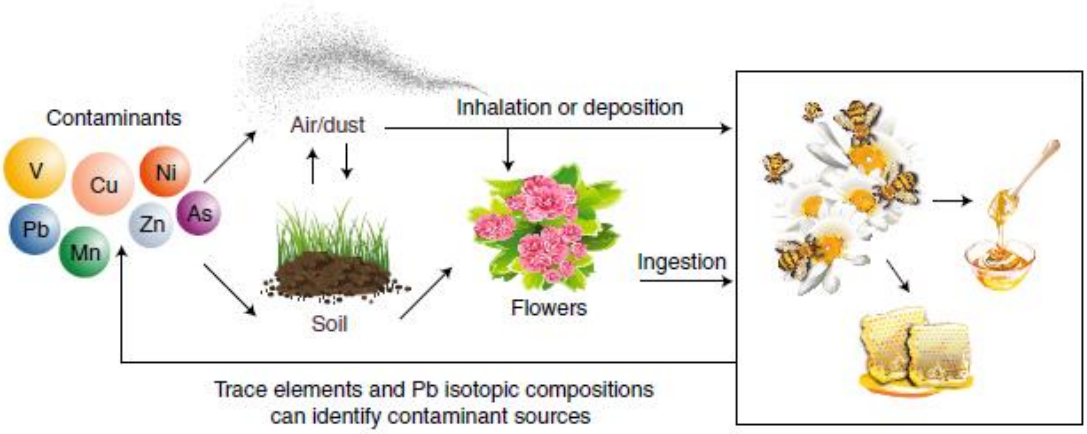
Often the need for water in the hive is met through the collection of nectar. At other times, bees must collect water specifically particularly when it is cold or over winter. They do not keep large quantities of water in the hive so when demand increases they must collect more – again there are specialised bees who are designated as water collectors (Ostwald et al. 2016).

They also use the water as a source for the various minerals the larvae and adults need as nutrients (Whitford et al. 2017).

5.2 Movement of metals into bee products

Metals can be present in bees and bee products.

Figure 4 shows the ways metals can move through the environment to reach the bees or bee products (Taylor 2019). The potential for exposure of the bees from the water they access is not included in this figure but would also potentially contribute.



Honey bee exposures to trace element contaminants. Environmental sources of metal and metalloid contaminants held in air, dust and soils can be accumulated on and in honey bees, which then transfer these to their beehive products (wax and honey). Adapted from ref. [8], ACS.

Figure 4: Movement of metals into bees and bee products (Taylor 2019)

Metals in soils get taken up by plants through their roots and transferred to the leaves and stems and eventually into flowers and fruit. Not all metals move through a plant easily and, while some may move from roots into stems and leaves, they may not move into flowers then to the nectar or pollen. Metals taken up by the plant may be present in the nectar, pollen or propolis. Only metals in the nectar will end up in honey but the bees may be exposed to metals via all these materials.

Metals in dust deposited onto plants can also move from the dust into the leaves and into flowers/nectar/pollen.

A study by Pellecchia and Negri (2018) used a scanning electron microscope to see the particles bees accumulate on their bodies near a cement manufacturing facility. They found that particles did adhere to the wings and heads of the bees presumably while they are flying or when they land on surfaces (flowers etc). They also found that there were more particles attached to bees found close to the facility compared to bees collected around 7 km away from the facility (Pellecchia & Negri 2018).

An earlier study by these authors also showed that particles were accumulated on the bodies of bees in areas where mining was occurring. The following photo (**Figure 5**) shows in red where particles were seen to accumulate (Negri et al. 2015).

Figure 5: Location of dust/pollen accumulation on bees (marked in red) (Negri et al. 2015)

It is more likely that such dust would end up in the pollen rather than the nectar.

To reach the nectar the dust would need to get into the part of the flower where nectar is produced which is often inside other parts of the flower so protected from direct deposition of dust. The metals in those particles would then need to be able to dissolve into the nectar. Given that metals in such particles are often not very soluble it would be expected that only small amounts could dissolve.

It is important to note that bees don't actually eat all the nectar they collect and metabolise it in some way to turn it into honey. They take nectar into their honey stomachs, add the enzyme to breakdown the sugars and then bring it back up when they return to the hive – it does not travel throughout their bodies. Any contamination they have in their bodies does not get added into the nectar where it could accumulate. Metals can end up in honey only if present in the nectar in the flowers. This appears to be most likely to occur via uptake from soil or water into the plant and then translocation into the flowers.

The dust is likely to end up mixing into the pollen as the particles attach to the outside of the bees. Pollen is used by the bees for food, so it is a pathway of exposure for the bees, but it does not contribute to the process for producing honey so metals in pollen would not add to levels in honey.

Particles that get deposited from the atmosphere could also get mixed in with the resin the bees collect and this could lead to the bees being exposed when they collect the resin and produce the wax. However, metals from this type of exposure do not have a mechanism to move into the honey.

5.3 Metal levels in honey

5.3.1 General

Solayman et al. provide a review of minerals and trace elements in honey from all over the world (Solayman et al. 2016). Because honey is derived from collection of nectar from many plants and plants contain a range of minerals and metals due to the geology of the soil they grow in, water used to keep sufficient moisture in the plants and the nutrient requirements of the plants, honey also contains a range of minerals and metals. This review took data from many studies from numerous sources and found the following concentrations ranges for various metals:

- Copper – 0.05-17 mg/kg (i.e. 50-17000 µg/kg)
- Iron – 0.4-224 mg/kg (i.e. 400-224000 µg/kg)
- Zinc – 0.2-74 mg/kg (i.e. 200-74000 µg/kg)
- Arsenic – not detected to 0.1 mg/kg (i.e. ND-100 µg/kg)
- Nickel – not detected to 9 mg/kg (i.e. ND-9000 µg/kg)
- Manganese – not detected to 4 mg/kg (i.e. ND-4000 µg/kg)
- Selenium – 0.01 mg/kg (i.e. 10 µg/kg)
- Aluminium – 1-11 mg/kg (i.e. 1000-11000 µg/kg)
- Cadmium – 0.2-373 mg/kg (i.e. 200-373000 µg/kg)
- Lead – 0.6->3000 mg/kg (i.e. 600->3000000 µg/kg)
- Mercury – 0.3-10 mg/kg (i.e. 300-10000 µg/kg)
- Chromium – not detected to 370 mg/kg (i.e. ND-370000 µg/kg)
- Silver – 3-600 mg/kg (i.e. 3000-600000 µg/kg) (Solayman et al. 2016)

The review notes that heavy metals may be found at higher levels in honey from areas near industrial facilities or near busy roads (traffic related emissions) (Solayman et al. 2016).

In particular, studies of honey produced in New Zealand reported the following concentration ranges:

- Copper – 0.09-0.7 mg/kg (i.e. 90-700 µg/kg)
- Iron – 0.7-3 mg/kg (i.e. 700-3000 µg/kg)
- Zinc – 0.2-2 mg/kg (i.e. 200-2000 µg/kg)
- Arsenic – 0.04-0.2 mg/kg (i.e. 40-200 µg/kg)
- Nickel – 0.02 to 0.7 mg/kg (i.e. 20-700 µg/kg)
- Manganese – 0.2 to 5 mg/kg (i.e. 200-5000 µg/kg)
- Selenium – not reported
- Aluminium – 0.2-21 mg/kg (i.e. 200-21000 µg/kg)
- Cadmium – 10-450 mg/kg (i.e. 10000-450000 µg/kg)
- Lead – 10-40 mg/kg (i.e. 10000-40000 µg/kg)
- Mercury – not reported
- Chromium – 120-550 mg/kg (i.e. 120000-550000 µg/kg)
- Silver – not reported (Solayman et al. 2016)

5.3.2 Bioindicator studies

There have been a large number of studies that have looked at metal levels in honey, pollen and bees around industrial facilities or other areas known to have elevated metal levels. Many of these studies have found that honey does provide a useful way of looking at metals in the environment. A selection of papers is provided here to show the range of information available.

Aldgini et al. 2019

Metals were measured in pollen collected from hives (i.e. pollen collected by bees) in Jordan and China in 2017. Hives sampled were present in urban, industrial and agricultural areas. There was little difference between the levels in pollen for the various areas. Concentrations ranged as follows:

- Copper – 0.032-11 mg/kg
- Zinc – 25-77 mg/kg
- Nickel – <0.010-2.8 mg/kg
- Selenium – <0.040-3 mg/kg
- Lead – <0.030-2.5 mg/kg
- Cadmium – <0.005 mg/kg
- Arsenic – <0.020 mg/kg (Aldgini et al. 2019)

Alvarez-Ayuso & Abad-Valle 2017

This study looked at honey, pollen and soil around an ancient gold mining area in Spain. They also took samples in an area not affected by the ancient mining processes. Honey samples reported low levels for most metals and the concentrations were similar for both locations. The pollen samples were more useful showing some differences between the two locations (Álvarez-Ayuso & Abad-Valle 2017).

Metal	Ancient Mining Area		Reference Area	
	Honey (mg/kg)	Pollen (mg/kg)	Honey (mg/kg)	Pollen (mg/kg)
Arsenic	<0.05	0.16-0.32	<0.05	0.05-0.21
Cadmium	<0.05	0.06-0.14	<0.05	0.09-0.26
Antimony	<0.01	<0.01	<0.01	<0.01
Zinc	2.1	53-89	<1	47-131
Molybdenum	<0.05	0.08-0.21	<0.05	0.05-0.13

Conti & Botre 2001

This study investigated cadmium, chromium and lead in bees, honey, pollen, propolis and wax collected around Rome. There were five sites investigated – three that were background urban areas, one that was near a major road and another that was located near industrial facilities and high traffic areas (Conti & Botrè 2001).

Metal	Honey (mg/kg)	Pollen (mg/kg)	Bees (mg/kg)	Propolis (mg/kg)	Wax (mg/kg)
Lead	0.003-0.045	<0.02-0.33	0.0005-0.0013	<0.001-0.004	0.056-0.206
Cadmium	<0.002-0.06	<0.015-0.09	0.0029-0.0042	0.0006-0.007	<0.015-0.052
Chromium	0.008-0.1	<0.03-0.112	0.00005-0.00012	0.002-0.007	0.032-0.094

Dzugan et al. 2018

This study was undertaken in Poland and measured a range of metals in bees and honey. The locations sampled represented three different types of potential for contamination – an urban area, a clean or reference area and an industrial area. The higher levels were reported for the industrial area. For most metals, the concentrations in the bees were higher than in the honey. Mean concentrations reported are shown in the table below (Dzugan et al. 2018).

Metal	Honey (mg/kg)	Bees (mg/kg)
Manganese	3.7	99
Iron	1	52
Zinc	2.1	34
Copper	1	8.9
Aluminium	14.2	6.5
Cadmium	0.02	0.3
Nickel	0.2	0.2
Selenium	0.1	Not detected
Thallium	0.08	Not detected
Lead	0.050	0.070
Mercury	Not detected	Not detected

Ernest et al. 2018

The study measured a range of metals in honey samples collected around Nigeria. Forty samples were collected from two urban areas (Ernest et al. 2018). Concentrations in honey were:

- Copper – 46-58 mg/kg
- Zinc – 37-40 mg/kg
- Chromium – 5-6.7 mg/kg
- Lead – 0.175-0.35 mg/kg
- Cadmium – 0.088-0.163 mg/kg
- Mercury – 0.046-0.13 mg/kg

Leita et al. 1996

The study investigated levels of lead, cadmium and zinc in bees, royal jelly and honey from 12 hives located around busy roadways. Pollen and propolis were also collected and analysed. Mean concentrations are reported in the table below. The results showed a good relationship between cadmium levels in the flowers of the species targeted by the bees and in the honey but such a relationship did not occur for lead or zinc which may be due to the characteristics of these metals, the uptake of zinc as an essential micronutrient, potential for other plant species to be higher contributors for these metals and a range of other environmental and chemical characteristics (Leita et al. 1996).

Metal	Honey (mg/kg)	Royal jelly (mg/kg)	Pollen (mg/kg)	Propolis (mg/kg)
Zinc	29	86.6	99	325
Lead	1.8	13.1	3.9	13.7
Cadmium	1.9	2.9	2.1	1.5

Roman 2009

This study looked at metal levels (arsenic, lead, cadmium and mercury) in bee pollen. They collected pollen from hives in two locations – an agricultural woodland area and near a former military airport (Roman 2009).

For the agricultural woodland, the mean concentration of lead ranged from 0.49 to 0.8 mg/kg depending on the year sampled. For cadmium the mean concentrations were 0.234-0.272 mg/kg. For arsenic the mean concentrations were 0.036-0.060 mg/kg and for mercury the mean concentrations were approximately 0.004 mg/kg (Roman 2009).

For the former airfield, the mean concentration of lead ranged from 0.700 to 0.840 mg/kg depending on the year sampled. For cadmium the mean concentrations were around 0.360 mg/kg. For arsenic the mean concentrations were 0.090-0.1 mg/kg and for mercury the mean concentrations were 0.006-0.007 mg/kg (Roman 2009).

Guidelines are available in Poland for metal levels in pollen where the pollen is for human consumption. These guidelines were 0.200 mg/kg for arsenic, 0.050 mg/kg for cadmium, 0.033 mg/kg for mercury and 0.5 mg/kg for lead (Roman 2009).

Ruschioni et al. 2013

The study investigated the metals levels in bees in nature reserves in Italy. The study collected bees and honey in 10 different nature reserves over 3 years and measured cadmium, chromium, nickel and lead. These authors proposed guidelines for bees and honey based on the work of earlier studies (i.e. not national or international guidance). It is not known how these guidelines were developed nor whether they are designed to protect the bees or people who consume honey as the source article was not able to be obtained (Ruschioni et al. 2013).

Metal	Threshold – Bee (mg/kg)	Measured – Bee (mg/kg)	Threshold – Honey (mg/kg)	Measured – Honey (mg/kg) (mean)
Cadmium	0.100	<LOR-0.4	0.010	Not detected
Chromium	0.120	<LOR-0.500 *(2 samples only at 1.5 and 3)*	0.020	<LOR-0.060
Lead	0.700	<LOR-1	0.050	Not detected
Nickel	0.300	<LOR-0.6	0.2	<LOR-0.450

Sadowksa et al. 2019

This study investigated levels of various metals in bees from urban and rural areas in Poland. The metals evaluated included aluminium, arsenic, cadmium, cobalt, chromium, copper, manganese, lead and zinc. The study also looked at whether the metals present in bees were from particles attached to the outside of the bees or whether they had been taken into the bodies of the bees. The study found that aluminium, arsenic and chromium were mainly present on the outside of the bees (in particles stuck to the hairs). Cadmium, on the other hand, was mostly found to be present inside the bees (Sadowska et al. 2019).

Metal	Bees (mg/kg) (mean values)			
	Urban, unwashed	Urban, washed	Rural, unwashed	Rural, washed
Aluminium	9	7	25	11
Arsenic	0.620	0.210	0.090	0.020
Cadmium	1.1	1.1	0.210	0.160
Cobalt	0.220	0.180	0.200	0.130
Chromium	0.400	0.260	0.720	0.220
Copper	19	21	15	15
Manganese	74	74	83	85
Lead	0.580	Not reported	0.500	0.220
Zinc	136	138	139	120

These results show there is little difference between urban and rural areas. They also show that for some metals there is no difference between washed and unwashed bees (washed bees are those subject to a process to remove the particles attached to the outside of the bees) (Sadowska et al. 2019).

Satta et al. 2012

This study evaluated the use of bees and ants for assessing heavy metals in an area where mining had occurred in Italy. The study was undertaken over three years and looked at ant biodiversity as well as metal levels in bees, honey and pollen. Soil levels were also investigated. Samples of bees and bee products were collected four times per year for three years. There were three areas evaluated within the region where mining had occurred. Levels of cadmium, chromium and lead were measured (Satta et al. 2012).

Cadmium in soil ranged from not detected to 32 mg/kg; in honey ranged from not detected to 0.081 mg/kg; in bees ranged from 0.5-10 mg/kg and in pollen ranged from 0.13-15 mg/kg (Satta et al. 2012).

Lead in soil ranged from 140 to 12800 mg/kg; in honey ranged from 0.009-0.220 mg/kg; in bees ranged from not detected to 4 mg/kg and in pollen ranged from 0.230-12 mg/kg (Satta et al. 2012).

Levels of chromium in soil ranged from 9 to 173 mg/kg; in honey ranged from not detected to 0.170 mg/kg; in bees ranged from 0.030-46 mg/kg and in pollen ranged from not detected to 0.240 mg/kg (Satta et al. 2012).

Saunier et al. 2013

This study looked at metals in honey, royal jelly and wax as well as lichen and moss from a location where historical mining for zinc and lead had occurred. Samples were collected from two locations with multiple hives at each. Results are provided in the table following. It is noted that concentrations in soil at the mine sites are significantly higher than those in soil near the hives. It is also noted that results for honey, bees and other bee products are reported in µg/kg compared to soils reported as mg/kg – a 1000 fold difference (lower). This is to make these results comparable to those reported in other studies (Saunier et al. 2013).

Metal	Soil at the mines (mg/kg)	Soil near the hives (mg/kg)	Honey (mg/kg)	Royal jelly (mg/kg)	Wax (mg/kg)	Bees (mg/kg)
Arsenic	100-4200	75-160	<LOR-0.008	0.005	0.012	0.056-0.059
Antimony	--	--	<LOR-0.003	0.002	0.001	0.025-0.026
Cadmium	400-1600	Not detected-9	0.001-0.022	0.007	0.006	2.5-2.9
Manganese	--	--	3-13	0.300	16	81-93
Lead	3700-88000	370-1800	0.003-0.1	0.170	<LOR	0.8-1.4
Thallium	6-320	3-16	0.001-0.037	<LOR	0.013	0.130-0.150
Zinc	57000-125000	50-3600	<LOR-1.4	0.900	1.5	170

Silici et al. 2016

This study investigated metals in bees and honey in Turkey in an area near power stations. The metals investigated included aluminium, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc. Honey (6 samples) and forager bees (11 samples) were sampled. The results indicate that sampling both honey and bees is more useful for assessing regional contamination than honey alone. The article also notes that, while there are no maximum residue limits specified for metals in honey in the Codex Alimentarius Standard, there has been a proposal in Europe to set a limit of 100 µg/kg (i.e. 0.1 mg/kg) for cadmium and 1000 µg/kg (i.e. 1 mg/kg) for lead. These results were also similar to levels found in other studies around Europe (Silici et al. 2016).

Metal	Honey (mg/kg)	Bees (mg/kg)
Aluminium	0.670-1.3	3-7
Cadmium	Not detected	Not detected – 0.008
Chromium	0.003-0.024	0.004-0.014
Copper	0.360-0.400	6-10.4
Iron	Not detected – 10.2	49-102
Manganese	0.170-0.370	4-19
Nickel	Not detected – 0.145	0.013-0.310
Lead	Not detected – 0.016	0.004-0.024
Zinc	0.150-0.300	8.6-17

Skorbilowicz et al. 2018

This study investigated copper, chromium, zinc, manganese and zinc levels in the bodies of bees in an urban area in Poland. The hive may have been constructed with timber that had been treated with CCA (copper chrome arsenate) which may explain higher than expected levels of chromium in the bees (2-3 times higher than other studies discussed). They reported similar concentrations of the other metals to other studies (Skorbiłowicz et al. 2018).

Smith et al. 2019

These authors investigated metals in honey collected at hives at various locations around Vancouver, Canada. They measured a wide range of elements including aluminium, arsenic, barium, cadmium, cobalt, chromium, copper, iron, gallium, magnesium, manganese, molybdenum, nickel, lead, rubidium, antimony, tin, strontium, titanium, vanadium, zinc and zirconium. The study focused on lead. The levels of lead in honey over 4 years ranged from 0.001-0.0123 mg/kg (Smith et al. 2019).

Taha et al. 2017

An investigation of metals levels in bees, honey and pollen around an industrial cement production facility in Saudi Arabia collected samples 3, 6, 9, 12, 15, 18 and 21 km from the facility. Lead, chromium and cobalt were not measured above the limit of reporting in honey, pollen and bees. Manganese was not found in the honey samples (Taha et al. 2017).

Metal	Honey (mg/kg)	Bees (mg/kg)	Pollen (mg/kg)
Iron	13-44	170-500	348-440
Zinc	0.7-1	18-100	18-23
Copper	0.5-1	9-16	4-8
Nickel	Not detected – 1.5	Not detected – 2	1-3
Manganese	Not detected	12-41	12-20
Lead	Not detected	Not detected	Not detected
Chromium	Not detected	Not detected	Not detected
Cobalt	Not detected	Not detected	Not detected

Van der Steen et al. 2012

This study investigated potential to use bees as bioindicators of metal concentrations in three locations in the Netherlands. The spatial and temporal variation in concentration for a range of metals including aluminium, arsenic, cadmium, cobalt, chromium, copper, lithium, manganese, molybdenum, nickel, lead, antimony, selenium, tin, strontium, titanium, vanadium and zinc. These authors note that metals may be taken up by bees from airborne particles resulting from the combustion of fossil fuels (vehicles, power stations, fires etc). The pathways by which the bees might be exposed include ingestion of polluted surface water, pollen or nectar; accumulation on the surface of the bee of particles in the air or as they crawl over plants and inside flowers etc as well as inhalation of particles (van der Steen, Jozef J. M. et al. 2012).

Samples of the bees were collected every two weeks for three months (three hives at each location). For many of the metals there was no significant difference across the three months. For all but three metals, there was no real difference between mean concentrations for the different locations. There were differences between locations for cobalt, strontium and vanadium but these are not metals that are commonly present due to pollution. Concentration ranges in this study and reported in other studies are provided in the table below (van der Steen, Jozef J. M. et al. 2012).

Metal	Bees (mg/kg dry weight)	
	This study	Other previous studies
Aluminium	9.1-9.3	--
Arsenic	0.690-0.730	<0.5 (rural/urban sites) <0.1 (hives without CCA treated timber) 0.770-1.11 (hives with CCA treated timber)
Cadmium	0.110-0.210	<0.600->1.8 (rural/urban) 3 (non contaminated) 1-4 (heavy traffic areas) 0.030-0.180 (reference sites) 0.140-0.160 (forested area) 0.100-0.170 (industrialised) 0.160-1.3 (relatively clean) 0.740-1.75 (industrialised)
Cobalt	0.100-0.210	--
Chromium	0.210-0.220	0.054-0.080 (non contaminated)

Metal	Bees (mg/kg dry weight)	
	This study	Other previous studies
		0.052-0.116 (heavy traffic) <0.060-0.340 (hives without CCA treated timber) 0.580-0.800 (hives with CCA treated timber) <0.100-3.6 (national park) <0.100-1.2 (urban) 0.050-0.180 (forested) 0.160-0.230 (industrialised)
Copper	13.8-17.7	13-15 (reference) 14-27 (industrialised) 8.7-9.7 (hives without CCA treated timber) 9.9-10.5 (hives with CCA treated timber) 15-30 (relatively clean) 32-38 (industrialised)
Lithium	0.020	--
Manganese	31-38	76 (range of land uses)
Molybdenum	0.530-0.790	--
Nickel	0.300-0.310	0.120-0.420 (national park) 0.130-0.430 (urban) 0.270-0.420 (forested) 0.360-0.500 (industrialised)
Lead	0.420-0.550	0.520-1 (non contaminated) 0.640-3 (heavy traffic) 0.580-0.620 (reference) 0.150-0.550 (national park) <0.100-1.2 (urban) 0.280-0.290 (forested) 0.270-9.3 (industrialised)
Antimony	0.110-0.120	--
Selenium	1.2-1.4	1.8-2.4 (forested) 2.2-6 (industrialised)
Strontium	0.9-1.6	--
Tin	0.5-0.51	--
Titanium	0.280-0.340	--
Vanadium	0.020-0.150	--
Zinc	66.7-79.6	55-73 (reference) 59-204 (industrialised) 53-76 (heavy traffic) 90-189 (relatively clean)

Van der Steen et al. 2015

This study looked at using bees for monitoring heavy metals in air, particularly cadmium, lead and vanadium. The study used three hives at each of three locations in the Netherlands where air monitoring devices were deployed. The concentrations in air and in the bees showed a correlation for vanadium but not for the other two metals. The levels of cadmium and lead in air were relatively low at all three locations – well below air quality guidelines (Van der Steen, J. J. M. et al. 2015).

Van der Steen et al. 2016

This study built on the results from that reported by the same authors in 2012 where bees were analysed for a range of metals. In this study 150 hives were sampled. Land use was assessed for the area surrounding the location of the hives (28 km^2). The locations were broken down into those with >50% wooded area or >50% urban area or >50% agricultural area or where a mix of uses occurred. The highest concentrations in the bees for most metals were reported for those locations which were surrounded by >50% wooded area (van der Steen, J. J. M. et al. 2016).

Metal	Bees (mg/kg dry weight)	
	Mean	Maximum
Aluminium	17.8	44
Arsenic	0.790	1.6
Barium	2	8.7
Cadmium	0.240	0.730
Cobalt	0.190	0.630
Chromium	0.450	1.4
Copper	20	32.2
Lithium	0.030	0.130
Manganese	168	524
Molybdenum	0.750	5.3
Nickel	0.600	1.5
Antimony	0.310	3.2
Selenium	2.1	4.8
Strontium	1.8	4.6
Tin	0.390	3.3
Titanium	1.8	3
Vanadium	0.040	0.320
Zinc	100	170

Zhou et al 2018a&b

These authors investigated metals in honey, pollen, wax and bees in Australia (Sydney and Broken Hill). They also collected soil and dust samples. Broken Hill is an area known for its mineralisation resulting in elevated lead and other metals. Sydney has metal contamination from a range of sources including traffic, paint, industrial emissions etc. The study measured arsenic, manganese, lead and zinc in the various samples. Honey produced by European bees collected in Broken Hill contained up to 0.295 mg/kg of lead while in Sydney no sample had more than 0.022 mg/kg. Honey produced by a native Australian species could only be sampled around Sydney. Lead levels were quite low in most samples (below the limit of reporting) but ranged up to 0.034 mg/kg – similar to the European bees. No arsenic was detected in honey for either species. Manganese and zinc were present in honey for both species with the native bee honey reporting higher levels than those for the European bees. Levels of these metals in bees, pollen and wax were higher than those in the honey. (Zhou et al. 2018a; Zhou et al. 2018b).

Section 6. Effects Assessment – Bees

6.1 Studies on effects of metals on bees

A range of journal articles describing experiments to determine the potential for effects on bees when exposed to a range of metals and other chemicals relevant to this site have been reviewed.

Burden et al. 2019

This study looked at the effects of copper, cadmium and lead on honey bee feeding behaviour. They looked at how the bees fed when offered sugar solutions containing one of these metals compared to clean sugar solutions. The response of the bees when their antennae or proboscis were stimulated was assessed. Also, the ability of the bees to respond to the presence of sucrose was also evaluated (Burden et al. 2019).

For cadmium, there was no change in these behaviours up to the highest concentration tested. Bees were exposed to 0.001 to 10 mg/L. There was no difference in the ability of the bees to determine a sucrose solution from just water when pre treated with exposure of antenna (and related) to sucrose plus cadmium. Other studies have shown malaise in bees at exposure to around 50-100 mg/L of cadmium (Burden et al. 2019).

For copper, there was a change in these behaviours. The bees reduced their response to sucrose and this effect increased with increasing copper concentrations. Copper concentrations ranged from 0.002 to 20 mg/L. The effect was seen at all concentrations of copper. There was some difference in the ability of the bees to determine a sucrose solution from just water when pre treated with exposure of antenna (and related) to sucrose plus copper but they still were able to discern increasing concentrations of sucrose. There was a difference between antenna stimulation and proboscis stimulation. The antenna could sense presence of copper but proboscis could not. The bees did not show malaise induced even at the maximum concentration tested (Burden et al. 2019).

For lead, there was a significant interaction between pre-treatment with lead. Bees were exposed to 0.001 to 10 mg/L. There was no difference at the highest treatment for the response to sucrose. There was a difference in the ability of the bees to determine a sucrose solution from just water when pre treated with exposure of antenna (and related) to sucrose plus lead at the lower concentrations tested. Exposure to lead seemed to reduce ability of the bees to sense sucrose. The bees did seem to prefer consuming the lead/sugar mix rather than just the sugar alone. Other studies have shown that bees reject sucrose when it contains more than 400 mg/L of lead (Burden et al. 2019).

Burden 2016

A postgraduate student studied the sublethal effects of copper, cadmium, lead and selenium (these data are also reported in the article above except for selenium – more detail is provided here). The study found that bees detect and reject copper containing sugar solutions (i.e. synthetic nectar) but do not seem to notice the presence of cadmium or lead in these solutions, however, exposure to lead changed the way the bees could detect sucrose and this could impact on their collection of nectar. Exposure to selenium in a sugar solution appeared to impact on learning and memory (Burden 2016).

The study looked at the response a bee makes where it extends its proboscis to feed when the antennae are stimulated with a sugar solution or pollen (PER – proboscis extension response). This response can be used to test the bees' motivation or ability to respond to smell, taste or feel stimuli and their willingness to feed in response to such stimuli (Burden 2016).

The review of literature in this thesis (Burden 2016) noted the following:

- At sufficiently high levels, exposure to heavy metals and metalloids is lethal to honey bees (Di et al. 2016; Hladun, Kristen R. et al. 2016; Hladun, K. R. et al. 2012).
- In some wild bee species, proximity to a source of metal contamination is correlated with reduced species diversity and abundance (Moroń et al. 2014).
- At sublethal levels, some metals and metalloids reduce larval growth rate and increase mortality in both honey bee larvae and adult workers (Di et al. 2016; Hladun, Kristen R. et al. 2016; Hladun, K. R. et al. 2012).
- There is evidence that some heavy metals affect honey bee behaviour, since they alter foraging behaviour both in honey bees and other bee species (Meindl & Ashman 2013).

These are similar to the findings noted in this assessment from review of these papers.

Di et al. 2016

This study undertook laboratory bioassays with bees to evaluate the impact of cadmium, copper and lead on larvae and foraging bees.

Two types of bioassays were undertaken – a 10 day exposure starting with 1 day old larvae to assess impacts on larvae as well as the standard USEPA oral toxicity test for adult bees.

The LC50s for larvae were 0.275 mg/L for cadmium; 6.97 mg/L for copper and 1.12 mg/L for lead when the larvae were fed the metal dissolved in the sugar solutions used to feed the larvae.

The LC50s for the foraging bees when exposed for 72 hours were 78 mg/L for cadmium, 72 mg/L for copper and 345 mg/L for lead (Di et al. 2016).

Hladun et al. 2016

This study investigated impact on whole colony health of the presence of cadmium, copper, lead and selenium. The bees were fed these metals in sugar solution and/or pollen patty. They based treatment concentrations on levels of these metals found in honey and pollen reported in the literature. They found lead had minimal impact on the health of the colony although the bees did accumulate lead into their bodies. Selenium exposure was related to lower weight for worker bees compared to unexposed bees. For cadmium and copper, there were more dead pupae in the colony compared to controls (Hladun, Kristen R. et al. 2016).

Concentrations in sugar solution were 240 µg/kg for cadmium, 25000 µg/kg for copper, 500 µg/kg for lead and 600 µg/kg for selenium. In the pollen patties, concentrations used were 460 µg/kg for cadmium, 50000 µg/kg for copper, 1600 µg/kg for lead and 6000 µg/kg for selenium. Bees were also exposed to water containing the metals – 0.08 mg/L for cadmium, 1.9 mg/L for copper, 0.24 mg/L for lead and 0.05 mg/L for selenium. Sugar solutions were renewed weekly. The pollen patties were added twice to the colonies – at the beginning and middle of the experimental period which was 60 days (Hladun, Kristen R. et al. 2016).

Honey and bees were also analysed to see how much of each metal they had accumulated with this exposure. For cadmium, honey was found to contain about 500 µg/kg and foraging bees contained around 4500 µg/kg. For copper, honey contained 200000 µg/kg and foraging bees contained 800000 µg/kg. For lead, honey contained around 300 µg/kg and foraging bees contained 30000 µg/kg. For selenium, honey contained around 2000 µg/kg and foraging bees contained 14000 µg/kg. Dead foraging bees were also analysed. They contained slightly more of each of the metals except for lead when compared to the live foraging bees. For lead, it was slightly less than the live bees (Hladun, Kristen R. et al. 2016).

The levels in the honey are essentially the same as the sugar solutions to which they were exposed when the evaporation step in the hive is considered – i.e. there was no increase in metal levels due to exposure via water or via pollen patties. (Hladun, Kristen R. et al. 2016).

The authors noted that in other studies honey had lower concentrations even though bees were exposed to similar levels in flowers/nectar when exposure occurred around a contaminated site rather than in a controlled situation. They proposed that this was likely to be because the bees in these areas were exposed to both contaminated and uncontaminated flowers. This study was designed so that the bees could only fed on the contaminated sugar solutions so that this potential for dilution of metal levels in the honey was not possible (Hladun, Kristen R. et al. 2016).

Hladun et al. 2013

This study used toxicity tests for adult forager bees and bee larvae to assess the toxicity of the various salts of selenium commonly found in the environment. The LC50 for the inorganic salts to adult foragers was 58 mg/L and for organic forms was 150 mg/L. For larvae, the LC50 for in inorganic salts was 0.7-1 mg/L and for organic forms of selenium was 4.4 mg/L (Hladun, Kristen R. et al. 2013).

These authors compared their findings for bees with LC50 values for selenium for other insect species. They found that other insect species reported LC50s for selenium in the range 9-400 mg/kg for terrestrial insects and 1-50 mg/L for aquatic insects. The results for bees (including larvae) are within these ranges (Hladun, Kristen R. et al. 2013).

Hladun et al. 2012

This study looked at effects of selenium exposure on bees using taste and other sensory based responses as indicators of short term response. The bees were also fed sugar solution containing selenium in a single dose or daily over 5 days. Effects on survival for bees exposed over a number of days were seen at doses over 60 mg/L while, after a single dose, survival was affected at 600 mg/L and above. The ability of the bees to respond to the presence of sucrose was affected to some extent (Hladun, K. R. et al. 2012).

Meindl & Ashman 2013

This study looked at the effects of aluminium and nickel in nectar on the behaviour of foraging bumblebees. Flowers were collected each day and their nectar was replaced with sugar solution (40%) (i.e. controls), sugar solution plus 100 mg/L aluminium or sugar solution plus 100 mg/L nickel. The flowers were grouped – 2 controls plus two of the flowers from either the nickel or the aluminium treatment. Bumble bees were then allowed to visit the flowers and their behaviour was observed. Nectar containing these metals did have an impact on the behaviour of the bees. The time spent foraging at a flower was shorter for flowers with nickel in nectar but not for aluminium treated flowers. Also, the presence of nickel affected which flower a bee would visit next but this did not occur for aluminium. The levels chosen for this experiment were based on what could be present in nectar in plants that hyperaccumulate metals which might be used for remediating contamination. Nectar from most plants could not have such high levels (Meindl & Ashman 2013).

Moron et al. 2012

This study investigated the impact of metals on the abundance and diversity of wild bees along gradients of metal contamination. There were two locations where they found a gradient in metal levels which they could study around smelters – one in Poland and on in the UK. They used standard traps to collect the bees. They looked at richness and abundance of different species in the traps and at metal levels in pollen collected by the red mason bee (*Osmia rufa*). The wild bees have much smaller foraging areas than honey bees (Moroń et al. 2012).

In pollen the metal levels were around 1000 µg/kg for cadmium, around 42000 µg/kg for lead and around 56000-100000 µg/kg for zinc in the background areas. In pollen the metal levels were 7000-9000 µg/kg for cadmium, 277000-365000 µg/kg for lead and 440000-592000 µg/kg for zinc in the areas near the smelters. Closest to the smelters almost no bees were caught in the traps whereas in the background areas 4-5 species with up to 10 individuals were caught in the traps (Moroń et al. 2012).

Moron et al. 2014

This study looked in more detail at the potential for effects on survival, reproduction and population growth of the red mason bee (*Osmia rufa*) along the metal gradients found around the two smelters described above (Moroń et al. 2014).

They found that the most impacted locations had fewer brood cells (i.e. eggs, larvae and pupae) and more dead offspring than for the least impacted locations. Also, the population growth rate decreased along the metals gradient (i.e. population grew more slowly closer to the smelters) (Moroń et al. 2014).

Rothman et al. 2019

These authors investigated the impacts of cadmium and selenium on honey bees. In particular, the study focused on impacts on the microorganisms present in bees from exposure to these metals. Bees have a relatively consistent microbiome throughout the world and, as with many organisms including people, having a healthy group of microorganisms helps the bee function well (Rothman et al. 2019).

Bees were exposed to cadmium and selenium via a sucrose solution or artificial pollen patty (Cd – 0.24 mg/L (sucrose); 0.46 mg/L (pollen) and Se – 0.6 mg/L (sucrose); 6 mg/L (pollen)). Results showed that exposure at these levels resulted in changes in the microorganisms present and changes in metabolism within the bee. Most changes were subtle at these treatment levels and the microbiome as a whole was quite resilient to metals exposure. It was also noted that some of microorganisms can take in metals like cadmium limiting the exposure of the bee itself (Rothman et al. 2019).

Sovik et al. 2015

This study evaluated the potential impacts of manganese on honey bees. Bees were fed different concentrations of manganese in sugar solutions. Reduced numbers of foraging trips were noted for bees treated with the highest concentration. They also spent longer away from the hive on these trips. The treatment concentrations ranged from the controls who just accessed clean sugar solution to 0.05-50 millimolar which is equivalent to approximately 3 mg/L to 3000 mg/L. The bees exposed to 3000 mg/L showed clear differences to all the other treatments. This level is much higher than any concentrations found in honey or pollen reported in **Section 5.3.2** (Søvik et al. 2015).

6.2 Assessment

The concentrations of metals in nectar or pollen that might impact on the survival of bees has not been well studied, potentially due to the number of researchers with experience working with bees and the need to undertake assessments for pesticides as a priority. The studies summarised in **Section 6.1** do provide an indication of the types of concentrations in nectar or pollen that might result in impacts on bee survival and colony health.

These studies show the following:

- Arsenic – Mortality occurs at 400-500 µg/bee – this is >1000 mg/kg in the sugar solution if it is assumed that the dose is received in 20 µL of sugar solution (Johnson 2015)
- Cadmium – a number of studies have looked at the effects of cadmium on bees and have found:
    - Concentrations around 1 mg/kg in pollen resulted in no effects while effects on survival in foraging bees were seen at 7-9 mg/kg (Moroń et al. 2012).
    - The LC50 (lethal concentration for 50% of exposed bees) for larvae was 0.275 mg/L (i.e. 0.275 mg/kg) in nectar and for foraging bees the LC50 was 78 mg/L (i.e. 78 mg/kg) in nectar (Di et al. 2016).
    - No significant effects were seen at 10 mg/L in nectar (i.e. 10 mg/kg) in the study by Burden et al (Burden et al. 2019).
    - Some minor effects were reported in a study where bees were exposed to 0.24 mg/kg in nectar and 0.46 mg/kg in pollen (Hladun, Kristen R. et al. 2016).
- Copper – a number of relevant studies have found:
    - The LC50 (lethal concentration for 50% of exposed bees) for larvae was 7 mg/L (i.e. 7 mg/kg) and for foraging bees the LC50 was 72 mg/L (i.e. 72 mg/kg) (Di et al. 2016).
    - Some minor effects were reported in a study where bees were exposed to 25 mg/kg in nectar and 50 mg/kg in pollen (Hladun, Kristen R. et al. 2016).
    - No significant effects were seen at 20 mg/L in nectar (i.e. 20 mg/kg) in the study by Burden et al (Burden et al. 2019).
- Lead – a number of relevant studies have found:
    - Concentrations around 42 mg/kg in pollen resulted in no effects while effects on survival in foraging bees were seen at 277-365 mg/kg (Moroń et al. 2012).
    - The LC50 (lethal concentration for 50% of exposed bees) for larvae was 1 mg/L (i.e. 1 mg/kg) and for foraging bees the LC50 was 345 mg/L (i.e. 345 mg/kg) (Di et al. 2016).

- Little effect was noted in a study where bees were exposed to 0.5 mg/kg in nectar and 1.6 mg/kg in pollen (Hladun, Kristen R. et al. 2016).
  - No significant effects were seen at 10 mg/L in nectar (i.e. 10 mg/kg) in the study by Burden et al (Burden et al. 2019).
- Nickel – one study on effects of nickel shows there were effects on bees at 100 mg/L in nectar (which is equivalent to 100 mg/kg) (Meindl & Ashman 2013)
- Selenium – a number of relevant studies found:
  - One off doses above 600 mg/L in nectar affected survival (Hladun, K. R. et al. 2012)
  - Daily exposure to 60 mg/L in nectar affected survival (Hladun, K. R. et al. 2012)
  - The LC50 (lethal concentration for 50% of exposed bees) for larvae was 0.7 mg/L (i.e. 0.7 mg/kg) and for foraging bees the LC50 was 58 mg/L (i.e. 58 mg/kg) (Hladun, Kristen R. et al. 2013)
  - Concentrations around 0.6 mg/kg in sugar solutions and 6 mg/kg in pollen resulted in lower weights for worker bees (Hladun, Kristen R. et al. 2016)
- Zinc – a single study showed that few effects were reported for bees in background areas where zinc concentrations in pollen were around 56-100 mg/kg while definite effects on survival in foraging bees were noted when zinc concentrations were around 440-592 mg/kg (Moroń et al. 2012).

Given the limited information, some assumptions have been made to determine conservative toxicity reference values for use in this assessment including:

- Metals with no toxicity data – cadmium is known to be a metal that causes effects at concentrations that are amongst the lowest for any of the metals. For this assessment, the LC50 values for larvae and foraging bees for cadmium have been used for cadmium and for the metals that have no specific toxicity data (i.e. 0.3 mg/kg for larvae and 70 mg/kg for foraging bees)
- Arsenic – the LC50 value reported was >1000 mg/kg for adult bees – values for cadmium will be used for this assessment as the data provided in the review article was from a study undertaken in 1926 where lead arsenate was applied to an orchard
- Copper – the LC50 values for copper in nectar listed above will be used for this assessment (i.e. 7 mg/kg for larvae and 70 mg/kg for foraging bees)
- Lead – the LC50 values for lead in nectar listed above will be used for this assessment (i.e. 1 mg/kg for larvae and 345 mg/kg for foraging bees)
- Nickel – the limited information only provides observations based on exposure to one concentration – this indicates a similar response to copper so the LC50 values for copper will be used in this assessment (i.e. 7 mg/kg for larvae and 70 mg/kg for foraging bees)
- Selenium – the LC50 values for selenium in nectar listed above will be used for this assessment (i.e. 0.7 mg/kg for larvae and 58 mg/kg for foraging bees)
- Zinc – no effects are expected at concentrations around 50 mg/kg in pollen; for nectar the LC50 values for copper will be used (i.e. 7 mg/kg for larvae and 70 mg/kg for foraging bees)

The standard approach used by the APVMA for converting LC50 values to toxicity reference values is to divide the LC50 by a factor of 2.5 (APVMA 2019; EPHC 2009a). Using this factor, the relevant toxicity reference values for use in this assessment are listed in **Table 1**.

Table 1: Toxicity reference values for metals present in food consumed by bees

Metal	Lifestage	Toxicity Reference Value in Food (mg/kg)
Antimony (Sb)	Adult foraging bee	28
	Larvae	0.1
Arsenic (As)	Adult foraging bee	28
	Larvae	0.1
Barium (Ba)	Adult foraging bee	28
	Larvae	0.1
Beryllium (Be)	Adult foraging bee	28
	Larvae	0.1
Cadmium (Cd)	Adult foraging bee	28
	Larvae	0.1
Chromium (Cr)	Adult foraging bee	28
	Larvae	0.1
Copper (Cu)	Adult foraging bee	28
	Larvae	0.1
Lead (Pb)	Adult foraging bee	138
	Larvae	0.4
Manganese (Mn)	Adult foraging bee	28
	Larvae	2.8
Mercury (Hg)	Adult foraging bee	28
	Larvae	0.1
Selenium (Se)	Adult foraging bee	23
	Larvae	0.3
Silver (Ag)	Adult foraging bee	28
	Larvae	0.1
Nickel (Ni)	Adult foraging bee	28
	Larvae	2.8
Zinc (Zn)	Adult foraging bee	28
	Larvae	2.8

Section 7. Exposure Assessment – Bees

7.1 General

This section presents an assessment of potential exposures of metals to bees located around the region surrounding the proposed gold mine. Also, potential for exposure of people who may consume the honey produced is considered.

The following figure outlines how such exposure might occur.

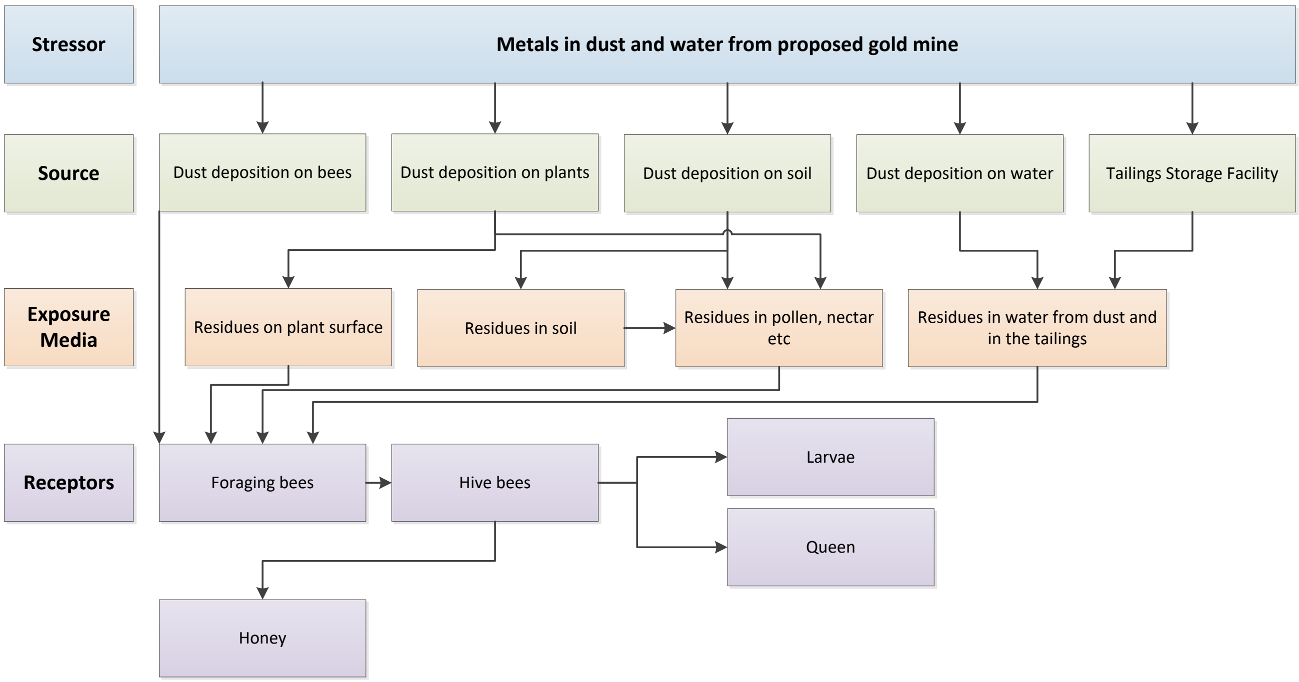


Figure 6: Potential exposure pathways to metals in dust and water from the proposed mine

As discussed in **Section 5.1**, the pathway by which metals might be present in honey is if they are present in nectar. To be present in nectar, they really need to be taken up from soil through the roots and be transferred up into the plant and then the flowers. Bees themselves can be exposed to metals if they are present in nectar, pollen, water they drink or in dust deposited directly on plants, soil, water and bee products.

7.2 Dust deposition

Air quality modelling undertaken as part of the environmental impact assessment for this project assessed the potential for dust from the mining works and estimated how much dust would be deposited in the surrounding area.

These data were used in the human health risk assessment to estimate exposures to metals when the dust mixes in with soil, settles on plants or gets washed into rainwater tanks. In addition, uptake into livestock like cattle and chickens was assessed based on modelled soil concentrations after dust had fallen onto and mixed in with soil. These data can also be used to evaluate the potential for metals to affect the bees.

Dust deposition data from the air quality modelling are listed in **Table 2**. Details about how deposition was modelled are provided in the air quality modelling report included as Appendix M in the environmental impact statement. Calculations to allocate the dust deposition rates for each metal based on proportions of the metals in the dust used to estimate concentrations in air are provided in **Appendix A**. The results of these allocations are listed in **Table 3**.

It is noted that all the data used here are for the maximum location from all receptors around the mine – i.e. the worst case location. The deposition of dust will decrease further from the mine and so these deposition rates are likely to overestimate exposure potential for soil, plants and water the bees might encounter – i.e. providing a conservative assessment.

Table 2: Predicted air concentrations for relevant metals (Table 8.1 Appendix M EIS)

COPC	Air Concentration – maximum from all receptors (µg/m^3)			
	Year 1	Year 2	Year 4	Year 8
Antimony (Sb)	1.79E-04	2.35E-04	3.39E-04	1.58E-04
Arsenic (As)	5.89E-03	7.71E-03	1.11E-02	5.20E-03
Barium (Ba)	1.00E-02	1.31E-02	1.89E-02	8.84E-03
Beryllium (Be)	1.56E-05	2.04E-05	2.94E-05	1.38E-05
Cadmium (Cd)	1.56E-05	2.04E-05	2.94E-05	1.38E-05
Chromium (Cr)	2.86E-04	3.74E-04	5.40E-04	2.52E-04
Copper (Cu)	3.04E-02	3.92E-02	5.74E-02	2.68E-02
Lead (Pb)	5.21E-04	8.33E-04	7.81E-04	2.38E-04
Manganese (Mn)	2.00E-01	2.00E-01	4.00E-01	2.00E-01
Mercury (Hg)	2.93E-06	3.83E-06	5.53E-06	2.59E-06
Selenium (Se)	Deposition rate provided directly by air quality modeller			
Silver (Ag)	3.79E-05	4.96E-05	7.16E-05	3.35E-05
Nickel (Ni)	9.12E-04	1.19E-03	1.72E-03	8.05E-04
Zinc (Zn)	1.37E-02	1.79E-02	2.59E-02	1.21E-02
Total Suspended Particulate (TSP)	3.2	5.1	4.8	1.4

Table 3: Predicted deposition rates for relevant metals

COPC	Deposition Rates – maximum from all receptors (mg/m^2/year)				
	Year 1	Year 2	Year 4	Year 8	Average
Antimony (Sb)	0.027	0.035	0.054	0.032	0.037
Arsenic (As)	0.88	1.2	1.8	1.1	1.2
Barium (Ba)	1.5	2	3	1.8	2.1
Beryllium (Be)	0.0023	0.0031	0.0047	0.0028	0.0032
Cadmium (Cd)	0.0023	0.0031	0.0047	0.0028	0.0032
Chromium (Cr)	0.043	0.056	0.086	0.052	0.059
Copper (Cu)	4.6	5.9	9.2	5.5	6.3
Lead (Pb)	0.078	0.13	0.13	0.049	0.094
Manganese (Mn)	30	30	64	41	41
Mercury (Hg)	0.00044	0.00058	0.00089	0.00053	0.00061
Selenium (Se)					
Silver (Ag)	0.0057	0.0075	0.012	0.0069	0.0079
Nickel (Ni)	0.14	0.18	0.028	0.17	0.19
Zinc (Zn)	2.1	2.7	4.1	2.5	2.85
Deposition Rate (TSP)	6000	9600	9600	3600	--

7.3 Calculation of concentrations in various media

7.3.1 Soil

The potential accumulation of metals in soil (relevant to Project emissions), which may be the result of deposition from a number of air emissions sources, can be estimated using a soil accumulation model (OEHHA 2015; Stevens 1991).

The concentration in soil, which may be the result of deposition following emission of dust containing metals, can be calculated using the following equation, with assumptions adopted in this assessment presented in **Table 4**.

In this case, the focus is on what could end up in the root zone of any flowering plants from deposition of dust, so the calculations have been undertaken assuming the dust mixes into the soil to a depth of 15 cm (i.e. "agricultural" soil as per descriptions in HHRA).

$$C_s = \frac{DR \cdot [1 - e^{-k \cdot t}]}{d \cdot \rho \cdot k} \cdot 1000 \qquad \text{(mg/kg)}$$

Table 4: Assumptions adopted to estimate soil concentrations

Parameter		Value adopted	Basis
		Soil	
DR	Particle deposition rate (mg/m^2/year)	Calculated based on the maximum deposition rate of TSP and proportion of metals in TSP	Relevant to areas where multi-pathway exposures may occur
k	Chemical-specific soil-loss constant (1/year) = ln(2)/$T^{0.5}$	Calculated	
$T^{0.5}$	Chemical half-life in soil (years)	273973	Default values for metals as per OEHHA (2015) (very long default value used as metals do not degrade with time as they are elements)
t	Accumulation time (years)	70 years	Default value (OEHHA 2015)
d	Soil mixing depth (m)	0.15 m	Default values (OEHHA 2015)
ρ	Soil bulk-density (g/m^3)	1600000	Default for fill material (CRC CARE 2011)
1000	Conversion from g to kg	Default requirement for conversion of units	

Using this calculation, the average (average of 4 indicative years as provided in EIS) soil concentrations for each metal at the location where the maximum amount of deposition occurs for the life of the mine, are listed in **Table 5**. Spreadsheets showing these calculations are provided in **Appendix B**.

Table 5: Predicted concentrations in soil due to dust deposition

Metal	Average Concentration in Soil using Maximum Deposition Rate (mg/kg)	Soil Quality Guideline Values (Ecological) (mg/kg) #
Antimony (Sb)	0.01	20[1]
Arsenic (As)	0.4	40[2]
Barium (Ba)	0.6	500[3]
Beryllium (Be)	0.0009	4[4]
Cadmium (Cd)	0.0009	3.8[5]
Chromium (Cr)	0.02	60[6]
Copper (Cu)	1.8	20[7]
Lead (Pb)	0.03	470[8]

Metal	Average Concentration in Soil using Maximum Deposition Rate (mg/kg)	Soil Quality Guideline Values (Ecological) (mg/kg) #
Manganese (Mn)	12	220[9]
Mercury (Hg)	0.0002	12[10]
Selenium (Se)	0.03	1[11]
Silver (Ag)	0.002	20[12]
Nickel (Ni)	0.06	5[13]
Zinc (Zn)	0.8	15[14]

Notes:

1 Antimony guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines for any land use type (residential/parkland/agricultural) (CCME 2018).

2 Arsenic guideline is lowest value for the ecological investigation level for any land use type (i.e. areas of ecological significance) (NEPC 1999 amended 2013c).

3 Barium guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines for any land use type (residential/parkland) (CCME 2018).

4 Beryllium guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines for any land use type (residential/parkland/agricultural) (CCME 2018).

5 Cadmium guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines designed to be protective of ecological systems for any land use type (agricultural) (CCME 1999a).

6 Chromium guideline is lowest value for the added contaminant limit for any land use type (i.e. low clay content soil characteristics in areas of ecological significance) (NEPC 1999 amended 2013c). It is noted that this value should be added to the naturally occurring level in soil for the area to determine a guideline value. The predicted soil concentration is well below the acceptable “added” level so will be below the sum of the added contaminant limit and the background soil concentration.

7 Copper guideline is lowest value for the added contaminant limit for any land use type (i.e. low pH soil in areas of ecological significance) (NEPC 1999 amended 2013c). It is noted that this guideline value should be added to the naturally occurring level in soil for the area to determine a guideline value. The predicted soil concentration is well below the acceptable “added” level so will be below the sum of the added contaminant limit and the background soil concentration.

8 Lead guideline is lowest value for the added contaminant limit for any land use type (i.e. areas of ecological significance) (NEPC 1999 amended 2013c). It is noted that this value should be added to the naturally occurring level in soil for the area to determine a guideline value. The predicted soil concentration is well below the acceptable “added” level so will be below the sum of the added contaminant limit and the background soil concentration.

9 Manganese guideline is lowest value for the ecological soil screening level from the USEPA for any organism type (plants in this case) (USEPA 2007)

10 Mercury guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines designed to be protective of ecological systems for any land use type (residential/parkland/agricultural) (CCME 1999b).

11 Selenium guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines designed to be protective of ecological systems for any land use type (residential/parkland/agricultural) (CCME 2009)

12 Silver guideline is lowest value for soil guidelines from the Canadian Soil Quality Guidelines for any land use type (residential/parkland/agricultural) (CCME 2018).

13 Nickel guideline is lowest value for the added contaminant limit for any land use type (i.e. low cation exchange capacity soil characteristics in areas of ecological significance) (NEPC 1999 amended 2013c). It is noted that this value should be added to the naturally occurring level in soil for the area to determine a guideline value. The predicted soil concentration is well below the acceptable “added” level so will be below the sum of the added contaminant limit and the background soil concentration.

14 Zinc guideline is lowest value for the added contaminant limit for any land use type (i.e. low pH and low cation exchange capacity soil characteristics in areas of ecological significance) (NEPC 1999 amended 2013c). It is noted that this value should be added to the naturally occurring level in soil for the area to determine a guideline value. The predicted soil concentration is well below the acceptable “added” level so will be below the sum of the added contaminant limit and the background soil concentration.

Australian soil quality guidelines are available for some metals in the National Environment Protection (Assessment of Site Contamination) Measure – the national guidance for assessing soil contamination arising from human activities (NEPC 1999 amended 2013c). For other metals, guidelines are available from the Canadian Soil Quality Guidelines or the USEPA Ecological Soil Screening Levels (https://www.epa.gov/chemical-research/ecological-soil-screening-level or http://st-ts.ccme.ca/en/index.html (CCME 2018; USEPA 2007).

For all of these guidelines, the calculations assume organisms are exposed to the guideline level of the metal for their entire lifetimes.

The predicted soil concentrations are all well below the relevant guideline values for protecting plants and animals from impacts from these different metals, so impacts are not expected for soil organisms, other insects, plants or larger organisms. This is a worst case estimate as it estimates the soil concentration after 70 years of deposition at the location(s) where the deposition rate is highest without any loss of the dust that has deposited from the location. Given this worst case type calculation and that all calculated concentrations are lower than relevant guideline values, it is not expected that there will be any impacts on the growth of plants or the presence of soil organisms which could impact on plant growth which could indirectly impacts bees in the area.

These predicted soil concentrations have also been used to evaluate potential uptake into nectar and other parts of a flowering plant in **Section 7.3.3**.

7.3.2 Water

The concentration in a water body depends on the deposition rate of dust (i.e. mass of dust deposited over a year) and the size and depth of a surface water body. The concentration in surface water for project related emissions, which could impact on aquatic organisms or terrestrial organisms (like bees) who may occasionally encounter a surface water body, is calculated as follows, where the parameters adopted for this assessment are detailed in **Table 6**:

$$C_W = \frac{DM}{\text{Volume} \times Kd \times \rho}$$

Table 6: Assumptions adopted to estimate concentration in water

Parameter		Value adopted	Basis
DM	Mass of dust deposited on the surface of a water body each year (mg)	DR x Area	
DR	Particle deposition rate for accidental release (mg/m^2/year)	Calculated in **Section 7.2**	
Area	Area of the water body (m^2)	10000 m^2	Based on a 1 hectare pond that is 15 cm deep – standard assumption used in pesticide assessments in Australia
Volume	Volume of water body (m^3)	1500 m^3	Based on a 1 hectare pond that is 15 cm deep – standard assumption used in pesticide assessments in Australia
Kd	Soil-water partition coefficient (cm^3/g)	Chemical-specific	All values from RAIS (RAIS)
ρ	Soil bulk density (g/m^3)	0.5	Assumed for loose deposited dust on roof (upper end measured for powders)

Using this calculation, the average dissolved concentrations for each metal in a surface water body at the location where the maximum amount of deposition occurs for the life of the mine, are listed in **Table 7**. Spreadsheets showing these calculations are provided in **Appendix B**.

Table 7: Predicted dissolved concentrations in surface waters due to dust deposition

Metal	Average Dissolved Concentration in Water Body using Maximum Deposition Rate (mg/L)	Water Quality Guideline Values (mg/L) #
Antimony (Sb)	0.00001	0.009
Arsenic (As)	0.0006	0.001
Barium (Ba)	0.0007	0.05@
Beryllium (Be)	0.00000006	0.0001
Cadmium (Cd)	0.0000006	0.0002
Chromium (Cr)	0.00004	0.001

Metal	Average Dissolved Concentration in Water Body using Maximum Deposition Rate (mg/L)	Water Quality Guideline Values (mg/L) #
Copper (Cu)	0.002	0.001
Lead (Pb)	0.000001	0.003
Manganese (Mn)	0.009	1.9
Mercury (Hg)	0.0000002	0.00006
Selenium (Se)	0.0002	0.01
Silver (Ag)	0.00001	0.00005
Nickel (Ni)	0.00004	0.01
Zinc (Zn)	0.0006	0.008

Notes:

\# Values listed are taken from Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) unless otherwise indicated and the value chosen is relevant for effects on invertebrates (i.e. not values relevant for bioaccumulation into birds and other higher organisms – i.e. 95% species protection values)

@ There is no Australian guideline for barium as it is usually considered to have very little toxicity. However, the USEPA ECOTOX database includes relevant data that can be used to develop an indicative guideline using the approach outlined in the Australian guidance (ANZG 2018; USEPA 2020). The laboratory ecotoxicity data for barium salts listed in this database indicates that barium is not very toxic to fish with LC50 values of 10s to 1000s mg/L. Some algae and aquatic plants show small levels of effect around 1 mg/L. Aquatic invertebrates reported toxicity at concentrations between 1 and 100s mg/L. Using the assessment factor approach, the results for the most sensitive species are divided by 100 for chemicals that are not also essential micronutrients, however, barium is required for growth in plants and perhaps in animals so an assessment factor of 20 is applied. The indicative guideline for barium is, therefore, 0.05 mg/L.

The Australian and New Zealand Water quality guidelines are indicative of water quality that is generally expected to be of appropriate quality for aquatic species (including fish, invertebrates (including insects), algae – species who live in the water) as well as terrestrial species who might occasionally interact with the water including insects that land on the water and birds, reptiles or mammals who may drink the water (ANZG 2018).

The predicted dissolved concentrations are all well below the relevant guideline value apart from copper (which is essentially equal to the guideline given sampling and measurement errors).

The calculations to determine the predicted dissolved concentrations have assumed that the total amount of dust deposited over a year is allowed to dissolve within a standard pond which is 1 hectare in area and 15 cm deep. This is the standard pond size used in pesticide assessments in Australia. Increases in the volume of water within the pond over a year from runoff during rain or from other sources into the pond has not been considered – it has been assumed the volume of water in the pond remains the same all the time. This is a worst case assessment and shows that all metal concentrations are the same or less than the relevant water quality guideline which indicates appropriate water quality for aquatic organisms (and by inference terrestrial organisms who have occasional interaction with the water).

7.3.3 Plants

Plants may become contaminated with metals via deposition directly onto the plant outer surface and following uptake via the root system. Both mechanisms have been assessed.

Uptake from soil

Uptake via the root system has been assessed using the same approach as adopted in the ASC NEPM (i.e. national guidance on contaminated soil). Appendix B of Schedule B7 of this guidance details the models adopted for calculating plant concentration factors. The approaches have been taken from the UK Environment Agency guidance for assessing plant uptake. Generally, the approach involves undertaking experiments where plants are grown in soil containing the metal of interest. At the end of the experiment, the concentration in various parts of the plants are measured. Ratios are then calculated indicating how much of what was in the soil moved into and around the plant – these ratios are known as concentration factors or uptake factors. For this situation, where the flowers are the focus rather than the edible portions of the plants, the approach for uptake into fruit has been adopted.

Appendix A1 of Schedule B7 of the ASC NEPM provides a profile for each metal for which soil guidelines have been developed. The profile includes a discussion of whether a particular metal has been found to move through a plant or be taken up through the roots in the first place (NEPC 1999 amended 2013d). The concentration factors for what moves into fruit from soil have been determined in the ASC NEPM for some of the metals of interest in this assessment. These values from the ASC NEPM are provided in **Table 8**. For other metals, the conclusion reached in the review used for the ASC NEPM that very little of those metals get taken up into plants.

Table 8: Concentration factors for uptake of relevant metals into fruit (NEPC 1999 amended 2013d)

COPC	Concentration Factor (mg/kg fresh weight per mg/kg in soil dry weight)
Arsenic (As)	0.0011
Cadmium (Cd)	0.0014
Mercury (Hg)	0.001
Nickel (Ni)	0.0034
Selenium (Se)	0.003

The lack of concentration factors in the ASC NEPM for the other metals is based on the findings for each metal in the relevant section of Appendix A1 from Schedule B7 (NEPC 1999 amended 2013d). For each metal without a listed concentration factor, the following reasoning is provided in the toxicological profile from this appendix:

- Beryllium – under the environmental conditions in most soils this metal is predominantly in a form that is insoluble so is not readily accumulated into plants. The US ATSDR found that if this metal is taken up in the roots it needs to be in a form that is water soluble for it to move from the roots into the rest of a plant including the flowers (NEPC 1999 amended 2013d).
- Chromium – under the environmental conditions in most soils this metal is predominantly in a form that is insoluble so is not readily accumulated into plants. The US ATSDR reported that movement of chromium from roots to leaves/fruit/flowers is poor (NEPC 1999 amended 2013d).
- Copper – this metal is a micronutrient that plants require for optimal growth. It is also a metal that causes impacts on plants at fairly low levels. As a result, it will be taken into the plant and can be moved around the plant, but the amount taken in will be controlled. If levels significantly higher than naturally occurring levels are present in soil, then the plants are unlikely to grow and flower as normal (NEPC 1999 amended 2013d).
- Lead – international agencies have reported that uptake of lead from soil is low as the lead in soil is usually in a form that is insoluble. Also, if it does get into the roots, movement from the roots to the rest of the plant is very low (NEPC 1999 amended 2013d).
- Manganese - this metal is a micronutrient that plants require for optimal growth. It is also a metal that causes impacts on the plants. A large proportion of manganese usually present in soils is in a form that is highly insoluble. Some manganese can be taken up by plants but it is

not thought to be moved around the plant well, especially for the insoluble forms (NEPC 1999 amended 2013d).

- Zinc – again the potential for uptake of this metal into plants is affected by what form it is present as in the soil. Many salts are quite insoluble and so are not likely to be taken up by the roots. In addition, toxicity to the plant may occur when soil concentrations are only a small amount higher than naturally occurring levels (NEPC 1999 amended 2013d).

For all of these metals, it is unlikely that uptake of high levels will occur into plants and then into the flowers, so this pathway is not relevant for this assessment.

Some of the metals being evaluated in this assessment are not included in the ASC NEPM. Information about plant uptake for these metals has been sought from the literature and is summarised following:

- Antimony – US ATSDR report that antimony can be taken up into plants through roots. Studies reviewed indicated that antimony was present in flowers (as well as other parts) of *Viola* species at 0.25-0.47 mg/kg. These concentrations were similar to concentrations in the stems of the plant and lower than concentrations in the roots, leaves or seeds. One study reviewed reported concentrations in shoots compared to concentrations in soil. From this information, an uptake factor of 0.0675 mg/kg fresh weight per mg/kg soil can be determined. This value is from only one study on one plant species but is an order of magnitude higher than those for the other metals listed in **Table 8** so is considered conservative for this assessment (ATSDR 2019).
- Barium – US ATSDR noted that very little barium is taken up by plants from soil compared to how much is in soil. Again, this is due to the insoluble nature of the usual forms found soil. (ATSDR 2007).
- Silver – US ATSDR noted that uptake of silver from soil is usually confined to the roots. Silver may be present in shoots and leaves but usually from deposition of dust rather than movement of silver from soil via the roots (ATSDR 1990).

Uptake into nectar via roots is expected to be relevant only for arsenic, antimony, nickel, mercury, selenium and cadmium.

The potential uptake of these metals into flowers/nectar via the roots can be estimated using the following equation (OEHHA 2015; USEPA 2005), with the parameters and assumptions adopted outlined in **Table 9**:

$$C_{flowers/nectar} = C_s \bullet UF \qquad \text{(mg/kg plant – wet weight)}$$

Table 9: Assumptions adopted to estimate concentration in nectar via uptake through roots

Parameter		Value adopted	Basis
Cs	Concentration of pollutant in soil (mg/kg)	Calculated value for root zone soil	Calculated as described in **Section 7.3.1** and assumptions in **Table 4**
UF	Uptake factor (unitless)	Chemical specific value adopted	Uptake factors from ASC NEPM and relevant US ATSDR Profiles as indicated above.

Using this calculation, the average predicted concentrations for each metal in nectar from uptake via the roots at the location where the maximum amount of deposition occurs for the life of the mine, are listed in **Table 10**. Spreadsheets showing these calculations are provided in **Appendix B**.

Table 10: Predicted concentrations in nectar via uptake from soil

Metal	Concentration in Nectar using Maximum Deposition Rate (mg/kg)
Antimony (Sb)	0.0008
Arsenic (As)	0.0004
Cadmium (Cd)	0.000001
Mercury (Hg)	0.0000002
Nickel (Ni)	0.0002
Selenium (Se)	0.00008

While it is not expected that the other metals will be taken up by plants and moved into the flowers and nectar, it is possible to find uptake factors for these metals in international databases. These uptake factors are based on a range of assumptions about how metals could be taken up by plants and are primarily based on uptake into the roots only. This is not actually relevant for this assessment of potential for impacts on bees. These factors for uptake into the roots only are also likely to be from experiments which used very soluble salts of these metals. Such experiments are not likely to be reflective of actual environmental exposures especially where the metals are sourced from dust from an ore body (i.e. relevant for this situation) – i.e. where the metals are present in a highly insoluble form.

Such uptake factors have been sourced from the relevant database (USEPA Risk Assessment Information System (RAIS) https://rais.ornl.gov/index.html) and the same calculation as described above can be used to estimate a concentration in nectar.

The RAIS database includes uptake factors from soil to plant for all the metals being assessed here. The factors listed in the RAIS database for those metals that have recommended concentration factors in **Table 8** are generally much higher than the values adopted for this assessment from the ASC NEPM and ATSDR profiles (i.e. values listed in **Table 8**).

For example, the RAIS listed uptake factor for arsenic is 0.01 while the factor for uptake into fruit from the ASC NEPM is 0.0011 (i.e. 10 fold lower). For cadmium, the RAIS listed uptake factor for arsenic is 0.125 while the factor for uptake into fruit from the ASC NEPM is 0.0014 (i.e. 100 fold lower).

So, using the RAIS factors for the other metals is likely to significantly overestimate concentrations in nectar for the following reasons:

- Based on tests using very soluble salts not those normally present in dust from ore bodies
- Usually taken from studies looking into uptake into roots only

The values listed in **Table 8** are more relevant for this assessment which is focused on uptake into flowers and so only those values have been used in this assessment. Further discussion of this area of uncertainty on the conclusions is included in the **Section 8**.

Direct deposition onto leaves and flowers

The potential concentration of metals that may be present within the plant following atmospheric deposition can be estimated using the following equation (Stevens 1991), with the parameters and assumptions adopted outlined in **Table 11**:

$$Cplant = \frac{DR * IF}{Y * k} * (1 - e^{-kT})$$

(mg/kg plant – wet weight)

Table 11: Assumptions adopted to estimate concentration in flowers and pollen due to dust deposition

Parameter		Value adopted	Basis
DR	Particle deposition rate ($mg/m^2/day$)	Calculated based on the maximum deposition rate of TSP and proportion of metals in TSP	Average values as provided in **Table 3** converted to per day values by dividing by 365
IF	Interception fraction for the surface area of plant (unitless)	0.008	Relevant to the small surface area for legumes which has been assumed similar to a flower and the pollen within it as per (Travis & Hattemer-Frey 1991) based on Stevens (1991) and used in OEHHA (OEHHA 2012)
k	Chemical-specific loss constant for particles on plants (1/day) = $ln(2)/T^{0.5}$	calculated	
$T^{0.5}$	Chemical half-life on plant (day)	14 days	Loss of particles from plant surfaces due to the effects of weather (wind/rain etc) and it is generally assumed that pollutants deposited onto the outer portion of plant surfaces have a weathering half-life of 14 days (Stevens, 1991)
t	Deposition time or length of growing season (days)	70 days	Conservative assumption for flowers, consistent with the value adopted by Stevens (1991)
Y	Yield (kg/m^2) (i.e. dry weight of plant material compared to volume)	2 kg/m^2	Value for aboveground crops (OEHHA 2015)
Cs	Concentration of pollutant in soil (mg/kg)	Calculated value for root zone soil	Calculated as described above and assumptions in **Table 4**

Using this calculation, the average concentrations for each metal that is likely to be in pollen or in dust to which bees may be exposed at the location where the maximum amount of deposition occurs for the life of the mine, are listed in **Table 12**. Spreadsheets showing these calculations are provided in **Appendix B**.

Table 12: Predicted concentrations in flowers/pollen due to dust deposition

Metal	Average Concentration in Flowers/Pollen using Maximum Deposition Rate (mg/kg)
Antimony (Sb)	0.000008
Arsenic (As)	0.0003
Barium (Ba)	0.0005
Beryllium (Be)	0.0000007
Cadmium (Cd)	0.0000007
Chromium (Cr)	0.00001
Copper (Cu)	0.001
Lead (Pb)	0.00002
Manganese (Mn)	0.009
Mercury (Hg)	0.0000001
Selenium (Se)	0.00002

Metal	Average Concentration in Flowers/Pollen using Maximum Deposition Rate (mg/kg)
Silver (Ag)	0.000002
Nickel (Ni)	0.00004
Zinc (Zn)	0.0006

7.4 Calculation of exposure to bees

The toxicity data discussed in **Section 6** include experiments where effects on bees have been related to the concentrations of metals in sugar solutions or pollen patties – i.e. what the bees ingest – rather than the concentration that could accumulate in the bee itself.

Section 7.3 describes how concentrations in pollen and nectar can be estimated. The estimated concentrations are listed in **Table 13**. As noted in **Section 7.3.3**, concentrations in nectar have been estimated only for metals considered likely to be taken up from soil via the roots and transferred to the flowers of a plant. Further consideration of the uncertainties associated with this matter is provided in **Section 8**.

Table 13: Predicted concentrations in flowers/pollen or nectar

Metal	Average Concentration in Flowers/Pollen (mg/kg)	Average Concentration in Nectar (mg/kg)
Antimony (Sb)	0.000008	0.0008
Arsenic (As)	0.0003	0.0004
Barium (Ba)	0.0005	--
Beryllium (Be)	0.0000007	--
Cadmium (Cd)	0.0000007	0.000001
Chromium (Cr)	0.00001	--
Copper (Cu)	0.001	--
Lead (Pb)	0.00002	--
Manganese (Mn)	0.009	--
Mercury (Hg)	0.0000001	0.0000002
Selenium (Se)	0.00002	0.00008
Silver (Ag)	0.000002	--
Nickel (Ni)	0.00004	0.0002
Zinc (Zn)	0.0006	--

The APVMA recommend a two tier assessment process for assessing the potential for pesticides to effect bees (APVMA 2015). The first step involves an initial screening step using conservative assumptions. A screening risk assessment to determine if there could be effects on bees at the concentrations of metals that could be present in the food the bees ingest – i.e. pollen or nectar – involves comparing the dose they are likely to receive in their food with the dose in their food that is unlikely to cause any adverse effects as determined in toxicity tests. If the predicted concentrations are higher than these conservative guidelines a more detailed assessment is required.

The screening assessment is shown in **Table 14**.

Table 14: Screening risk assessment for bees

Metal	Maximum predicted concentration in flowers/pollen/nectar (mg metal/kg food)	Lifestage	Toxicity Reference Value (mg/kg)
Antimony (Sb)	0.0008	Adult foraging bee	28

Metal	Maximum predicted concentration in flowers/pollen/nectar (mg metal/kg food)	Lifestage	Toxicity Reference Value (mg/kg)
		Larvae	0.1
Arsenic (As)	0.0004	Adult foraging bee	28
		Larvae	0.1
Barium (Ba)	0.0005	Adult foraging bee	28
		Larvae	0.1
Beryllium (Be)	0.0000007	Adult foraging bee	28
		Larvae	0.1
Cadmium (Cd)	0.000001	Adult foraging bee	28
		Larvae	0.1
Chromium (Cr)	0.00001	Adult foraging bee	28
		Larvae	0.1
Copper (Cu)	0.001	Adult foraging bee	28
		Larvae	0.1
Lead (Pb)	0.00002	Adult foraging bee	138
		Larvae	0.4
Manganese (Mn)	0.009	Adult foraging bee	28
		Larvae	2.8
Mercury (Hg)	0.0000002	Adult foraging bee	28
		Larvae	0.1
Selenium (Se)	0.00008	Adult foraging bee	23
		Larvae	0.3
Silver (Ag)	0.000002	Adult foraging bee	28
		Larvae	0.1
Nickel (Ni)	0.0002	Adult foraging bee	28
		Larvae	2.8
Zinc (Zn)	0.0006	Adult foraging bee	28
		Larvae	2.8

The estimated exposure concentrations for all metals in flowers, pollen or nectar at the location most affected by dust deposition from the proposed mine are all well below indicative guideline concentrations. These values are designed to indicate concentrations that are unlikely to cause any impacts on the bees. If the bees are exposed to concentrations below these values, it is even less likely that effects could occur.

A more specific assessment can be undertaken if the toxicity reference value is converted to a value based on mg/bee. Standard toxicity tests assume that each honey bee consumes 20 µL of sugar solution each day during the test for both adult and larvae. The conversion is undertaken by multiplying the toxicity reference value by 0.00002 (i.e. 20 µL as L).

The predicted dose for the bees is then determined by multiplying the concentration by the amount of food a bee might consume each day – 0.000292 kg/day for adult bees and 0.00012 kg/day for larvae. This approach is as per APVMA guidance (APVMA 2015).

Table 14: Screening risk assessment for bees

Metal	Predicted dose for bee (mg metal/bee)	Lifestage	Toxicity Reference Value (mg metal/bee)
Antimony (Sb)	0.0000002	Adult foraging bee	0.0056
	0.0000001	Larvae	0.000002
Arsenic (As)	0.0000001	Adult foraging bee	0.0056
	0.00000005	Larvae	0.000002
Barium (Ba)	0.00000015	Adult foraging bee	0.0056

Metal	Predicted dose for bee (mg metal/bee)	Lifestage	Toxicity Reference Value (mg metal/bee)
	0.00000006	Larvae	0.000002
Beryllium (Be)	0.0000000002	Adult foraging bee	0.0056
	0.00000000008	Larvae	0.000002
Cadmium (Cd)	0.0000000003	Adult foraging bee	0.0056
	0.0000000001	Larvae	0.000002
Chromium (Cr)	0.000000003	Adult foraging bee	0.0056
	0.000000001	Larvae	0.000002
Copper (Cu)	0.0000003	Adult foraging bee	0.0056
	0.0000001	Larvae	0.000002
Lead (Pb)	0.000000006	Adult foraging bee	0.0028
	0.000000002	Larvae	0.000008
Manganese (Mn)	0.000003	Adult foraging bee	0.0056
	0.000001	Larvae	0.00056
Mercury (Hg)	0.00000000006	Adult foraging bee	0.0056
	0.00000000002	Larvae	0.000002
Selenium (Se)	0.00000002	Adult foraging bee	0.00046
	0.00000001	Larvae	0.000006
Silver (Ag)	0.0000000006	Adult foraging bee	0.0056
	0.0000000002	Larvae	0.000002
Nickel (Ni)	0.00000006	Adult foraging bee	0.0056
	0.00000002	Larvae	0.00056
Zinc (Zn)	0.0000002	Adult foraging bee	0.0056
	0.0000001	Larvae	0.00056

Using this approach shows again that exposure to metals via dust deposition at the location most affected by dust deposition from the proposed mine is well below indicative guidelines for each metal. No further consideration of the impact of metals in the dust deposited from the proposed mine on bee health is required.

7.5 Calculation of exposure in tailings

7.5.1 Metals

In addition to metals being present in dust that may add to naturally occurring levels in soil, water, pollen and nectar, it is possible that the bees may drink directly from the tailings storage facility. Metal concentrations within this surface water body have been taken from the EIS (Table 4.14 in Appendix G – Geochemical characterisation (SRK Consulting dated July 2019)). This table lists the results for metal concentrations in tailings determined in pilot trials using the ore and proposed treatments and these metal concentrations are summarised in **Table 15**.

It is unlikely that the concentrations in water within the tailings storage facility will be the same as these values for the following reasons:

- Rain will accumulate in the tailings storage facility in addition to the tailings which will result in dilution
- These metals result primarily from the treatment of the ore and are mainly present as insoluble salts

This means that if the bees drink water from the tailings storage facility or other water storages they are likely to consume water containing concentrations lower than reported in **Table 15**.

Table 15: Estimated concentrations of metals in tailings

Metal	Average Concentration in Tailings (mg/L)	Water Quality Guideline Values (mg/L) #
Antimony (Sb)	0.009	0.009
Arsenic (As)	0.02	0.001
Barium (Ba)	0.09	0.05@
Beryllium (Be)	Not detected (<0.001)	0.0001
Cadmium (Cd)	Not detected (<0.0002)	0.0002
Chromium (Cr)	Not detected (<0.1)	0.001
Copper (Cu)	Not detected (<0.1)	0.001
Lead (Pb)	Not detected (<0.005)	0.003
Manganese (Mn)	0.4	1.9
Mercury (Hg)	Not detected (<0.001)	0.00006
Selenium (Se)	0.08	0.011
Silver (Ag)	0.0001	0.00005
Nickel (Ni)	Not detected (<0.1)	0.01
Zinc (Zn)	Not detected (<0.1)	0.008

Notes:

Values listed are taken from Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) unless otherwise indicated and the value chosen is relevant for effects on invertebrates (i.e. not values relevant for bioaccumulation into birds and other higher organisms – i.e. 95% species protection values)

@ There is no Australian guideline for barium as it is usually considered to have very little toxicity. However, the USEPA ECOTOX database includes relevant data that can be used to develop an indicative guideline using the approach outlined in the Australian guidance (ANZG 2018; USEPA 2020). The laboratory ecotoxicity data for barium salts listed in this database indicates that barium is not very toxic to fish with LC50 values of 10s to 1000s mg/L. Some algae and aquatic plants show small levels of effect around 1 mg/L. Aquatic invertebrates reported toxicity at concentrations between 1 and 100s mg/L. Using the assessment factor approach, the results for the most sensitive species are divided by 100 for chemicals that are not also essential micronutrients, however, barium is required for growth in plants and perhaps in animals so an assessment factor of 20 is applied. The indicative guideline for barium is, therefore, 0.05 mg/L.

APVMA guidance notes that exposure to pesticides via consumption of water containing a pesticide is not considered to be a major exposure route for bees and so is not normally included in the environmental assessments undertaken by the APVMA (APVMA 2015). However, APVMA notes that guidance from the European Food Safety Agency (EFSA) provides guidance on assessing exposure via water (EFSA 2014).

A study on thirst in honeybees notes that most water required by bees comes from the nectar they collect (Ostwald et al. 2016). When it is very hot or when the hive is very active, bees may require additional water for the hive. In these cases, the foraging bees are triggered to collect more water which they store in their crop (also known as their honey stomach) and then pass onto other worker bees within the hive when they return.

A study (and various websites about beekeeping) noted that larvae are typically fed from the secretions of the nurse bees (Lucchetti et al. 2018). The larvae don't directly eat nectar or pollen. This process has been shown to be protective of larval bees for the range of chemicals normally present in some plants (and, therefore, nectar and pollen) that do not affect adult bees but may cause unacceptable impacts in larval bees. These chemicals like naturally occurring alkaloids (present in, for example, the plant *Echium vulgare*) or cyanide containing glycosides in almond and related plants.

On this basis, the assessment of exposure of the bees via water from the tailings storage facility or other surface water bodies on the site will only be considered for the adult bees.

The same approach as used in **Section 7.4** has been adopted – where the predicted concentration in nectar, pollen etc is compared to the toxicity reference value (i.e. LC50 values from oral studies divided by 2.5 as per APVMA guidance).

In this case, the concentration in water was compared to the toxicity reference values after converting from units of mg/L to mg/kg using the density of water or 1 (i.e. mg/L = mg/kg for water solutions).

This screening assessment is shown in **Table 16**.

Table 16: Screening risk assessment for bees

Metal	Predicted concentration water bees consume (mg metal/kg water)	Lifestage	Toxicity Reference Value (mg/kg)
Antimony (Sb)	0.009	Adult foraging bee	28
Arsenic (As)	0.02	Adult foraging bee	28
Barium (Ba)	0.09	Adult foraging bee	28
Beryllium (Be)	Not detected (<0.001)	Adult foraging bee	28
Cadmium (Cd)	Not detected (<0.0002)	Adult foraging bee	28
Chromium (Cr)	Not detected (<0.1)	Adult foraging bee	28
Copper (Cu)	Not detected (<0.1)	Adult foraging bee	28
Lead (Pb)	Not detected (<0.005)	Adult foraging bee	138
Manganese (Mn)	0.4	Adult foraging bee	28
Mercury (Hg)	Not detected (<0.001)	Adult foraging bee	28
Selenium (Se)	0.08	Adult foraging bee	23
Silver (Ag)	0.0001	Adult foraging bee	28
Nickel (Ni)	Not detected (<0.1)	Adult foraging bee	28
Zinc (Zn)	Not detected (<0.1)	Adult foraging bee	28

All concentrations in water are well below the toxicity reference values.

A more specific assessment can be undertaken if the toxicity reference value is converted to a value based on mg/bee as shown in **Table 14**. Standard toxicity tests assume that each honey bee consumes 20 µL of sugar solution each day during the test for both adult and larvae. The conversion is undertaken by multiplying the toxicity reference value by 0.00002 (i.e. 20 µL as L).

The predicted dose for the bees is then determined by multiplying the concentration in the water by the amount of water a bee might consume each day based on EFSA guidance (EFSA 2014). This guidance indicates that adult bees consume 11 µL per day.

This assessment is shown in **Table 17**.

Table 17: Screening risk assessment for bees

Metal	Predicted dose for bee (mg metal/bee)	Lifestage	Toxicity Reference Value (mg metal/bee)
Antimony (Sb)	0.0000001	Adult foraging bee	0.00056
Arsenic (As)	0.0000002	Adult foraging bee	0.00056
Barium (Ba)	0.000001	Adult foraging bee	0.00056
Beryllium (Be)	Not detected	Adult foraging bee	0.00056
Cadmium (Cd)	Not detected	Adult foraging bee	0.00056
Chromium (Cr)	Not detected	Adult foraging bee	0.00056
Copper (Cu)	Not detected	Adult foraging bee	0.00056
Lead (Pb)	Not detected	Adult foraging bee	0.0028

Metal	Predicted dose for bee (mg metal/bee)	Lifestage	Toxicity Reference Value (mg metal/bee)
Manganese (Mn)	0.000004	Adult foraging bee	0.00056
Mercury (Hg)	Not detected	Adult foraging bee	0.00056
Selenium (Se)	0.0000009	Adult foraging bee	0.00046
Silver (Ag)	0.000000001	Adult foraging bee	0.00056
Nickel (Ni)	Not detected	Adult foraging bee	0.00056
Zinc (Zn)	Not detected	Adult foraging bee	0.00056

Using this approach shows again that exposure to metals via drinking water from the tailings storage facility will be well below indicative guidelines for each metal. No further consideration of the impact of metals in the tailings on bee health is required.

7.5.2 Cyanide

In addition to the metals that may be present in dust or tailings, there is also potential for cyanide to be present at the proposed mine. Cyanide is used to extract gold.

After processing and treatment to destroy excess cyanide, any remaining cyanide will end up in the tailings storage facility. Much of the cyanide in the tailings storage facility will react with some of the metals to form insoluble salts. These salts settle out of the liquid tailings onto the base of the dam.

In addition, the function of the tailings storage facility is to allow the fine waste particles from crushing the rock (ore) to settle out in a sand like form. Ongoing deposition of these fine particles causes layers of deposited tailings to be present in the base of the dam and these layers rise over time.

There is almost no information available in the scientific literature about the sort of concentrations of cyanide in water that might cause impacts to bees.

A number of studies have looked at the potential for bees to be exposed to cyanide when they collect nectar or pollen from plants that have naturally occurring chemicals in them that break down to release cyanide – plants like almonds. The studies have found that bees are not affected by these compounds much but this is because they don’t have the enzyme that breaks down the compounds to release cyanide (Lecocq et al. 2018; London-Shafir et al. 2003).

It is known that beekeepers in Canada and in other locations used various cyanide salts to kill bees during winter or if there were hives in inappropriate locations (Barnett et al. 2007).

The US Department of Agriculture published a recent review of the use of sodium cyanide in controlling wildlife like foxes, coyotes and wild dogs to prevent them from damaging livestock (USDA 2019). Sodium cyanide is placed in capsules for this use that are not readily accessed for small organisms. The review noted:

“Toxicity to pollinators such as honeybees and other above-ground invertebrates is unknown”

There are some data for earthworms and army worms indicating that they are quite resistant to the effects of cyanide so it is not appropriate to try and adapt that data (USDA 2019).

NICNAS undertook an assessment of the use of sodium cyanide in Australia in 2010 and they found that aquatic organisms were particularly sensitive. So, one approach to assessing potential for effects from cyanide on bees is to look at the water quality guideline for cyanide and compare that to the water quality guidelines for some of the metals assessed above.

Table 18: Water Quality Guidelines – metals and cyanide

Metal	Water Quality Guideline Values (mg/L) #
Antimony (Sb)	0.009
Arsenic (As)	0.001
Cadmium (Cd)	0.0002
Chromium (Cr)	0.001
Copper (Cu)	0.001
Lead (Pb)	0.003
Silver (Ag)	0.00005
Nickel (Ni)	0.01
Zinc (Zn)	0.008
Cyanide	0.007

Notes:

Values listed are taken from Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) and the value chosen is relevant for effects on invertebrates (i.e. not values relevant for bioaccumulation into birds and other higher organisms – i.e. 95% species protection values)

The water quality guideline for cyanide is similar to the value for zinc, antimony and nickel. Metals like copper, chromium and cadmium all have more sensitive water quality guidelines than cyanide.

For this assessment, the toxicity reference value for cadmium was used for metals with no data for bees as it was the most sensitive/conservative for all the metals generally as evidenced by the water quality guideline for cadmium compared to other metals. The same approach has been adopted for cyanide on the basis that cadmium is a more toxic metal than most other metals and there is a 35 fold difference between the water quality guideline for cyanide and cadmium. Water quality guidelines include consideration of the toxicity of a relevant chemical to a range of aquatic organisms including insects.

As described in the EIS for this project, cyanide will be used to extract gold from the ore. This is a common approach used at gold mines. Gold has a particular preference for reacting with cyanide but other metals present in the ore also react with the cyanide. Once the gold has been extracted the water is treated to destroy the cyanide lowering the cyanide concentration to levels in the tailings below the relevant licence limits prior to discharge to the tailings storage facility.

There are a range of forms of cyanide that might be present in the tailings. The different types of analyses include:

- Free cyanide
- Total cyanide
- Weak acid dissociable cyanide

Many of the forms of cyanide measured in the total cyanide method are forms that do not release cyanide in the environment. Weak acid dissociable cyanide measures the forms that do release cyanide in the environment if exposed to weakly acidic conditions. The most relevant type of cyanide that might impact on bees would be free cyanide.

The usual type of analysis required by NSW EPA in a licence is the weak acid dissociable cyanide as they are managing the potential for impact on birds. Birds have acid in their stomachs (like people do) so it is important to not underestimate the concentration of cyanide in the water that they could drink – hence the use of the weak acid dissociable analysis.

Bees do not have these acidic conditions. They store water in their honey stomach where it mixes with nectar so the only relevant type of cyanide for bees is free cyanide.

The process for destroying cyanide in the tailings will minimise the amount of free cyanide. In addition, once tailings are discharged to the tailings storage facility the free cyanide will evaporate from the water or react with metals in the suspended solids (Appendix F and CC of the EIS).

The maximum amount of weak acid dissociable cyanide (WAD) that is permitted to be present in the tailings at the point where they are discharged into the tailings storage facility is 30 mg/L. This assessment has been based on this concentration. It is probable that concentrations for WAD cyanide in the storage facility will be much lower than this value and it is definitely the case that free cyanide concentrations will be much lower than this value.

Table 19: Screening risk assessment for bees

Metal	Predicted concentration water bees consume (mg metal/kg water)	Lifestage	Toxicity Reference Value (mg/kg)
Antimony (Sb)	0.009	Adult foraging bee	28
Arsenic (As)	0.02	Adult foraging bee	28
Cadmium (Cd)	Not detected (<0.0002)	Adult foraging bee	28
Chromium (Cr)	Not detected (<0.1)	Adult foraging bee	28
Copper (Cu)	Not detected (<0.1)	Adult foraging bee	28
Lead (Pb)	Not detected (<0.005)	Adult foraging bee	138
Silver (Ag)	0.0001	Adult foraging bee	28
Nickel (Ni)	Not detected (<0.1)	Adult foraging bee	28
Zinc (Zn)	Not detected (<0.1)	Adult foraging bee	28
Cyanide	30	Adult foraging bee	28

The maximum concentration of weak acid dissociable cyanide in water is essentially the same as the toxicity reference value assumed for this assessment. Given that the water quality guideline for cyanide is 35 times higher than the one for cadmium, it is expected that the use of the value for cadmium is conservative in regard to the potential for effects of cyanide on bees.

Further assessment can be undertaken as is shown in **Section 7.5.1**. The predicted dose for the bees is then determined by multiplying the concentration in the water by the amount of water a bee might consume each day based on EFSA guidance (EFSA 2014). This guidance indicates that adult bees consume 11 µL per day. The conversion to a predicted dose is undertaken by multiplying the maximum concentration by 0.000011 (i.e. 11 µL as L).

Table 20: Screening risk assessment for bees

Metal	Predicted dose for bee (mg metal/bee)	Lifestage	Toxicity Reference Value (mg metal/bee)
Antimony (Sb)	0.0000001	Adult foraging bee	0.00056
Arsenic (As)	0.0000002	Adult foraging bee	0.00056
Cadmium (Cd)	Not detected	Adult foraging bee	0.00056
Chromium (Cr)	Not detected	Adult foraging bee	0.00056
Copper (Cu)	Not detected	Adult foraging bee	0.00056

Metal	Predicted dose for bee (mg metal/bee)	Lifestage	Toxicity Reference Value (mg metal/bee)
Lead (Pb)	Not detected	Adult foraging bee	0.0028
Silver (Ag)	0.000000001	Adult foraging bee	0.00056
Nickel (Ni)	Not detected	Adult foraging bee	0.00056
Zinc (Zn)	Not detected	Adult foraging bee	0.00056
Cyanide	0.00033	Adult foraging bee	0.00056

Using this approach shows again that exposure to cyanide via drinking water from the tailings storage facility will be well below indicative guidelines. No further consideration of the impact of cyanide in the tailings on bee health is required.

7.6 Estimated concentration in honey

Honey is formed within the hive by the conversion of some complex sugars into simple sugars in nectar collected and brought to the hive followed by the evaporation of water from the nectar.

The conversion of complex sugars (like sucrose and others) into simple sugars (glucose and fructose) will not affect the presence of metals or change their concentration in the nectar or honey. However, the evaporation of water from the nectar to produce honey will impact on the concentration of the metals in the final product as the same amount of metal originally present in the nectar will now be present in an overall smaller volume/mass.

Nectar contains 60-80% water. The honey produced from this nectar contains only about 20% water. So, if 100 g of nectar is converted to honey it would produce approximately 40-60 g honey. The mass of a metal present in the original mass of nectar is now present in approximately half the mass of honey so the concentration of the metal is essentially doubled.

The estimated concentrations of each metal in honey based on the estimated concentrations in nectar are listed in **Table 21**.

Table 21: Predicted concentrations in nectar and honey via uptake from soil

Metal	Estimated Concentration in Nectar (mg/kg)	Estimated Concentration in Honey (mg/kg)
Antimony (Sb)	0.0008	0.002
Arsenic (As)	0.0004	0.0008
Cadmium (Cd)	0.000001	0.000002
Mercury (Hg)	0.0000002	0.0000004
Nickel (Ni)	0.0002	0.0004

Concentrations in nectar listed in **Table 21** have been estimated only for metals considered likely to be taken up from soil via the roots and transferred to the flowers of a plant.

As noted in **Section 7.3.3**, while it is not expected that the other metals will be taken up by plants and moved into the flowers and nectar, it is possible to find uptake factors for these metals in international databases. These uptake factors are based on a range of assumptions about how metals could be taken up by plants and are primarily based on uptake into the roots only. This is not actually relevant for this assessment of potential for impacts on bees. These factors for uptake into the roots only are also likely to be from experiments which used very soluble salts of these metals. Such experiments are not likely to be reflective of actual environmental exposures where the metals are sourced from dust from an ore body (i.e. relevant for this situation) as the metals in such situations are present in a highly insoluble form.

However, given that there are no alternative methods to estimate uptake of these metals into nectar and then into honey, these uptake factors have been used here to allow an assessment of the potential for impacts on honey quality. It is noted from the discussion in **Section 7.3.3**, that the factors for uptake into roots for the metals where uptake factors for fruit are available are 10 – 100 times higher than the more realistic values for uptake into fruit so using this approach for estimating concentrations in nectar is likely to overestimate the concentrations by at least an order of magnitude (and maybe more). **Table 22** lists the highly conservative nectar concentrations for these metals.

Table 22: Predicted concentrations in nectar and honey via uptake from soil for metals that are not expected to be moved from roots to flowers

Metal	Estimated Concentration in Nectar (mg/kg)	Estimated Concentration in Honey (mg/kg)
Barium (Ba)	0.02	0.04
Beryllium (Be)	0.000002	0.000004
Chromium (Cr)	0.00003	0.00006
Copper (Cu)	0.2	0.4
Lead (Pb)	0.0003	0.0006
Manganese (Mn)	0.8	1.6
Silver (Ag)	0.0002	0.0004
Zinc (Zn)	0.2	0.4

Table 23 compares the predicted honey concentrations (including presumably highly conservative estimates for metals that are not easily moved through plants from roots to flowers) to the range of concentrations of metals in honey from a study that looked at metals in honey from a wide range of locations worldwide (Solayman et al. 2016).

It is noted that these estimates for this assessment are based on dust deposition to soil at the most affected location around the proposed mine. Dust deposition at all other locations around the mine will be less than this maximum value so if bees visit flowers growing in these other locations the concentrations of metals in nectar and honey will be lower than estimated here.

Table 23: Predicted concentrations in honey compared to general range of concentrations worldwide

Metal	Estimated Concentration in Honey (mg/kg)	Range in Concentrations in Honey Worldwide (mg/kg) (Solayman et al. 2016)
Antimony (Sb)	0.002	No information available
Arsenic (As)	0.0008	Non detect – 0.2
Barium (Ba)	0.04	No information available
Beryllium (Be)	0.000004	No information available
Cadmium (Cd)	0.000002	0.2 – 450
Chromium (Cr)	0.00006	Non detect – 550
Copper (Cu)	0.4	0.05 – 17
Lead (Pb)	0.0006	0.6 – 40
Manganese (Mn)	1.6	Non detect – 5
Mercury (Hg)	0.0000004	0.3 – 10
Silver (Ag)	0.0004	3 – 600
Nickel (Ni)	0.0004	Non detect – 9
Zinc (Zn)	0.4	0.2 – 74

The estimated concentrations in honey due to dust deposition at the most affected location for the proposed mine are well within (or even well below) normal ranges found worldwide. No further consideration of the impact of the proposed mine on honey quality is required.

Section 8. Uncertainties

Uncertainty in any assessment refers to a lack of knowledge (that could be better refined through the collection of additional data or conduct of additional studies or better understanding of how a process works) and is an important aspect of the risk assessment process. Variability refers to the normal variation that is present in many parameters such as chemical concentrations or body weight etc.

An assessment of uncertainty is a qualitative process relating to the selection and rejection of specific data, estimates or scenarios within the risk assessment. In general, to compensate for uncertainty, conservative assumptions are made that result in an overestimate rather than an underestimate of risk.

A number of approaches and assumptions have been adopted in this assessment that are expected to result in an overestimate of risk. These approaches/assumptions include:

- Using the effects data for cadmium for other metals without toxicity data. This is considered conservative because cadmium soil and water quality are amongst the most stringent for any of the metals so this approach is considered to overestimate the concentration in nectar or pollen that might affect the bees for all the other metals meaning that effects are not likely to be seen for these other metals until higher concentrations are present. These data are also appropriate for cadmium.
- Using the deposition rate for the most affected location around the proposed mine to estimate all relevant concentrations. The most affected location is usually close to but outside the boundary of proposed mine. All other locations will have lower deposition rates which will result in lower concentrations of metals in soil or water or nectar or pollen. Given the bees collect nectar and pollen from many plants around their hives, they may be exposed to the worst case concentrations at times but they will also be exposed to lower concentrations when accessing plants in other areas around the proposed mine.
- Use of standard soil and water quality guidelines to screen estimated concentrations in soil and water. This is conservative because such guidelines are designed to protect organisms (including insects) that live in/on the soil or in the water for their entire lifecycles whereas bees are only exposed to the affected soil or water occasionally as they source drinking water from a range of sources depending on where they go during foraging and only occasionally land on the soil.

A specific aspect where uncertainty is present is estimating uptake of metals from soil through the roots into flowers.

As noted in **Section 7.3.3**, while it is not expected that the other metals will be taken up by plants and moved into the flowers and nectar, it is possible to find uptake factors for these metals in international databases. These uptake factors are based on a range of assumptions about how metals could be taken up by plants and are primarily based on uptake into the roots only. This is not actually relevant for this assessment of potential for impacts on bees. These factors for uptake into the roots only are also likely to be from experiments which used very soluble salts of these metals. Such experiments are not likely to be reflective of actual environmental exposures especially where the metals are sourced from dust from an ore body (i.e. relevant for this situation) – i.e. where the metals are present in a highly insoluble form.

Such uptake factors have been sourced from the relevant database (USEPA Risk Assessment Information System (RAIS) https://rais.ornl.gov/index.html) and the same calculation as described above can be used to estimate a concentration in nectar.

The RAIS database includes uptake factors from soil to plant for all the metals being assessed here. The uptake factors from the RAIS database for those metals that have concentrations factors listed in **Table 8** are generally much higher than the values adopted for this assessment from the ASC NEPM and ATSDR profiles (i.e. values listed in **Table 8**). For example, the RAIS listed uptake factor for arsenic is 0.01 while the factor for uptake into fruit from the ASC NEPM is 0.0011 (i.e. 10 fold lower). For cadmium, the RAIS listed uptake factor for arsenic is 0.125 while the factor for uptake into fruit from the ASC NEPM is 0.0014 (i.e. 100 fold lower). So, using the RAIS factors for the other metals is likely to overestimate concentrations in nectar by more than 10 times. The values listed in **Table 8** are likely to be more relevant for this assessment which is focused on uptake into flowers and only those values have been used in this assessment.

Despite this lack of relevance of these concentration factors for this assessment, the concentrations in nectar have been estimated using them and the results have been reviewed to determine if conclusions would change. In this case, even if these highly conservative concentration factors were used, the concentrations in nectar are still below the concentrations thought to be sufficient to cause impacts in the bees. Consequently, no change in conclusions is required for this screening risk assessment. **Table 24** lists the results for the average concentration in nectar using these concentration factors (calculation spreadsheets in **Appendix B**). **Table 25** compares these results to the toxicity reference values adopted for this assessment.

Table 24: Predicted concentrations in nectar via uptake from soil for metals likely to be too insoluble in dust from the mine to be taken up by plants

Metal	Average Concentration in Nectar using Maximum Deposition Rate (mg/kg)
Barium (Ba)	0.02
Beryllium (Be)	0.000002
Chromium (Cr)	0.00003
Copper (Cu)	0.2
Lead (Pb)	0.0003
Manganese (Mn)	0.8
Silver (Ag)	0.0002
Zinc (Zn)	0.2

Table 25: Screening risk assessment for bees

Metal	Maximum predicted concentration in flowers/pollen/nectar (mg/kg)	Toxicity Reference Value (mg/kg)
Antimony (Sb)	0.0008	0.3 larvae; 70 foraging bees
Arsenic (As)	0.0004	0.3 larvae; 70 foraging bees
Barium (Ba)	0.02	0.3 larvae; 70 foraging bees
Beryllium (Be)	0.000002	0.3 larvae; 70 foraging bees
Cadmium (Cd)	0.000001	0.3 larvae; 70 foraging bees
Chromium (Cr)	0.00003	0.3 larvae; 70 foraging bees
Copper (Cu)	0.2	7 larvae; 70 foraging bees
Lead (Pb)	0.0003	1 larvae; 345 foraging bees
Manganese (Mn)	0.8	7 larvae; 70 foraging bees
Mercury (Hg)	0.0000002	0.3 larvae; 70 foraging bees

Metal	Maximum predicted concentration in flowers/pollen/nectar (mg/kg)	Toxicity Reference Value (mg/kg)
Silver (Ag)	0.0002	0.3 larvae; 70 foraging bees
Nickel (Ni)	0.0002	7 larvae; 70 foraging bees
Zinc (Zn)	0.2	7 larvae; 70 foraging bees

All concentrations estimated in nectar are below the relevant toxicity reference value, so no further assessment is required.

Section 9. Conclusions

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Regis Resources Pty Ltd (Regis) to undertake a review of the potential for impacts on bees of the proposed McPhillamys Gold Project near Blayney in New South Wales.

The environmental impact statement (EIS) for the development of this gold mine near Blayney, NSW was on public exhibition in mid 2019. One question that arose in consultations and in the submissions on the EIS is whether there is potential for the mine to have impacts on the local bee industry, both from dust blown from the mine site directly onto the plants the bees visit as well as indirectly when they drink water that may be impacted by dust from the site or water in the tailings storage facility.

This assessment has been designed to evaluate whether the mine could have impacts on bees via dust or water. The assessment has used the outcomes of the air quality impact assessment in regard to dust deposition from the proposed mine to characterise exposure of bees from dust and information from the geochemical assessment to estimate exposure via water in the tailings storage facility.

Reviews of the scientific literature in regard to:

- metal levels in honey, nectar, pollen and/or bees generally worldwide and around specific locations where metal contamination is known to be present
- metal concentrations that might cause impacts on the survival and health of bees

have been undertaken and are included in this assessment.

The assessment has found the following:

- concentrations of metals in soil due to deposition of dust are estimated to be below soil quality guidelines that are protective for soil organisms that live in or on the soil for their entire lifecycles
- concentrations of metals in water due to deposition of dust are estimated to be below water quality guidelines that are protective for aquatic organisms that live in the affected water for their entire lifecycles
- concentrations of metals that may get into nectar or pollen in plants around the proposed mine are all estimated to be below concentrations that might indicate effects on the survival or health of the bees could occur
- concentrations of metals or cyanide that may be present in water in the tailings storage facility are all estimated to be below concentrations that might indicate effects on the survival or health of the bees could occur
- concentrations of metals that could be present in honey are within or below the general levels reported for honey worldwide

Consequently, it is not expected that there will be any adverse impacts on the bee industry from metals in dust or from water in the tailings storage facility at the proposed mine.

Section 10. References

Aldgini, HMM, Abdullah Al-Abbadi, A, Abu-Nameh, ESM & Alghazeer, RO 2019, 'Determination of metals as bio indicators in some selected bee pollen samples from Jordan', *Saudi Journal of Biological Sciences,* vol. 26, no. 7, 2019/11/01/, pp. 1418-1422.

Álvarez-Ayuso, E & Abad-Valle, P 2017, 'Trace element levels in an area impacted by old mining operations and their relationship with beehive products', *Science of The Total Environment,* vol. 599-600, 2017/12/01/, pp. 671-678.

ANZG 2018, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, A joint initiative of the Australian and New Zealand Governments in partnership with the Australian state and territory governments, Online. <http://www.waterquality.gov.au/anz-guidelines>.

APVMA 2015, *Roadmap for insect pollinator risk assessment in Australia*, APVMA. <https://apvma.gov.au/node/18536>.

APVMA 2019, *APVMA Risk Assessment Manual - Environment*, Australian Pesticides and Veterinary Medicines Authority.

ATSDR 1990, *Toxicological Profile for Silver*, Agency for Toxic Substances and Disease Registry.

ATSDR 2007, *Toxicological Profile for Barium*, Agency for Toxic Substances and Disease Registry. <https://www.atsdr.cdc.gov/toxprofiles/TP.asp?id=327&tid=57>.

ATSDR 2019, *Toxicological Profile for Antimony and Compounds*, Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services. <https://www.atsdr.cdc.gov/ToxProfiles/tp23.pdf>.

Barnett, EA, Charlton, AJ & Fletcher, MR 2007, 'Incidents of bee poisoning with pesticides in the United Kingdom, 1994–2003', *Pest management science,* vol. 63, no. 11, pp. 1051-1057.

Burden, CM 2016, 'Sublethal Effects of Heavy Metal and Metalloid Exposure in Honey Bees: Behavioural Modifications and Potential Mechanisms', Doctoral Dissertation thesis, Neuroscience, Arizona State University, Phoenix, Arizona. <https://repository.asu.edu/items/40693>.

Burden, CM, Morgan, MO, Hladun, KR, Amdam, GV, Trumble, JJ & Smith, BH 2019, 'Acute sublethal exposure to toxic heavy metals alters honey bee (*Apis mellifera*) feeding behavior', *Scientific Reports,* vol. 9, no. 1, 2019/03/12, p. 4253.

CCME 1999a, *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health - Cadmium*, Canadian Council of Ministers of the Environment. <http://ceqg-rcqe.ccme.ca/download/en/261/>.

CCME 1999b, *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health, Mercury (Inorganic)*, Canadian Council of Ministers of the Environment.

CCME 2009, *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health - Selenium*, Canadian Council of Ministers of the Environment, 2002, updated 2007, revised 2009.

CCME 2018, *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health - Summary Page*, Canadian Council of Ministers of the Environment. <http://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/>.

Codex Alimentarius 2019, *STANDARD FOR HONEY (CXS 12-1981)*, Food and Agriculture Organisation of the United Nations and World Health Organisation. <http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B12-1981%252FCXS_012e.pdf>.

Conti, ME & Botrè, F 2001, 'Honeybees and Their Products as Potential Bioindicators of Heavy Metals Contamination', *Environmental monitoring and assessment,* vol. 69, no. 3, July 01, pp. 267-282.

CRC CARE 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC for Contamination Assessment and Remediation of the Environment, CRC CARE Technical Report no. 10, Adelaide. <http://www.crccare.com/products-and-services/health-screening-levels>.

Di, N, Hladun, KR, Zhang, K, Liu, T-X & Trumble, JT 2016, 'Laboratory bioassays on the impact of cadmium, copper and lead on the development and survival of honeybee (*Apis mellifera* L.) larvae and foragers', *Chemosphere,* vol. 152, 2016/06/01/, pp. 530-538.

Dzugan, M, Wesolowska, M, Zagula, G, Kaczmarski, M, Czernicka, M & Puchalski, C 2018, 'Honeybees (Apis mellifera) as a biological barrier for contamination of honey by environmental toxic metals', *Environmental monitoring and assessment,* vol. 190, no. 2, Jan 27, p. 101.

EFSA 2014, 'EFSA Guidance Document on the risk assessment of plant protection products on bees (*Apis mellifera*, *Bombus* spp. and solitary bees)', *EFSA Journal,* vol. 11, no. 7, pp. 3295-3563.

enHealth 2012a, *Australian Exposure Factors Guide*, Commonwealth of Australia, Canberra. <http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-publicat-environ.htm>.

enHealth 2012b, *Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards*, Commonwealth of Australia, Canberra. <http://www.health.gov.au/internet/main/publishing.nsf/content/804F8795BABFB1C7CA256F1900045479/$File/DoHA-EHRA-120910.pdf >.

EPHC 2009a, *Environmental Risk Assessment Guidance Manual for Agricultural and Veterinary Chemicals*, Environment Protection and Heritage Council. <http://www.scew.gov.au/publications/pubs/chemicals/cmgt_nchem__eragm_for_agricultural_and_veterinary_chemicals_200902.pdf>.

EPHC 2009b, *Environmental Risk Assessment Guidance Manual for Industrial Chemicals*, Environment Protection and Heritage Council. <http://scew.gov.au/resource/chemical-risk-assessment-guidance-manuals>.

Ernest, E, Onyeka, O, Ozuah, AC & Benard, N 2018, 'Comparative Assessment of the Heavy and Trace Metal Levels in Honey Produced within Nsukka and Enugu Metropolis', *Food and Public Health,* vol. 8, no. 2, pp. 42-46.

FSANZ 2001, *Generally Expected Levels (GELs) for Metal Contaminants: Additional Guidelines to Standard 1.4.1 – Contaminants and Natural Toxicants*, Food Standards Australia and New Zealand. <http://www.foodstandards.gov.au/code/userguide/documents/GELs_0801.pdf>.

FSANZ 2016, *Food Standards Code 1.4.1 Contaminants and natural toxicants*, Food Standards Australia and New Zealand. <https://www.foodstandards.gov.au/code/Pages/default.aspx>.

FSANZ 2017, *Food Standards Code Schedule 19 Maximum levels of contaminants and natural toxicants*, Food Standards Australia and New Zealand. <https://www.foodstandards.gov.au/code/Pages/default.aspx>.

Hladun, KR, Smith, BH, Mustard, JA, Morton, RR & Trumble, JT 2012, 'Selenium toxicity to honey bee (Apis mellifera L.) pollinators: effects on behaviors and survival', *PLoS One,* vol. 7, no. 4, p. e34137.

Hladun, KR, Kaftanoglu, O, Parker, DR, Tran, KD & Trumble, JT 2013, 'Effects of selenium on development, survival, and accumulation in the honeybee (Apis mellifera L.)', *Environmental Toxicology and Chemistry,* vol. 32, no. 11, pp. 2584-2592.

Hladun, KR, Di, N, Liu, T-X & Trumble, JT 2016, 'Metal contaminant accumulation in the hive: Consequences for whole-colony health and brood production in the honey bee (Apis mellifera L.)', *Environmental Toxicology and Chemistry,* vol. 35, no. 2, pp. 322-329.

Johnson, RM 2015, 'Honey Bee Toxicology', *Annual Review of Entomology,* vol. 60, no. 1, pp. 415-434.

Lecocq, A, Green, AA, Pinheiro De Castro, ÉC, Olsen, CE, Jensen, AB & Zagrobelny, M 2018, 'Honeybees Tolerate Cyanogenic Glucosides from Clover Nectar and Flowers', *Insects,* vol. 9, no. 1, p. 31.

Leita, L, Muhlbachova, G, Cesco, S, Barbattini, R & Mondini, C 1996, 'Investigation of the use of honey bees and honey bee products to assess heavy metals contamination', *Environmental monitoring and assessment,* vol. 43, no. 1, 1996/10/01, pp. 1-9.

London-Shafir, I, Shafir, S & Eisikowitch, D 2003, 'Amygdalin in almond nectar and pollen – facts and possible roles', *Plant Systematics and Evolution,* vol. 238, no. 1, 2003/05/01, pp. 87-95.

Lucchetti, MA, Kilchenmann, V, Glauser, G, Praz, C & Kast, C 2018, 'Nursing protects honeybee larvae from secondary metabolites of pollen', *Proceedings of the Royal Society B: Biological Sciences,* vol. 285, no. 1875, p. 20172849.

Meindl, GA & Ashman, T-L 2013, 'The effects of aluminum and nickel in nectar on the foraging behavior of bumblebees', *Environmental Pollution,* vol. 177, 2013/06/01/, pp. 78-81.

Moroń, D, Grześ, IM, Skórka, P, Szentgyörgyi, H, Laskowski, R, Potts, SG & Woyciechowski, M 2012, 'Abundance and diversity of wild bees along gradients of heavy metal pollution', *Journal of Applied Ecology,* vol. 49, no. 1, pp. 118-125.

Moroń, D, Szentgyörgyi, H, Skórka, P, Potts, SG & Woyciechowski, M 2014, 'Survival, reproduction and population growth of the bee pollinator, Osmia rufa (Hymenoptera: Megachilidae), along gradients of heavy metal pollution', *Insect Conservation and Diversity,* vol. 7, no. 2, pp. 113-121.

Negri, I, Mavris, C, Di Prisco, G, Caprio, E & Pellecchia, M 2015, 'Honey Bees (Apis mellifera, L.) as Active Samplers of Airborne Particulate Matter', *PLoS One,* vol. 10, no. 7, p. e0132491.

NEPC 1999 amended 2013a, *Schedule B4, Guideline on Health Risk Assessment Methodology, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 1999 amended 2013b, *Schedule B5 Guideline for Ecological Risk Assessment, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council.

NEPC 1999 amended 2013c, *Schedule B1, Guideline on Investigation Levels For Soil and Groundwater, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 1999 amended 2013d, *Schedule B7, Guideline on Health-Based Investigation Levels, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

OEHHA 2012, *Air Toxics Hot Spots Program, Risk Assessment Guidelines, Technical Support Document, Exposure Assessment and Stochastic Analysis*, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

OEHHA 2015, *Air Toxics Hot Spots Program, Risk Assessment Guidelines, Guidance Manual for Preparation of Health Risk Assessments*, Air, Community, and Environmental Research Branch, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Ostwald, MM, Smith, ML & Seeley, TD 2016, 'The behavioral regulation of thirst, water collection and water storage in honey bee colonies', *The Journal of Experimental Biology,* vol. 219, no. 14, pp. 2156-2165.

Pellecchia, M & Negri, I 2018, 'Particulate matter collection by honey bees (Apis mellifera, L.) near to a cement factory in Italy', *PeerJ,* vol. 6, pp. e5322-e5322.

RAIS *The Risk Assessment Information System*, Department of Energy's (DOE's) Oak Ridge Operations Office (ORO).

Roman, A 2009, 'Concentration of Chosen Trace Elements of Toxic Properties in Bee Pollen Loads', *Polish Journal of Environmental Studies,* vol. 18, no. 2, pp. 265-272.

Rothman, JA, Leger, L, Kirkwood, JS & McFrederick, QS 2019, 'Cadmium and Selenate Exposure Affects the Honey Bee Microbiome and Metabolome, and Bee-Associated Bacteria Show Potential for Bioaccumulation', *Applied and environmental microbiology,* vol. 85, no. 21, pp. e01411-01419.

Ruschioni, S, Riolo, P, Minuz, RL, Stefano, M, Cannella, M, Porrini, C & Isidoro, N 2013, 'Biomonitoring with Honeybees of Heavy Metals and Pesticides in Nature Reserves of the Marche Region (Italy)', *Biological trace element research,* vol. 154, no. 2, 2013/08/01, pp. 226-233.

Sadowska, M, Gogolewska, H, Pawelec, N, Sentkowska, A & Krasnodębska-Ostręga, B 2019, 'Comparison of the contents of selected elements and pesticides in honey bees with regard to their habitat', *Environmental Science and Pollution Research,* vol. 26, no. 1, 2019/01/01, pp. 371-380.

Satta, A, Verdinelli, M, Ruiu, L, Buffa, F, Salis, S, Sassu, A & Floris, I 2012, 'Combination of beehive matrices analysis and ant biodiversity to study heavy metal pollution impact in a post-mining area (Sardinia, Italy)', *Environmental Science and Pollution Research,* vol. 19, no. 9, 2012/11/01, pp. 3977-3988.

Saunier, J-B, Losfeld, G, Freydier, R & Grison, C 2013, 'Trace elements biomonitoring in a historical mining district (les Malines, France)', *Chemosphere,* vol. 93, no. 9, 2013/11/01/, pp. 2016-2023.

Silici, S, Uluozlu, OD, Tuzen, M & Soylak, M 2016, 'Honeybees and honey as monitors for heavy metal contamination near thermal power plants in Mugla, Turkey', *Toxicology and Industrial Health,* vol. 32, no. 3, pp. 507-516.

Skorbiłowicz, M, Skorbiłowicz, E & Cieśluk, I 2018, 'Bees as Bioindicators of Environmental Pollution with Metals in an Urban Area', *Journal of Ecological Engineering,* vol. 19, no. 3, pp. 229-234.

Smith, KE, Weis, D, Amini, M, Shiel, AE, Lai, VWM & Gordon, K 2019, 'Honey as a biomonitor for a changing world', *Nature Sustainability,* vol. 2, no. 3, 2019/03/01, pp. 223-232.

Solayman, M, Islam, MA, Paul, S, Ali, Y, Khalil, MI, Alam, N & Gan, SH 2016, 'Physicochemical Properties, Minerals, Trace Elements, and Heavy Metals in Honey of Different Origins: A Comprehensive Review', *Comprehensive Reviews in Food Science and Food Safety,* vol. 15, no. 1, pp. 219-233.

Søvik, E, Perry, CJ, LaMora, A, Barron, AB & Ben-Shahar, Y 2015, 'Negative impact of manganese on honeybee foraging', *Biology Letters,* vol. 11, no. 3, p. 20140989.

Stevens, B 1991, '2,3,7,8-Tetrachlorobenzo-p-Dioxin in the Agricultural Food Chain: Potential Impact of MSW Incineration on Human Health', in HA Hattemer-Frey & T Curtis (eds), *Health Effects of Municipal Waste Incineration*, CRC Press.

Taha, E-KA, Al-Jabr, AM & Al-Kahtani, SN 2017, 'Honey Bees, Bee-collected Pollen and Honey as Monitors of Environmental Pollution at an Industrial Cement Area in Saudi Arabia', *Journal of the Kansas Entomological Society,* vol. 90, no. 1, pp. 1-10, 10.

Taylor, MP 2019, 'Bees as biomarkers', *Nature Sustainability,* vol. 2, no. 3, 2019/03/01, pp. 169-170.

Travis, CC & Hattemer-Frey, HA 1991, *Health effects of municipal waste incineration / editors, Holly A. Hattemer-Frey and Curtis Travis*, CRC Press, Boca Raton.

USDA 2019, *THE USE OF SODIUM CYANIDE IN WILDLIFE DAMAGE MANAGEMENT, Chapter 7, Human Health and Ecological Risk Assessment for the Use of Wildlife Damage Management Methods by USDA-APHIS-Wildlife Services*, US Department of Agriculture.

USEPA 2005, *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities*, Office of Solid Waste and Emergency Response, US Environmental Protection Agency. <https://archive.epa.gov/epawaste/hazard/tsd/td/web/html/risk.html>.

USEPA 2007, *Ecological Soil Screening Levels for Manganese Interim Final*, US Environmental Protection Agency. <https://www.epa.gov/chemical-research/interim-ecological-soil-screening-level-documents>.

USEPA 2014, *Guidance for Assessing Pesticide Risks to Bees*, Office of Pesticide Programs United States Environmental Protection Agency Washington, D.C. ; Health Canada Pest Management Regulatory Agency Ottawa, Canada; California Department of Pesticide Regulation Sacramento, California. <https://www.epa.gov/sites/production/files/2014-06/documents/pollinator_risk_assessment_guidance_06_19_14.pdf>.

USEPA 2020, *ECOTOX Database*, US Environmental Protection Agency. <https://cfpub.epa.gov/ecotox/>.

van der Steen, JJM, de Kraker, J & Grotenhuis, T 2012, 'Spatial and temporal variation of metal concentrations in adult honeybees (Apis mellifera L.)', *Environmental monitoring and assessment,* vol. 184, no. 7, pp. 4119-4126.

Van der Steen, JJM, De Kraker, J & Grotenhuis, T 2015, 'Assessment of the Potential of Honeybees (Apis mellifera L.) in Biomonitoring of Air Pollution by Cadmium, Lead and Vanadium', *Journal of Environmental Protection,* vol. 6, pp. 96-102.

van der Steen, JJM, Cornelissen, B, Blacquière, T, Pijnenburg, JEML & Severijnen, M 2016, 'Think regionally, act locally: metals in honeybee workers in the Netherlands (surveillance study 2008)', *Environmental monitoring and assessment,* vol*.* 188, no. 8, pp. 463-463.

Whitford, F, Steeger, T, Feken, M, Krupke, C, Hunt, G, Johnson, R, Gerber, C, Obermeyer, J, Given, K & Leigh Smith, K 2017, *The complex life of the honey bee. Environmental, biological and chemical challenges to colony health*, Protecting Pollinators Series, Purdue Extension Education. <https://mdc.itap.purdue.edu/item.asp?Item_Number=POL-9>.

Zhou, X, Taylor, MP & Davies, PJ 2018a, 'Tracing natural and industrial contamination and lead isotopic compositions in an Australian native bee species', *Environmental Pollution,* vol*.* 242, 2018/11/01/, pp. 54-62.

Zhou, X, Taylor, MP, Davies, PJ & Prasad, S 2018b, 'Identifying Sources of Environmental Contamination in European Honey Bees (*Apis mellifera*) Using Trace Elements and Lead Isotopic Compositions', *Environmental science & technology,* vol*.* 52, no. 3, 2018/02/06, pp. 991-1001.

Appendix A Allocation of metals in dust using data from Air Quality Impact Assessment (Appendix M EIS)

Proportions of TSP for each metal

To determine proportions for each metal in the dust, the maximum 1 hour average for each metal is converted to an annual average (std factor of 0.08) and the annual average concentration is compared to the annual average for TSP. This proportion is then applied to the dust deposition rate to determine how much of each metal gets deposited over time.

	Concentrations as listed in Table 8.1 Appendix M EIS				*Concentrations converted to mg/m³*			
	Air Concentration - maximum from all receptors (µg/m3)				**Air Concentration - maximum from all receptors (mg/m3)**			
COPC	**Year 1**	**Year 2**	**Year 4**	**Year 8**	**Year 1**	**Year 2**	**Year 4**	**Year 8**
Antimony (Sb)	1.79E-04	2.35E-04	3.39E-04	1.58E-04	1.79E-07	2.35E-07	3.39E-07	1.58E-07
Arsenic (As)	5.89E-03	7.71E-03	1.11E-02	5.20E-03	5.89E-06	7.71E-06	1.11E-05	5.20E-06
Barium (Ba)	1.00E-02	1.31E-02	1.89E-02	8.84E-03	1.00E-05	1.31E-05	1.89E-05	8.84E-06
Beryllium (Be)	1.56E-05	2.04E-05	2.94E-05	1.38E-05	1.56E-08	2.04E-08	2.94E-08	1.38E-08
Cadmium (Cd)	1.56E-05	2.04E-05	2.94E-05	1.38E-05	1.56E-08	2.04E-08	2.94E-08	1.38E-08
Chromium (Cr)	2.86E-04	3.74E-04	5.40E-04	2.52E-04	2.86E-07	3.74E-07	5.40E-07	2.52E-07
Copper (Cu)	3.04E-02	3.92E-02	5.74E-02	2.68E-02	3.04E-05	3.92E-05	5.74E-05	2.68E-05
Lead (Pb)	5.21E-04	8.33E-04	7.81E-04	2.38E-04	5.21E-07	8.33E-07	7.81E-07	2.38E-07
Manganese (Mn)	2.00E-01	2.00E-01	4.00E-01	2.00E-01	2.00E-04	2.00E-04	4.00E-04	2.00E-04
Mercury (Hg)	2.93E-06	3.83E-06	5.53E-06	2.59E-06	2.93E-09	3.83E-09	5.53E-09	2.59E-09
Selenium (Se)	Deposition rate directly provided by air quality modeller							
Silver (Ag)	3.79E-05	4.96E-05	7.16E-05	3.35E-05	3.79E-08	4.96E-08	7.16E-08	3.35E-08
Nickel (Ni)	9.12E-04	1.19E-03	1.72E-03	8.05E-04	9.12E-07	1.19E-06	1.72E-06	8.05E-07
Zinc (Zn)	1.37E-02	1.79E-02	2.59E-02	1.21E-02	1.37E-05	1.79E-05	2.59E-05	1.21E-05

	1 hour average concentrations (mg/m³)				*Annual average concentrations (mg/m³)*			
	Air Concentration - maximum from all receptors (mg/m3)				**Air Concentration - maximum from all receptors (mg/m3)**			
COPC	**Year 1**	**Year 2**	**Year 4**	**Year 8**	**Year 1**	**Year 2**	**Year 4**	**Year 8**
Antimony (Sb)	1.79E-07	2.35E-07	3.39E-07	1.58E-07	1.43E-08	1.88E-08	2.71E-08	1.26E-08
Arsenic (As)	5.89E-06	7.71E-06	1.11E-05	5.20E-06	4.71E-07	6.17E-07	8.88E-07	4.16E-07
Barium (Ba)	1.00E-05	1.31E-05	1.89E-05	8.84E-06	8.00E-07	1.05E-06	1.51E-06	7.07E-07
Beryllium (Be)	1.56E-08	2.04E-08	2.94E-08	1.38E-08	1.25E-09	1.63E-09	2.35E-09	1.10E-09
Cadmium (Cd)	1.56E-08	2.04E-08	2.94E-08	1.38E-08	1.25E-09	1.63E-09	2.35E-09	1.10E-09
Chromium (Cr)	2.86E-07	3.74E-07	5.40E-07	2.52E-07	2.29E-08	2.99E-08	4.32E-08	2.02E-08
Copper (Cu)	3.04E-05	3.92E-05	5.74E-05	2.68E-05	2.43E-06	3.14E-06	4.59E-06	2.14E-06
Lead (Pb)	5.21E-07	8.33E-07	7.81E-07	2.38E-07	4.17E-08	6.66E-08	6.25E-08	1.90E-08
Manganese (Mn)	2.00E-04	2.00E-04	4.00E-04	2.00E-04	1.60E-05	1.60E-05	3.20E-05	1.60E-05
Mercury (Hg)	2.93E-09	3.83E-09	5.53E-09	2.59E-09	2.34E-10	3.06E-10	4.42E-10	2.07E-10
Selenium (Se)	Deposition rate directly provided by air quality modeller							
Silver (Ag)	3.79E-08	4.96E-08	7.16E-08	3.35E-08	3.03E-09	3.97E-09	5.73E-09	2.68E-09
Nickel (Ni)	9.12E-07	1.19E-06	1.72E-06	8.05E-07	7.30E-08	9.52E-08	1.38E-07	6.44E-08
Zinc (Zn)	1.37E-05	1.79E-05	2.59E-05	1.21E-05	1.10E-06	1.43E-06	2.07E-06	9.68E-07

	Annual average concentrations (mg/m³)							
	Air Concentration - maximum from all receptors (mg/m3)				**Proportion for each metal**			
COPC	**Year 1**	**Year 2**	**Year 4**	**Year 8**	**Year 1**	**Year 2**	**Year 4**	**Year 8**
TSP	0.0032	0.0051	0.0048	0.0014				
Antimony (Sb)	1.43E-08	1.88E-08	2.71E-08	1.26E-08	0.000448%	0.000369%	0.000565%	0.000903%
Arsenic (As)	4.71E-07	6.17E-07	8.88E-07	4.16E-07	0.0147%	0.0121%	0.0185%	0.0297%
Barium (Ba)	8.00E-07	1.05E-06	1.51E-06	7.07E-07	0.025%	0.0205%	0.0315%	0.0505%
Beryllium (Be)	1.25E-09	1.63E-09	2.35E-09	1.10E-09	0.0000390%	0.0000320%	0.0000490%	0.0000789%
Cadmium (Cd)	1.25E-09	1.63E-09	2.35E-09	1.10E-09	0.0000390%	0.0000320%	0.0000490%	0.0000789%
Chromium (Cr)	2.29E-08	2.99E-08	4.32E-08	2.02E-08	0.000715%	0.000587%	0.000900%	0.00144%
Copper (Cu)	2.43E-06	3.14E-06	4.59E-06	2.14E-06	0.076%	0.0615%	0.0957%	0.153%
Lead (Pb)	4.17E-08	6.66E-08	6.25E-08	1.90E-08	0.00130%	0.00131%	0.00130%	0.00136%
Manganese (Mn)	1.60E-05	1.60E-05	3.20E-05	1.60E-05	0.50%	0.314%	0.667%	1.14%
Mercury (Hg)	2.34E-10	3.06E-10	4.42E-10	2.07E-10	0.00000733%	0.00000601%	0.00000922%	0.0000148%
Selenium (Se)	Deposition rate directly provided by air quality modeller				0.00123769%	0.00127204%	0.00127486%	0.0013063%
Silver (Ag)	3.03E-09	3.97E-09	5.73E-09	2.68E-09	0.0000948%	0.0000778%	0.000119%	0.000191%
Nickel (Ni)	7.30E-08	9.52E-08	1.38E-07	6.44E-08	0.00228%	0.00187%	0.00287%	0.00460%
Zinc (Zn)	1.10E-06	1.43E-06	2.07E-06	9.68E-07	0.0343%	0.0281%	0.04317%	0.0691%

	Proportion for each metal				**Deposition rate for each metal (mg/m²/year)**				**Average Deposition Rate across years**
COPC	**Year 1**	**Year 2**	**Year 4**	**Year 8**	**Year 1**	**Year 2**	**Year 4**	**Year 8**	
Dust Deposition (mg/m²/year)					**6000**	**9600**	**9600**	**3600**	
Antimony (Sb)	0.000448%	0.000369%	0.000565%	0.000903%	0.02685	0.0354	0.0542	0.0325	0.037245273
Arsenic (As)	0.014725%	0.012094%	0.018500%	0.029714%	0.8835	1.16	1.776	1.07	1.222562395
Barium (Ba)	0.025000%	0.020549%	0.031500%	0.050514%	1.5	1.97	3.024	1.82	2.078805042
Beryllium (Be)	0.000039%	0.000032%	0.000049%	0.000079%	0.00234	0.00307	0.00470	0.00284	0.003238714
Cadmium (Cd)	0.000039%	0.000032%	0.000049%	0.000079%	0.00234	0.00307	0.00470	0.00284	0.003238714
Chromium (Cr)	0.000715%	0.000587%	0.000900%	0.001440%	0.0429	0.0563	0.0864	0.0518	0.059365
Copper (Cu)	0.076000%	0.061490%	0.095667%	0.153143%	4.56	5.903	9.18	5.51	6.29005042
Lead (Pb)	0.001303%	0.001306%	0.001302%	0.001357%	0.0781875	0.125	0.125	0.0489	0.094352337
Manganese (Mn)	0.500000%	0.313725%	0.666667%	1.142857%	30	30	64	41	41.31512605
Mercury (Hg)	0.000007%	0.000006%	0.000009%	0.000015%	0.0004395	0.000577	0.000885	0.000533	0.000608463
Selenium (Se)	0.001238%	0.001272%	0.001275%	0.001306%	0.07426122	0.122116	0.122386	0.047027	0.091447599
Silver (Ag)	0.000095%	0.000078%	0.000119%	0.000191%	0.005685	0.00747	0.0115	0.00689	0.007875401
Nickel (Ni)	0.002280%	0.001867%	0.002867%	0.004600%	0.1368	0.179	0.275	0.166	0.1892
Zinc (Zn)	0.034250%	0.028078%	0.043167%	0.069143%	2.055	2.70	4.14	2.49	2.845918067

Appendix B Exposure Modelling Calculations

Calculation of Concentrations in Soil

$$C_s = \frac{DR \bullet \left[1 - e^{-k \bullet t}\right]}{d \bullet \rho \bullet k} \bullet 1000 \quad \text{(mg/kg)}$$

ref: Stevens B. (1991)

where:

DR=	Particle deposition rate (mg/m²/year)
k =	Chemical-specific soil-loss constant (1/year) = ln(2)/T0.5
T0.5 =	Chemical half-life in soil (years)
t =	Accumulation time (years)
d =	Soil mixing depth (m)
ρ =	Soil bulk-density (g/m³)
1000 =	Conversion from g to kg

General Parameters		Depth (relevant for root zone of flowering plants)	
Soil bulk density (p)	g/m³	1600000	Default for fill materials
General mixing depth (d)	m	0.15	As per OEHHA (2015) guidance
Duration of deposition (T)	years	70	As per OEHHA (2015) guidance

Year 1

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	Half-life in soil years	Loss constant (K) per year	Deposition Rate (DR) mg/m²/year	Root Zone Concentration in Soil mg/kg	Average Root Zone Concentration in Soil mg/kg
Antimony (Sb)	273973	2.5E-06	0.0269	7.8E-03	1.1E-02
Arsenic (As)	273973	2.5E-06	0.8835	2.6E-01	3.6E-01
Barium (Ba)	273973	2.5E-06	1.5000	4.4E-01	6.1E-01
Beryllium (Be)	273973	2.5E-06	0.0023	6.8E-04	9.4E-04
Cadmium (Cd)	273973	2.5E-06	0.0023	6.8E-04	9.4E-04
Chromium (Cr)	273973	2.5E-06	0.0429	1.3E-02	1.7E-02
Copper (Cu)	273973	2.5E-06	4.5600	1.3E+00	1.8E+00
Lead (Pb)	273973	2.5E-06	0.0782	2.3E-02	2.8E-02
Manganese (Mn)	273973	2.5E-06	30.0000	8.7E+00	1.2E+01
Mercury (Hg)	273973	2.5E-06	0.0004	1.3E-04	1.8E-04
Selenium (Se)	273973	2.5E-06	0.0743	2.2E-02	2.7E-02
Silver (Ag)	273973	2.5E-06	0.0057	1.7E-03	2.3E-03
Nickel (Ni)	273973	2.5E-06	0.1368	4.0E-02	5.5E-02
Zinc (Zn)	273973	2.5E-06	2.0550	6.0E-01	8.3E-01

Year 2

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	Half-life in soil years	Loss constant (K) per year	Deposition Rate (DR) mg/m²/year	Root Zone Concentration in Soil mg/kg
Antimony (Sb)	273973	2.5E-06	0.0354	1.0E-02
Arsenic (As)	273973	2.5E-06	1.1610	3.4E-01
Barium (Ba)	273973	2.5E-06	1.9727	5.8E-01
Beryllium (Be)	273973	2.5E-06	0.0031	9.0E-04
Cadmium (Cd)	273973	2.5E-06	0.0031	9.0E-04
Chromium (Cr)	273973	2.5E-06	0.0563	1.6E-02
Copper (Cu)	273973	2.5E-06	5.9031	1.7E+00
Lead (Pb)	273973	2.5E-06	0.1254	3.7E-02
Manganese (Mn)	273973	2.5E-06	30.1176	8.8E+00
Mercury (Hg)	273973	2.5E-06	0.0006	1.7E-04
Selenium (Se)	273973	2.5E-06	0.1221	3.6E-02
Silver (Ag)	273973	2.5E-06	0.0075	2.2E-03
Nickel (Ni)	273973	2.5E-06	0.1792	5.2E-02
Zinc (Zn)	273973	2.5E-06	2.6955	7.9E-01

Year 4

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	Half-life in soil years	Loss constant (K) per year	Deposition Rate (DR) mg/m²/year	Root Zone Concentration in Soil mg/kg
Antimony (Sb)	273973	2.5E-06	0.0542	1.6E-02
Arsenic (As)	273973	2.5E-06	1.7760	5.2E-01
Barium (Ba)	273973	2.5E-06	3.0240	8.8E-01
Beryllium (Be)	273973	2.5E-06	0.0047	1.4E-03
Cadmium (Cd)	273973	2.5E-06	0.0047	1.4E-03
Chromium (Cr)	273973	2.5E-06	0.0864	2.5E-02
Copper (Cu)	273973	2.5E-06	9.1840	2.7E+00
Lead (Pb)	273973	2.5E-06	0.1250	3.6E-02
Manganese (Mn)	273973	2.5E-06	64.0000	1.9E+01
Mercury (Hg)	273973	2.5E-06	0.0009	2.6E-04
Selenium (Se)	273973	2.5E-06	0.1224	3.6E-02
Silver (Ag)	273973	2.5E-06	0.0115	3.3E-03
Nickel (Ni)	273973	2.5E-06	0.2752	8.0E-02
Zinc (Zn)	273973	2.5E-06	4.1440	1.2E+00

Year 8

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	Half-life in soil years	Loss constant (K) per year	Deposition Rate (DR) mg/m²/year	Root Zone Concentration in Soil mg/kg
Antimony (Sb)	273973	2.5E-06	0.0325	9.5E-03
Arsenic (As)	273973	2.5E-06	1.0697	3.1E-01
Barium (Ba)	273973	2.5E-06	1.8185	5.3E-01
Beryllium (Be)	273973	2.5E-06	0.0028	8.3E-04
Cadmium (Cd)	273973	2.5E-06	0.0028	8.3E-04
Chromium (Cr)	273973	2.5E-06	0.0518	1.5E-02
Copper (Cu)	273973	2.5E-06	5.5131	1.6E+00
Lead (Pb)	273973	2.5E-06	0.0489	1.4E-02
Manganese (Mn)	273973	2.5E-06	41.1429	1.2E+01
Mercury (Hg)	273973	2.5E-06	0.0005	1.6E-04
Selenium (Se)	273973	2.5E-06	0.0470	1.4E-02
Silver (Ag)	273973	2.5E-06	0.0069	2.0E-03
Nickel (Ni)	273973	2.5E-06	0.1656	4.8E-02
Zinc (Zn)	273973	2.5E-06	2.4891	7.3E-01

Calculation of Concentrations in Surface Water Body

Dissolved $C_W = DM/(V*Kd*\rho)$ (mg/L)

where:

DM =	Mass of dust deposited in a standard pond each year (mg) = DR x Area
DR =	Deposition rate from model (mg/m^2/year) (includes wet and dry deposition)(maximum for all receptors used in calculations)
Area =	Area of standard 1 hectare pond (m^2)
V =	Volume of water in the standard surface water body - calculation assumes dust mixes in the minimum volume of water that may be present instantaneously
ρ =	Soil bulk-density (g/m^3)
Kd =	Soil-water partition coefficient (cm3/g)

General Parameters			
Area of water body	m^2	10000	standard 1 hectare pond
Volume of water body	m^3	1500	standard 1 hectare pond with 15 cm depth
Volume of water body	L	1500000	convert from m3 to L
Bulk density of deposited dust	g/cm^3	0.5	assumed for loose deposited dust on roof (similar to upper end measured for powders)

Year 1

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	PM10 Deposition Rate (DR) mg/m^2/year	Mass deposited each year (DM) mg	Kd (cm^3/g)	Particulate Concentration in water mg/L	Dissolved Concentration in water mg/L	Average for all years (mg/L)
Antimony (Sb)	0.0269	268.5	45.0	1.8E-04	8.0E-06	1.1E-05
Arsenic (As)	0.8835	8835.0	29	5.9E-03	4.1E-04	5.6E-04
Barium (Ba)	1.5000	15000.0	41	1.0E-02	4.9E-04	6.8E-04
Beryllium (Be)	0.0023	23.4	790	1.6E-05	3.9E-08	5.5E-08
Cadmium (Cd)	0.0023	23.4	75	1.6E-05	4.2E-07	5.8E-07
Chromium (Cr)	0.0429	429.0	19	2.9E-04	3.0E-05	4.2E-05
Copper (Cu)	4.5600	45600.0	35	3.0E-02	1.7E-03	2.4E-03
Lead (Pb)	0.0782	781.9	900	5.2E-04	1.2E-06	1.4E-06
Manganese (Mn)	30.0000	300000.0	65	2.0E-01	6.2E-03	8.5E-03
Mercury (Hg)	0.0004	4.4	52	2.9E-06	1.1E-07	1.6E-07
Selenium (Se)	0.0743	742.6	5	5.0E-04	2.0E-04	2.4E-04
Silver (Ag)	0.0057	56.9	8	3.8E-05	9.1E-06	1.3E-05
Nickel (Ni)	0.1368	1368.0	65	9.1E-04	2.8E-05	3.9E-05
Zinc (Zn)	2.0550	20550.0	62	1.4E-02	4.4E-04	6.1E-04

Year 2

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	PM10 Deposition Rate (DR) mg/m^2/year	Mass deposited each year (DM) mg	Kd (cm3/g)	Particulate Concentration in water mg/L	Dissolved Concentration in water mg/L
Antimony (Sb)	0.0354	353.9	45	2.4E-04	1.0E-05
Arsenic (As)	1.1610	11610.4	29	7.7E-03	5.3E-04
Barium (Ba)	1.9727	19727.1	41	1.3E-02	6.4E-04
Beryllium (Be)	0.0031	30.7	790	2.0E-05	5.2E-08
Cadmium (Cd)	0.0031	30.7	75	2.0E-05	5.5E-07
Chromium (Cr)	0.0563	563.2	19	3.8E-04	4.0E-05
Copper (Cu)	5.9031	59030.6	35	3.9E-02	2.2E-03
Lead (Pb)	0.1254	1253.6	900	8.4E-04	1.9E-06
Manganese (Mn)	30.1176	301176.5	65	2.0E-01	6.2E-03
Mercury (Hg)	0.0006	5.8	52	3.8E-06	1.5E-07
Selenium (Se)	0.1221	1221.2	5	8.1E-04	3.3E-04
Silver (Ag)	0.0075	74.7	8	5.0E-05	1.2E-05
Nickel (Ni)	0.1792	1792.0	65	1.2E-03	3.7E-05
Zinc (Zn)	2.6955	26955.3	62	1.8E-02	5.8E-04

Year 4

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	PM10 Deposition Rate (DR) mg/m^2/year	Mass deposited each year (DM) mg	Kd (cm3/g)	Particulate Concentration in water mg/L	Dissolved Concentration in water mg/L
Antimony (Sb)	0.0542	542.4	45	3.6E-04	1.6E-05
Arsenic (As)	1.7760	17760.0	29	1.2E-02	8.2E-04
Barium (Ba)	3.0240	30240.0	41	2.0E-02	9.8E-04
Beryllium (Be)	0.0047	47.0	790	3.1E-05	7.9E-08
Cadmium (Cd)	0.0047	47.0	75	3.1E-05	8.4E-07
Chromium (Cr)	0.0864	864.0	19	5.8E-04	6.1E-05
Copper (Cu)	9.1840	91840.0	35	6.1E-02	3.5E-03
Lead (Pb)	0.1250	1250.0	900	8.3E-04	1.9E-06
Manganese (Mn)	64.0000	640000.0	65	4.3E-01	1.3E-02
Mercury (Hg)	0.0009	8.8	52	5.9E-06	2.3E-07
Selenium (Se)	0.1224	1223.9	5	8.2E-04	3.3E-04
Silver (Ag)	0.0115	114.6	8	7.6E-05	1.8E-05
Nickel (Ni)	0.2752	2752.0	65	1.8E-03	5.6E-05
Zinc (Zn)	4.1440	41440.0	62	2.8E-02	8.9E-04

Year 8

Chemical-specific Inputs and calculations - maximum all receptors

Chemical	PM10 Deposition Rate (DR) mg/m^2/year	Mass deposited each year (DM) mg	Kd (cm3/g)	Particulate Concentration in water mg/L	Dissolved Concentration in water mg/L
Antimony (Sb)	0.0325	325.0	45	2.2E-04	9.6E-06
Arsenic (As)	1.0697	10697.1	29	7.1E-03	4.9E-04
Barium (Ba)	1.8185	18185.1	41	1.2E-02	5.9E-04
Beryllium (Be)	0.0028	28.4	790	1.9E-05	4.8E-08
Cadmium (Cd)	0.0028	28.4	75	1.9E-05	5.0E-07
Chromium (Cr)	0.0518	518.4	19	3.5E-04	3.6E-05
Copper (Cu)	5.5131	55131.4	35	3.7E-02	2.1E-03
Lead (Pb)	0.0489	488.6	900	3.3E-04	7.2E-07
Manganese (Mn)	41.1429	411428.6	65	2.7E-01	8.4E-03
Mercury (Hg)	0.0005	5.3	52	3.6E-06	1.4E-07
Selenium (Se)	0.0470	470.3	5	3.1E-04	1.3E-04
Silver (Ag)	0.0069	68.9	8	4.6E-05	1.1E-05
Nickel (Ni)	0.1656	1656.0	65	1.1E-03	3.4E-05
Zinc (Zn)	2.4891	24891.4	62	1.7E-02	5.4E-04

Estimated Concentration in Pollen

ref: Stevens B. (1991)

Pollen concentration due to deposition

$$Cpollen = \frac{DR * IF}{Y * k} * (1 - e^{-kt})$$

(mg/kg plant – wet weight)

where:
DR= Particle deposition rate (mg/m^2/day)
IF= Interception fraction for the surface area of plant (unitless)
k= Chemical-specific soil-loss constant (1/years) = ln(2)/$T_{0.5}$
$T_{0.5}$= Chemical half-life as particulate on plant (days)
t= Deposition time (days)
Y= Crop yield (kg/m^2)

General Parameters	Units	Value	
Crop		Flowers/pollen	
Crop Yield (Y)	kg/m^2	2	default assumption (OEHHA 2015)
Deposition Time (t)	days	70	conservative assumption for flowers
Plant Interception fraction (IF)	unitless	0.008	interception fraction for legumes (Travis and Hattemer-Frey 1991)

Year 1

Chemical-specific Inputs and calculations - All receptors					
Chemical	Half-life in plant ($T_{0.5}$) days	Loss constant (k) per day	Deposition Rate (DR) mg/m^2/day	Pollen/Flower Concentration via Deposition mg/kg ww	Average Pollen/Flower Concentration via Deposition mg/kg ww
Antimony (Sb)	14	0.05	0.0000736	5.8E-06	8.0E-06
Arsenic (As)	14	0.05	0.0024205	1.9E-04	2.6E-04
Barium (Ba)	14	0.05	0.0041096	3.2E-04	4.5E-04
Beryllium (Be)	14	0.05	0.0000064	5.0E-07	6.9E-07
Cadmium (Cd)	14	0.05	0.0000064	5.0E-07	6.9E-07
Chromium (Cr)	14	0.05	0.0001175	9.2E-06	1.3E-05
Copper (Cu)	14	0.05	0.0124932	9.8E-04	1.3E-03
Lead (Pb)	14	0.05	0.0002142	1.7E-05	2.0E-05
Manganese (Mn)	14	0.05	0.0821918	6.4E-03	8.9E-03
Mercury (Hg)	14	0.05	0.0000012	9.4E-08	1.3E-07
Selenium (Se)	14	0.05	0.0002035	1.6E-05	2.0E-05
Silver (Ag)	14	0.05	0.0000156	1.2E-06	1.7E-06
Nickel (Ni)	14	0.05	0.0003748	2.9E-05	4.1E-05
Zinc (Zn)	14	0.05	0.0056301	4.4E-04	6.1E-04

Year 2

Chemical-specific Inputs and calculations - All receptors				
Chemical	Half-life in plant ($T_{0.5}$) days	Loss constant (k) per day	Deposition Rate (DR) mg/m^2/day	Pollen/Flower Concentration via Deposition mg/kg ww
Antimony (Sb)	14	0.05	0.0000970	7.6E-06
Arsenic (As)	14	0.05	0.0031809	2.5E-04
Barium (Ba)	14	0.05	0.0054047	4.2E-04
Beryllium (Be)	14	0.05	0.0000084	6.6E-07
Cadmium (Cd)	14	0.05	0.0000084	6.6E-07
Chromium (Cr)	14	0.05	0.0001543	1.2E-05
Copper (Cu)	14	0.05	0.0161728	1.3E-03
Lead (Pb)	14	0.05	0.0003435	2.7E-05
Manganese (Mn)	14	0.05	0.0825141	6.5E-03
Mercury (Hg)	14	0.05	0.0000016	1.2E-07
Selenium (Se)	14	0.05	0.0003346	2.6E-05
Silver (Ag)	14	0.05	0.0000205	1.6E-06
Nickel (Ni)	14	0.05	0.0004910	3.8E-05
Zinc (Zn)	14	0.05	0.0073850	5.8E-04

Year 4

Chemical-specific Inputs and calculations - All receptors				
Chemical	Half-life in plant ($T_{0.5}$) days	Loss constant (k) per day	Deposition Rate (DR) mg/m^2/day	Pollen/Flower Concentration via Deposition mg/kg ww
Antimony (Sb)	14	0.05	0.0001486	1.2E-05
Arsenic (As)	14	0.05	0.0048658	3.8E-04
Barium (Ba)	14	0.05	0.0082849	6.5E-04
Beryllium (Be)	14	0.05	0.0000129	1.0E-06
Cadmium (Cd)	14	0.05	0.0000129	1.0E-06
Chromium (Cr)	14	0.05	0.0002367	1.9E-05
Copper (Cu)	14	0.05	0.0251616	2.0E-03
Lead (Pb)	14	0.05	0.0003425	2.7E-05
Manganese (Mn)	14	0.05	0.1753425	1.4E-02
Mercury (Hg)	14	0.05	0.0000024	1.9E-07
Selenium (Se)	14	0.05	0.0003353	2.6E-05
Silver (Ag)	14	0.05	0.0000314	2.5E-06
Nickel (Ni)	14	0.05	0.0007540	5.9E-05
Zinc (Zn)	14	0.05	0.0113534	8.9E-04

Year 8

Chemical-specific Inputs and calculations - All receptors				
Chemical	Half-life in plant ($T_{0.5}$) days	Loss constant (k) per day	Deposition Rate (DR) mg/m^2/day	Pollen/Flower Concentration via Deposition mg/kg ww
Antimony (Sb)	14	0.05	0.0000890	7.0E-06
Arsenic (As)	14	0.05	0.0029307	2.3E-04
Barium (Ba)	14	0.05	0.0049822	3.9E-04
Beryllium (Be)	14	0.05	0.0000078	6.1E-07
Cadmium (Cd)	14	0.05	0.0000078	6.1E-07
Chromium (Cr)	14	0.05	0.0001420	1.1E-05
Copper (Cu)	14	0.05	0.0151045	1.2E-03
Lead (Pb)	14	0.05	0.0001339	1.0E-05
Manganese (Mn)	14	0.05	0.1127202	8.8E-03
Mercury (Hg)	14	0.05	0.0000015	1.1E-07
Selenium (Se)	14	0.05	0.0001288	1.0E-05
Silver (Ag)	14	0.05	0.0000189	1.5E-06
Nickel (Ni)	14	0.05	0.0004537	3.6E-05
Zinc (Zn)	14	0.05	0.0068196	5.3E-04

Estimated Concentration in Nectar

ref: Stevens B. (1991)

Uptake into flowers from soil via roots

$$Cnectar = Csoil \ast uptake\ factor$$

(mg/kg plant – wet weight)

where:
Cs = Concentration of metal in soil assuming 15 cm mixing depth
calculated using Soil Equation for each chemical assessed (mg/kg)
UF = Uptake factor which differs for each Chemical (unitless)

Year 1

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww	Average Plant Concentration (mg/kg ww)
Antimony (Sb)	0.07	7.8E-03	5.5E-04	7.6E-04
Arsenic (As)	0.0011	2.6E-01	2.8E-04	3.9E-04
Cadmium (Cd)	0.0014	6.8E-04	9.6E-07	1.3E-06
Mercury (Hg)	0.001	1.3E-04	1.3E-07	1.8E-07
Selenium (Se)	0.003	2.2E-02	6.5E-05	8.0E-05
Nickel (Ni)	0.0034	4.0E-02	1.4E-04	1.9E-04

Year 2

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Antimony (Sb)	0.07	1.0E-02	7.2E-04
Arsenic (As)	0.0011	3.4E-01	3.7E-04
Cadmium (Cd)	0.0014	9.0E-04	1.3E-06
Mercury (Hg)	0.001	1.7E-04	1.7E-07
Selenium (Se)	0.003	3.6E-02	1.1E-04
Nickel (Ni)	0.0034	5.2E-02	1.8E-04

Year 4

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Antimony (Sb)	0.07	1.6E-02	1.1E-03
Arsenic (As)	0.0011	5.2E-01	5.7E-04
Cadmium (Cd)	0.0014	1.4E-03	1.9E-06
Mercury (Hg)	0.001	2.6E-04	2.6E-07
Selenium (Se)	0.003	3.6E-02	1.1E-04
Nickel (Ni)	0.0034	8.0E-02	2.7E-04

Year 8

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Antimony (Sb)	0.07	9.5E-03	6.6E-04
Arsenic (As)	0.0011	3.1E-01	3.4E-04
Cadmium (Cd)	0.0014	8.3E-04	1.2E-06
Mercury (Hg)	0.001	1.6E-04	1.6E-07
Selenium (Se)	0.003	1.4E-02	4.1E-05
Nickel (Ni)	0.0034	4.8E-02	1.6E-04

Estimated Concentration in Nectar
(for metals likely to be too insoluble to be taken up)

ref: Stevens B. (1991)

Uptake into flowers from soil via roots

$$Cnectar = Csoil * uptake\ factor$$

(mg/kg plant – wet weight)

where:
Cs = Concentration of metal in soil assuming 15 cm mixing depth
calculated using Soil Equation for each chemical assessed (mg/kg)
UF = Uptake factor which differs for each Chemical (unitless)

Year 1

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Barium (Ba)	0.0375	4.4E-01	1.6E-02
Beryllium (Be)	0.0025	6.8E-04	1.7E-06
Chromium (Cr)	0.00187	1.3E-02	2.3E-05
Copper (Cu)	0.1	1.3E+00	1.3E-01
Lead (Pb)	0.0112	2.3E-02	2.6E-04
Manganese (Mn)	0.0625	8.7E+00	5.5E-01
Silver (Ag)	0.1	1.7E-03	1.7E-04
Zinc (Zn)	0.264	6.0E-01	1.6E-01

Average Plant Concentration - assumed nectar concentration mg/kg ww
2.3E-02
2.4E-06
3.2E-05
1.8E-01
3.1E-04
7.5E-01
2.3E-04
2.2E-01

Root uptake factors from RAIS (soil to wet weight of plant)

Year 2

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Barium (Ba)	0.0375	5.8E-01	2.2E-02
Beryllium (Be)	0.0025	9.0E-04	2.2E-06
Chromium (Cr)	0.00187	1.6E-02	3.1E-05
Copper (Cu)	0.1	1.7E+00	1.7E-01
Lead (Pb)	0.0112	3.7E-02	4.1E-04
Manganese (Mn)	0.0625	8.8E+00	5.5E-01
Silver (Ag)	0.1	2.2E-03	2.2E-04
Zinc (Zn)	0.264	7.9E-01	2.1E-01

Root uptake factors from RAIS (soil to wet weight of plant)

Year 4

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Barium (Ba)	0.0375	8.8E-01	3.3E-02
Beryllium (Be)	0.0025	1.4E-03	3.4E-06
Chromium (Cr)	0.00187	2.5E-02	4.7E-05
Copper (Cu)	0.1	2.7E+00	2.7E-01
Lead (Pb)	0.0112	3.6E-02	4.1E-04
Manganese (Mn)	0.0625	1.9E+01	1.2E+00
Silver (Ag)	0.1	3.3E-03	3.3E-04
Zinc (Zn)	0.264	1.2E+00	3.2E-01

Root uptake factors from RAIS (soil to wet weight of plant)

Year 8

Chemical-specific Inputs and calculations - All receptors

Chemical	Uptake Factor (UF) unitless	Soil Concentration (Cs) mg/kg	Plant Concentration - assumed nectar concentration mg/kg ww
Barium (Ba)	0.0375	5.3E-01	2.0E-02
Beryllium (Be)	0.0025	8.3E-04	2.1E-06
Chromium (Cr)	0.00187	1.5E-02	2.8E-05
Copper (Cu)	0.1	1.6E+00	1.6E-01
Lead (Pb)	0.0112	1.4E-02	1.6E-04
Manganese (Mn)	0.0625	1.2E+01	7.5E-01
Silver (Ag)	0.1	2.0E-03	2.0E-04
Zinc (Zn)	0.264	7.3E-01	1.9E-01

Root uptake factors from RAIS (soil to wet weight of plant)