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Broken Hill North Mine

Health Risk Assessment

Prepared by

Pacific Environment Limited

January 2017

Specialist Consultant Studies Compendium

Part 2

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Health Risk Assessment

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GLOSSARY OF COMMONLY USED TERMS AND ACRONYMS

ABS	Australian Bureau of Statistics
BLL	Blood Lead Levels
CML	Consolidated Mining Leases
DDG	Dust Deposition Gauges
DPE	Department of Planning and Environment
DSLL	Depositional Soil Lead Levels
EIS	Environmental Impact Statement
EPL	Environmental Protection License
FSANZ	Food Standards Australia and New Zealand
GLCs	Ground Level Concentrations
GM	Geometric Mean
GSD	Geometric Standard Deviation
HIL	Health Investigation Level
HRA	Health Risk Assessment
HVAS	High Volume Air Samplers
IEUBK	Integrated Exposure Uptake BioKinetic
NEPM	National Environmental Protection Measure
NHMRC	National Health and Medical Research Council
NSW	New South Wales
NSW EPA	New South Wales Environmental Protection Authority
PM	Particulate Matter
PM_{10}	Particulate Matter less than 10 micrometres in aerodynamic diameter
$PM_{2.5}$	Particulate Matter less than 2.5 micrometres in aerodynamic diameter
PPM	Parts per Million
RBA	Relative BioAvailability
ROM	Run of Mine
SEARs	Secretary's Environmental Assessment Requirements
TEOM	Tapered Element Oscillating Microbalance
TRW	Technical Review Workgroup
TSP	Total Suspended Particles
US EPA	United States Environmental Protection Agency
WHO	World Health Organisation

DEFINITION OF TERMS

Term	Definition
Air dispersion modelling	Mathematical simulation of how air pollutants disperse in the ambient atmosphere.
Ambient air quality	The state of quality and chemical characteristics of air as it exists in the environment.
Emissions	Release of pollutants to air
Epidemiological studies	These are studies that examine the patterns, causes, and effects of health and disease conditions in defined populations. Epidemiological information is used to plan and evaluate strategies to prevent illness
Exposure Assessment	This identifies the groups of people who may be exposed to hazardous pollutants and provides an estimate as to the potential exposure concentrations.
Hazard Assessment	Identifies hazards and health endpoints associated with exposure to hazardous pollutants and provides a review of the current understanding of the toxicity and risk relationship of the exposure of humans to the hazards.
Health Risk Assessment (HRA)	A Health Risk Assessment (HRA) is an analysis that uses information about potentially hazardous pollutants to estimate a theoretical level of risk for people who might be exposed to defined levels of these pollutants. The information comes from scientific studies and measurement data of air emissions.
Particulate Matter (PM)	Particulate Matter (PM) is a complex mixture of extremely small particles made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles.
PM_{10}	Particulate Matter less than 10 micrometres in aerodynamic diameter
$PM_{2.5}$	Particulate Matter less than 2.5 micrometres in aerodynamic diameter
Risk Characterisation	This provides the qualitative/quantitative evaluation of potential risks to human health. The characterisation of risk is based on the review of the dose-response relationship and the assessment of the magnitude of exposure.
Sensitive receiver/residence locations	Locations where vulnerable members of the community gather e.g. hospitals, schools

EXECUTIVE SUMMARY

Perilya Broken Hill Limited ("the Applicant") proposes the recommencement of mining operations ("the Proposal") at the Broken Hill North Mine ("the Mine") located on the Line of Lode, Broken Hill, within Consolidated Mining Leases (CML) 4 and 5 (**Figure 1-1**).

The Applicant contracted Pacific Environment Limited to conduct a Health Risk Assessment (HRA) using the air quality modelling outcomes for the proposal. The applied HRA methodology was consistent with the protocols and guidelines recommended by the Australian enHealth Council (**enHealth, 2012**). This HRA addresses likely impacts on community health from exposure to air emissions from the Proposal.

Ground Level Concentrations (GLCs) of key air quality metrics were predicted at a total of 39 receivers/residences in the vicinity of the Proposal using air dispersion modelling conducted by Pacific Environment (detailed within the standalone Air Quality Impact Assessment – *Part 1 of the Specialist Consultant Studies Compendium*). The emission of concern addressed in this HRA assessment is lead whose primary source is an upcast vent shaft at the Run of Mine (ROM) Pad and secondary source is Total Suspended Particles (TSP- Pb) from dust generating activities (**Figure 3-1**).

The Integrated Exposure Uptake BioKinetic (IEUBK) Model was used to assess site-specific risk for children aged 6 to 84 months, the most susceptible population group, exposed to lead from different media and through different pathways in their environment. The IEUBK model was setup using Australian values that were used in deriving the National Environmental Protection Measure (NEPM) Health Investigation Level (HIL) and modified to include site specific soil, water and air borne lead values, compiled from both provided data provided and literature reviews, to estimate exposure to lead. The model was also used to predict a plausible distribution of Blood Lead Levels (BLLs) centred on a Geometric Mean (GMBLL). On the basis of the currently acceptable BLL and the NHMRC recommended BLL, the probability that the population of children's BLLs would exceed both 5 µg/dL and 10 µg/dL with and without the Proposal was calculated from the distribution. The model outputs were then used for comparative purposes to explore the effect of the Proposal on the BLLs of the Broken Hill north children.

Eight scenarios were modelled i.e.

- District: Broken Hill north residences near the proposed Perilya Mine (BH6) if no further mining was to occur (background) and after 25 years of mining (cumulative);
- Point Specific: Compliance air and dust monitoring sites (LP26) and (LP27), without mining (background) and with mining (cumulative); and,
- Extreme Case: Broken Hill north residences near the mine but with the maximum recorded soil lead concentration in District 6 (BH6 max), without mining (background) and with mining (cumulative).

The modelling outputs showed that the GMBLL for all age groups in all scenarios (background and cumulative) was below 5 µg/dL. The percentage of children with a 5% probability of exceeding the 10 µg/dL BLL target was between 0.07% and 0.22%, lowest at LP26 background and highest at BH6 max cumulative. The GMBLL in children living near the mine after 25 years of operations (BH6 cumulative) was less than 5 µg/dL at soil lead concentrations around 2,500 µg Pb/g.

The model showed a very small increase in the GMBLL in children going from the background to the cumulative scenarios. Similarly, the percentage of children above the target BLLs of 5 µg/dL and 10 µg/dL increases when the background and cumulative scenarios were compared. A soil lead concentration of 2,815 µg Pb /g was found to result in a GMBLL of 10 µg/dL target and a concentration of 801 µg Pb/g resulted in a GMBLL of 5 µg/dL. Sensitivity analysis of the relative absorption fraction found, that increasing the adopted value from 5% through to 50% would result in significant increases in BLLs of children. Those living on soils with more than 1,000 µg Pb/g and 50% relative absorption or 1,400 µg Pb/g and 30% relative absorption have a 5% probability of exceeding the target BLL of 10 µg/dL. Based on the foregoing, the Proposal is not expected to result in a significant change of the current background BLL of the Broken Hill north area.

There are inherent uncertainties in the methods used to estimate emissions and concentrations and limitations on how accurately the impacts of the Proposal can be estimated in future years. As such, in order to minimise the risk of under estimation throughout the HRA, conservatism has been applied where possible. This includes but is not limited to the assumption that the proposed mine life will be 25 years instead of 16 years. Furthermore, it is recommended that lead monitoring and bioavailability studies at receptors that represent the most exposed parts of the Broken Hill north population are conducted. These data should then be used to refine the IEUBK modelling, making the outputs more specific to the Proposal.

1. INTRODUCTION

1.1 SCOPE OF WORK

Perilya Broken Hill Limited ("the Applicant") proposes the recommencement of mining operations ("the Proposal") at the Broken Hill North Mine ("the Mine"). The Mine is located on the Line of Lode, Broken Hill, within Consolidated Mining Leases (CML) 4 and 5 (**Figure 1-1**).

The Applicant has contracted Pacific Environment Limited to conduct a Health Risk Assessment (HRA) using the air quality modelling outcomes for the proposal. The applied HRA methodology is consistent with the protocols and guidelines recommended by the Australian enHealth Council (**enHealth, 2012**). This HRA addresses likely impacts on community health from exposure to air emissions from the Proposal.

Ground Level Concentrations (GLCs) of key air quality metrics were predicted at discrete locations in the vicinity of the Mine using air dispersion modelling conducted by Pacific Environment (detailed within the standalone Air Quality Impact Assessment – *Part 1 of the Specialist Consultant Studies Compendium*). The emission of concern addressed in this HRA assessment is lead in Total Suspended Particles (TSP- Pb) from dust generating activities and an upcast vent shaft at the Run of Mine (ROM) Pad (**Figure 3-1**).

The HRA has been facilitated by provision of spread sheet results from the dispersion modelling undertaken by Pacific Environment Limited (presented within the Air Quality Impact Assessment – *Part 1 of the Specialist Consultant Studies Compendium*). These modelled outputs contain predicted GLCs of individual pollutants at a total of 39 receivers/residences in the vicinity of the Site.

1.2 BACKGROUND

Between 2003 and 2008 the Applicant operated the Mine under DA 54/2003 granted by Broken Hill City Council on 6 March 2003. The consent permitted the following activities.

- Underground mining operations within the upper levels of the existing mine for a period of approximately two years.
- Crushing of the ore within the existing Cosmopolitan Open Cut.
- Transportation of crushed ore to the Applicants Broken Hill South Mine via the existing rail network.

Mining under that development consent ceased in 2008. During the intervening period, on-site activities have included maintenance of ventilation and essential infrastructure. Following the recommencement of mining operations, the Applicant proposes to undertake the following.

- Resume mining operations using the existing Cosmopolitan Decline to extract ore to a depth of between 1,750m and 2,250m below surface over a period of approximately 20 years.
- Crush extracted ore within a surface ROM pad using a mobile crusher.
- Transportation of crushed ore via the public road network to the South Mine using B-Double trucks or double road trains.

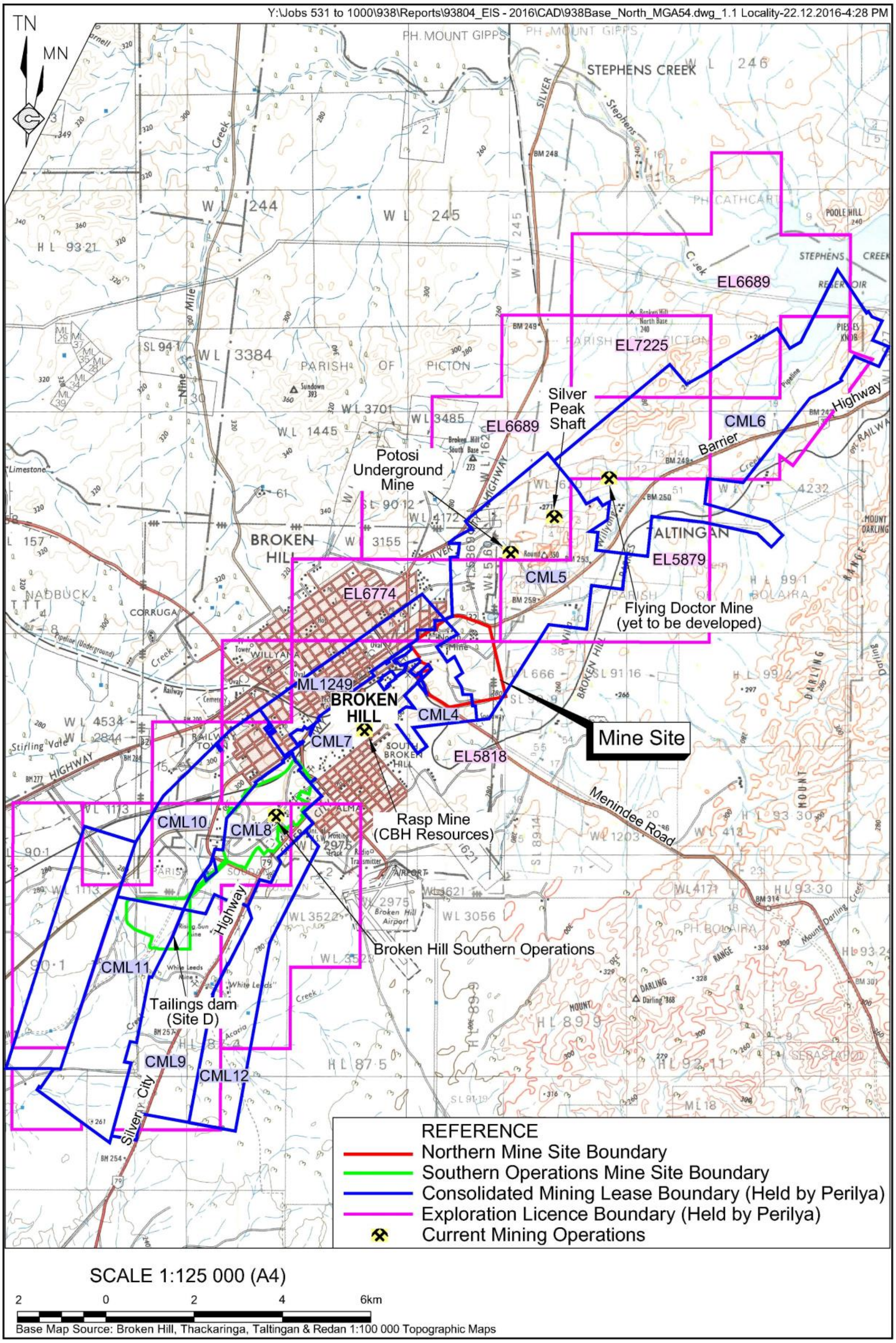


Figure 1-1: Locality Plan

1.3 OVERVIEW OF THE PROPOSAL

The Proposal would include the following (**Figure 1-2**).

- Remediate the existing Cosmopolitan access ramp, portal and decline to the 12 Level (limit of the existing decline) to facilitate safe and efficient access to the underground workings
- Restore and upgrade existing electrical, ventilation, air and water services, including on surface and within the decline, No. 2 and No. 3 Shafts, No. 3 Return Air Rise.
- Extend the existing decline from the 12 Level to link with the existing decline between the 32 Level and the 38 Level.
- Undertake exploration drilling from underground to further define remanent ore and identify additional ore lenses and lodes.
- Develop access drives to permit access by modern mining equipment.
- Extract remnant ore and ore below the base of previous mining operations, including within the Fitzpatrick Area.
- Transport extracted ore to the surface ROM Pad using underground haul trucks, including establishment of a haulage route utilising existing roads and a proposed haul road cutting.
- Transport extracted waste rock for placement either within completed stopes underground or within the in-pit waste rock emplacement in the Cosmopolitan Open Cut.
- Extract waste rock from the existing surface waste rock emplacement for transportation back underground as required.
- Extract tailings from a former Tailings Storage Facility for mixing with water and cement in a proposed pastefill plant for use backfilling completed stopes.
- Re-establish surface infrastructure required to support the mining operation, including a ROM pad, office and store, workshop and fuel store, change house and car park, services (power, water, air and communications), surface magazine and ancillary infrastructure.
- Stockpile and crush ore within the existing ROM Pad using a mobile crusher.
- Load and transport the crushed ore to the Southern Operations using double road trains utilising the transport route approved for the Applicant's Potosi Mine, namely Barrier Highway, Iodide Street, Crystal Street and Gypsum Street.
- Process the transported ore within the Southern Operations Concentrator under the continuing use rights held for that operation.
- Dewater the existing workings and transfer that water to on site evaporation ponds or the Southern Operations.

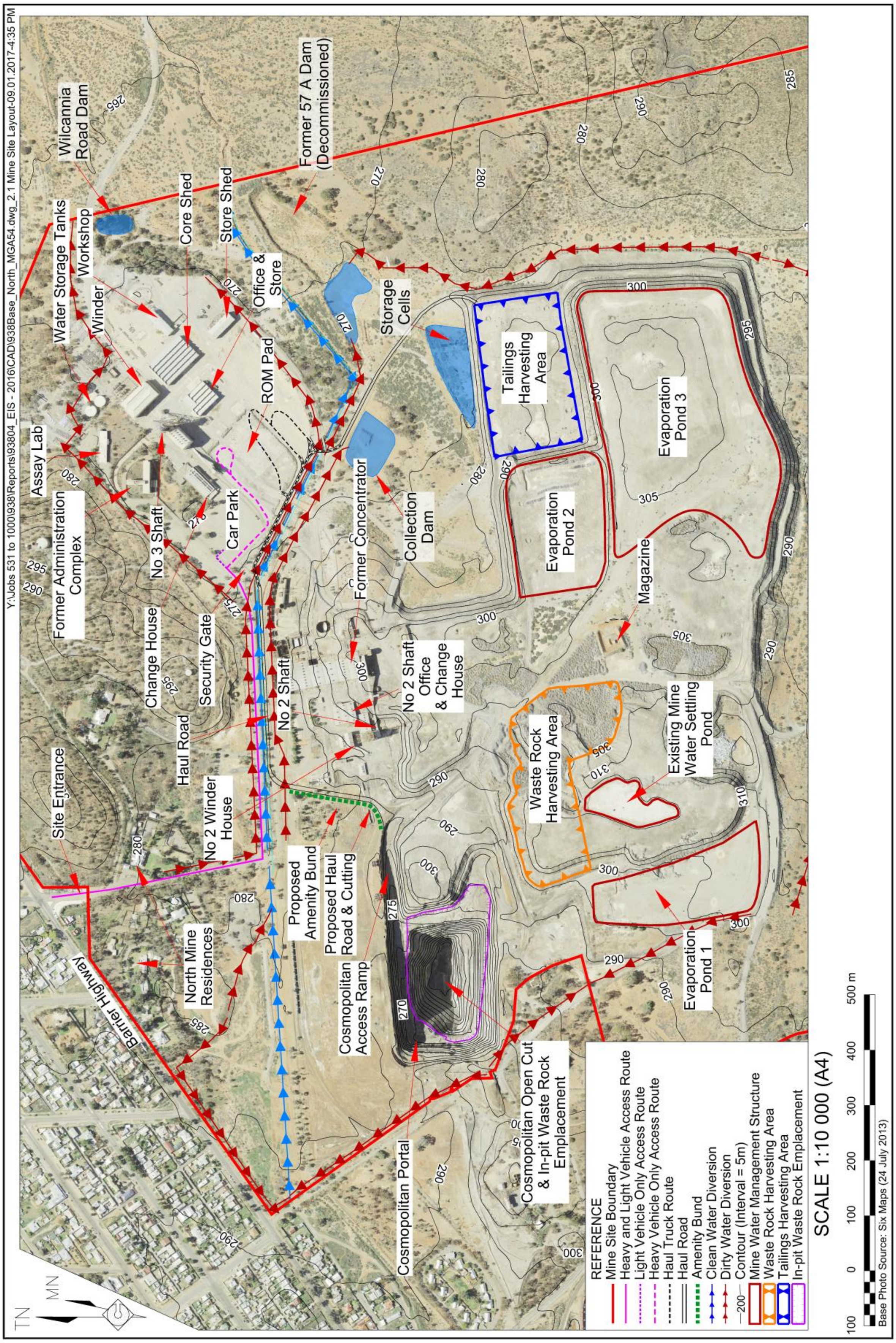


Figure 1-2: Mine Site Layout

1.4 SEARS AND AGENCY REQUIREMENTS FOR ASSESSMENT

The Secretary's Environmental Assessment Requirements (SEARs) requirements and where they are addressed in this document are outlined in **Table 1-1.**

Table 1-1: Coverage of Human Health

Government Agency	Paraphrased Requirement	Relevant Section(s)
Air Quality		
DPE (06/05/16)	• a Human Health Risk Assessment addressing how the project's environmental impacts in relation to air quality (including heavy metals) may impact on the health of the local community, having regard to NSW Health's requirements and commensurate with the likely level of risk.	**Section 5**
Department of Health (04/05/16)	• Given the historic link between mining activities in Broken Hill and elevated blood lead levels in the community, particularly among the 0-5 year age group, it would be important to do a Health Risk Assessment (HRA). The HRA should use the risk assessment model in "Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards", (**enHealth, 2012**). The HRA should focus on (but not be limited to) the increased risk of exposure to lead by the community from increased mine activity on the site, particularly the crushing, stockpiling and haulage of ore.	**Section 5.2.2**

2. METHODOLOGY

2.1 WHAT IS A RISK ASSESSMENT?

Health is defined by the World Health Organization (WHO) as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Well-being is broadly described as an individual's self-assessment of their state of happiness, healthiness and prosperity. It relates to the quality of life and one's ability to enjoy it. There are many social and economic factors that impinge upon well-being.

The following are examples of determinants of health well-being (**enHealth 2012**):

- Social and cultural factors (e.g. social support, participation, access to cultural resources).
- Economic factors (e.g. income levels, access to employment).
- Environmental factors (e.g. land use, air quality).
- Population-based services (e.g. health and disability services, leisure services).
- Individual/behavioural factors (e.g. physical activity, smoking).
- Biological factors (e.g. biological age).

According to **enHealth (2012),** all developments have a potential impact on health. Some will have positive health impacts by providing jobs, attracting health services to an area, and improving overall economic well-being of a community, etc. Other developments may have negative impacts such as increased risk of disease, social disruption, increased noise etc. Many developments will have both positive and negative aspects. It should be understood that the potential influence of the Proposal on local area economic factors, social disruption and other such factors are not addressed in this document. These matters are addressed as part of the Environmental Impact Statement prepared by RW Corkery & Co Pty Limited. Air quality is one of the many parameters influencing well-being. This HRA seeks to evaluate what the likelihood is for direct health effects when exposures to air emissions from the Proposal occur.

A health risk assessment is an analysis that uses information about potentially hazardous pollutants to estimate a theoretical level of risk for people who might be exposed to defined levels of these pollutants. Risk assessments are often conducted by considering possible or theoretical community exposures based on the outcomes of air dispersion modelling. Conservative safety margins are built into a risk assessment analysis to ensure protection of the public. Therefore, people will not necessarily become unwell even if they are exposed to pollutants at higher concentration levels than those estimated by the risk assessment. During a risk assessment analysis, the most vulnerable people (e.g. children, the sick and elderly) are carefully considered to make sure that all members of the public will be protected.

The risk assessment helps answer the following common questions for people who might be exposed to hazardous pollutants in the environment, in this case components of the air emissions from the Proposal.

- Under what circumstances might I, my family and neighbours be exposed to hazardous pollutants from the Proposal?
- Is it possible we might be exposed to hazardous pollutants at levels higher than those determined to be safe?

- If the levels of hazardous pollutants are higher than regulatory standards, what are the health effects that might occur?

The HRA is a useful tool for estimating the likelihood and severity of risks to human health, safety and the environment and for informing decisions about how to manage those risks. It is a document that assembles and synthesizes scientific information to determine whether a potential hazard exists and/or the extent of possible risk to human health.

Although this report describes certain technical aspects of the risk assessment, it does not address the processes of risk management and risk communication.

2.2 OVERALL APPROACH

The methodology adopted in the conduct of this HRA is consistent with the protocols and guidelines recommended by the enHealth Council. These are detailed in the document "Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards" (**enHealth, 2012**).

The development of a formalised HRA has resulted in the process being categorised into distinct stages. Some of the key factors and questions that are taken into consideration at each of these stages include the following.

1. Hazard Assessment

Identifies hazards and health endpoints associated with exposure to hazardous pollutants and provides a review of the current understanding of the toxicity and risk relationship of the exposure of humans to the hazards.

2. Exposure Assessment

This task identifies the groups of people who may be exposed to hazardous pollutants and provides an estimate as to the potential exposure concentrations.

3. Risk Characterisation

This task provides the qualitative/quantitative evaluation of potential risks to human health. The characterisation of risk is based on the review of the dose-response relationship and the assessment of the magnitude of exposure.

3. COMMUNITY PROFILE

This section discusses the community adjacent to the Mine that may potentially be affected by emissions over its lifetime. **Figure3-1** illustrates the location of the Proposal and the potentially affected communities.

3.1 SURROUNDING AREA AND POPULATION

The Proposal is located on the eastern side of the city of Broken Hill, New South Wales (NSW) (**Figure 1-1**). Nearby land uses include urban development within the city of Broken Hill, undeveloped arid landscapes beyond the city limits and extractive industries including mines and quarrying activities. There are a number of privately-owned and resource company-owned residences in the vicinity of the Mine, as shown in **Figure 3-1.** Receptor type and location details are provided in **Table 3-1.**

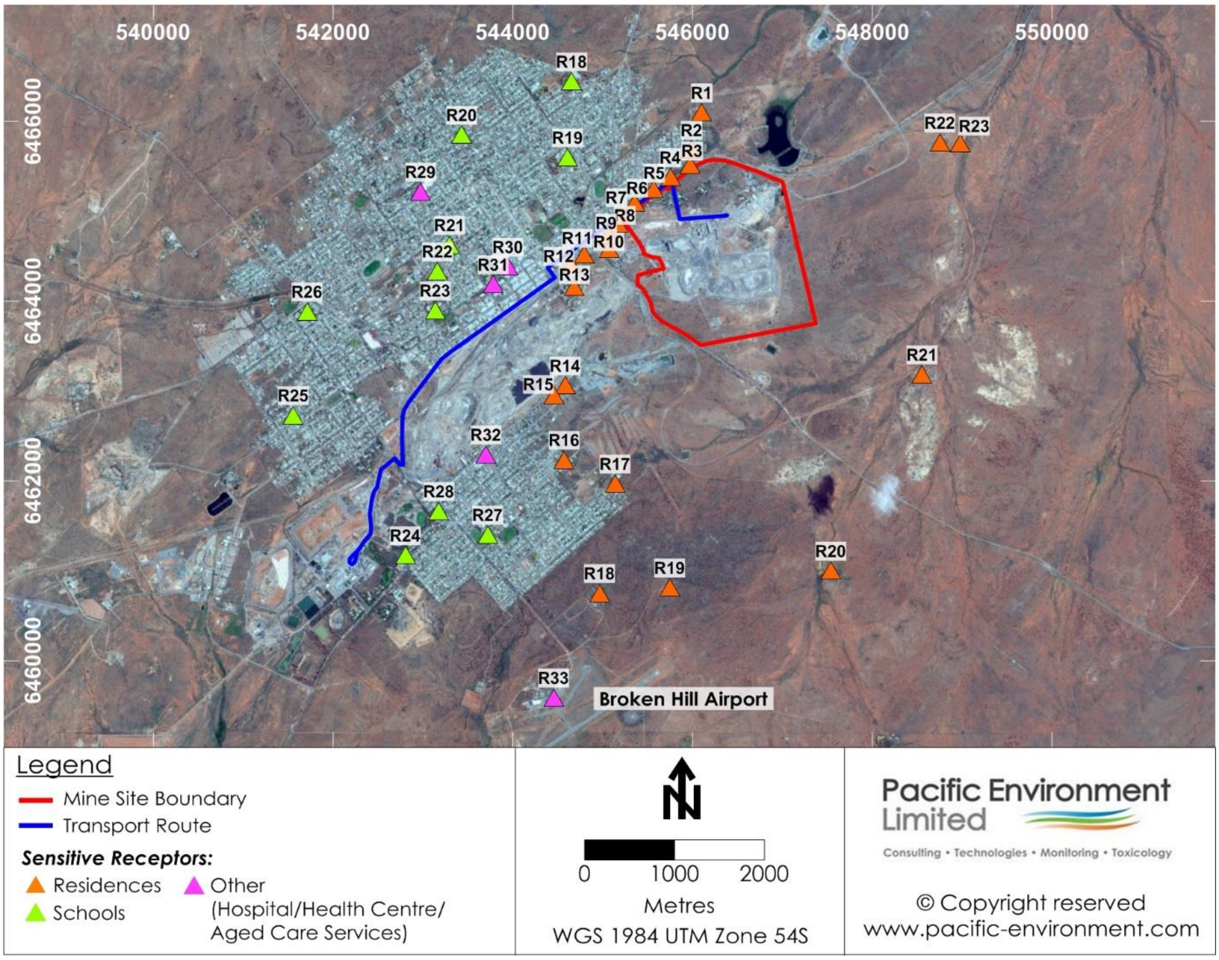


Figure 3-1: Location of the Mine and Sensitive Receptors

Table 3-1: Receptor Locations in the Vicinity of the Proposal (Datum Map Grid of Australia)

Type	ID	East (m)	North (m)	Description
Residential	R1	546102	6466100	Brady Street
Residential	R2	545989	6465688	Mann Street
Residential	R3	545971	6465521	Argent Street (Barrier Hwy)
Residential	R4	545752	6465380	Argent Street (Barrier Hwy)
Residential	R5	545564	6465248	Argent Street (Barrier Hwy)
Residential	R6	545355	6465097	Argent Street (Barrier Hwy)
Residential	R7	545189	6464985	Argent Street (Barrier Hwy)
Residential	R8	545166	6464867	Chettle Street
Residential	R9	545068	6464733	Sturt Street
Residential	R10	545071	6464581	Junction Circle
Residential	R11	544793	6464518	Crystal Street
Residential	R12	544642	6464418	Crystal Street
Residential	R13	544684	6464163	Iodide Street
Residential	R14	544582	6463063	Eyre Street North
Residential	R15	544456	6462950	Eyre Street North
Residential	R16	544570	6462236	Lawton Street
Residential	R17	545137	6461970	Duff Street
Residential	R18	544964	6460752	Airport Road
Residential	R19	545745	6460814	Airport Road
Residential	R20	547538	6461001	Menindee Road
Residential	R21	548552	6463185	Menindee Road
Residential	R22	548751	6465766	Barrier Highway
Residential	R23	548977	6465760	Barrier Highway
School	R24	544654	6466445	Willyama High School
School	R25	544609	6465600	Broken Hill North Public School
School	R26	543430	6465852	Morgan Street Public School
School	R27	543296	6464626	Sacred Heart Parish Primary School
School	R28	543161	6464333	Broken Hill Public School
School	R29	543136	6463898	Broken Hill High School
School	R30	542804	6461173	Rainbow Pre-School
School	R31	541557	6462732	Railway Public School
School	R32	541709	6463886	Burke Ward Primary School
School	R33	543720	6461402	Alma Public School
School	R34	543177	6461665	Alma Bugdlie Pre School
Hospital	R35	542973	6465219	Broken Hill Hospital
Health Centre	R36	543945	6464383	Far West Mental Health Recovery Centre
Aged care	R37	543781	6464187	Aruma Lodge Aged Care Service
Aged care	R38	543701	6462294	Harold Williams Home Aged Care Service
Flying Doctors Medical Centre	R39	544454	6459590	Broken Hill Airport

3.2 POPULATION PROFILE

Section 4.15 of the Environmental Impact Statement provides a detailed description of the population surrounding the Mine Site. In summary, the composition of the population in Broken Hill, as defined by the Census State Suburb boundaries, was reviewed. The population statistics considered for this assessment are available from the Australian Bureau of Statistics (ABS) website for the census year 2011 and are summarised in **Table 3-2.**

Table 3-2: Population Age Profile Used in Analysis

Age Group	Number of individuals
	Broken Hill State Suburb
All ages	18,777
65+ years	3,703
30+ years	12,170
15-64 years	11,697
0-14 years	3,377
Source: ABS data 2011 http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/SSC10349?opendocument&navpos=220	

3.3 RESIDENCES AND SENSITIVE RECEIVERS

The HRA considers locations where maximum impacts of the Proposal may occur as well as the adjacent locations where people live, i.e. Broken Hill North. A total of 39 receivers/residences where people reside and gather assessed i.e. 23 private residences, 11 schools and 5 medical centres. The receivers/residences therefore captured the sensitive members in the communities, i.e. the very young (0-14 years) and the elderly (65+years). For this assessment, the very young (0-5 years) are considered to be the most vulnerable population to lead exposure. As such the exposure assessment focussed on this age group.

4. OVERVIEW OF AIR QUALITY ASSESSMENT

A brief overview of the Air Quality Assessment is provided in the following subsections. Further detail regarding the existing air quality environment, modelling methodology and modelling outcome is provided within the Air Quality Assessment – *Part 1 of the Specialist Consultant Studies Compendium.*

4.1 EXISTING AIR QUALITY

A monitoring program comprising of dust and ambient air monitoring was established in July 2008 in the vicinity of the Proposal, as outlined in the Environmental Protection License (EPL 2683) for Perilya Broken Hill Limited.

The monitoring network established for the Proposal (**Figure 4-1: Location of Monitoring Stations**) consists of:

- Eleven dust deposition gauges, measuring dust deposition rates (TSP and lead) over the period of one month.
- Two high volume air samplers (HVASs), measuring PM_{10} concentrations for 24 hours periods on a one day in six run cycle.

As outlined in the EPL, the air quality sampling is undertaken in accordance with the AM-19, Australian Standard 2800 – 1985 and AS/NZS 3580.9.6:2003 (**Table 4-1**). Prevailing winds at the Mine are from the south and northeast on an annual basis. These patterns are reflected in varying degrees in all seasons throughout the years, with north-west winds also prevalent in winter.

Table 4-1: Monitoring Data Collected in Broken Hill

Mine Site	Parameter	Monitoring Method	Number of Locations	IDs	Date Commenced
Perilya	Dust Deposition	Dust Deposition Gauges (DDG)	11	LP15 to LP25	July 2011
Perilya	Concentration (TSP and Total Lead)	High Volume Air Sampler (HVAS)	2	LP26-LP27	July 2008
RASP Mine	Concentration (PM_{10})	Tapered element oscillating microbalance (TEOM)	2	EPL13-EPL14	February 2014

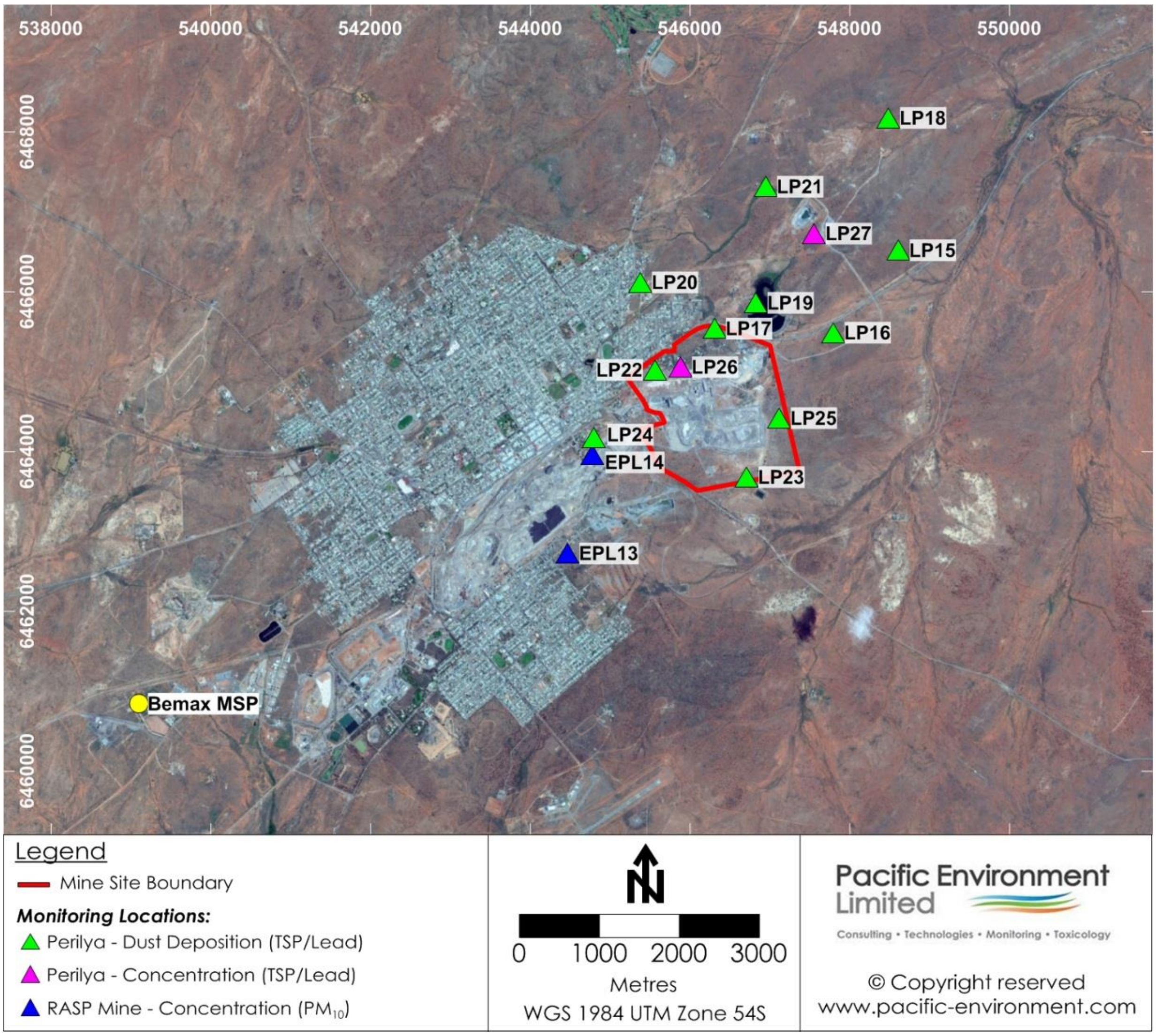


Figure 4-1: Location of Monitoring Stations

4.2 AIR QUALITY ASSESSMENT SCENARIOS

Two operational scenarios were chosen for quantitative dispersion modelling, as outlined below:

- Annual operations (Based on maximum annual transport off-site of 300,000 tonnes per annum); and
- Maximum daily production (Based on maximum daily transport off-site of 1,800 tonnes per day (which would equate to almost 500,000 tonnes per annum).

  The maximum daily emissions are applied for each day of the modelled year to ensure that the potential contribution from the maximum daily transport off-site is assessed under worst-case meteorological conditions.

  It is expected that that actual transportation rates on most days would be less than 1,800 tonnes per day. As a result, this does not represent a realistic estimate of annual dust emissions, although they could potentially reach these emission levels on a daily basis).

Most activities and emissions (including offsite hauling) are assumed to occur between 7am and 7pm, seven days per week. Wind erosion is assumed to occur 24 hours per day. TSP, PM_{10} and $PM_{2.5}$ emission rates were calculated using emission factors derived from **(US EPA 1995)**

4.3 AIR QUALITY ASSESSMENT OUTCOMES

The modelling indicates that no receivers/residences are predicted to experience annual average $PM_{2.5}$, PM_{10}, TSP or dust deposition levels above the relevant NSW Environmental Protection Authority (EPA) impact assessment criteria, either from the Proposal alone or cumulatively. Similarly the modelling also indicated that the Proposal would not cause any additional 24-hour exceedances of the 50µg/m^3 PM_{10} criterion at the assessed receivers/residences during maximum daily (worst case) operations. Further, no exceedances of the relevant NSW EPA impact assessment criteria for the assessed toxic air pollutants were predicted to occur.

5. HEALTH RISK ASSESSMENT

5.1 IDENTIFICATION OF EMISSIONS OF HAZARDOUS POLLUTANTS

Underground mines, such as that proposed in the Proposal, mine ore using underground mining techniques. In the case of the Proposal, the Applicant anticipates that mining methods would include Long Hole Open Stoping or a modified Avoca method. These mining methods are fully described in the Environmental Impact Statement, however, each involve drilling fans of drill holes from one level to the level above or below, filling those holes with explosives and fragmenting the ore.

Ore would be transported to the ROM Pad using underground haul trucks. The Applicant would construct a haul road to permit underground mobile plant to travel from the end of the Cosmopolitan Access ramp to the existing road network. The haul road would ensure that underground vehicles, are able to exit the Cosmopolitan Open Cut and access the existing road network without being in direct line of sight of residential areas to the north and northwest of the Mine Site.

Emissions during operation of the Proposal may occur during the following activities:

- Extraction of ore from underground.
- Transportation of extracted ore to the surface ROM Pad using underground trucks, including establishment of a haulage route utilising existing roads and a proposed haul road cutting.
- Transportation of extracted waste rock for placement either within completed stopes underground or within the Cosmopolitan Open Cut within the existing in-pit waste rock emplacement.
- Extraction and transport of tailings from an existing Tailings Storage Facility for use within a proposed paste fill plant and use of the resulting paste to backfill completed stopes.
- Stockpiling and crushing of ore within the existing ROM Pad using a mobile crusher.
- Loading and transport of the crushed ore to the boundary of the North Mine.
- The continuous operation of the upcast vent shaft at the ROM Pad.

In consideration of these activities, the main pollutants would be particulate matter (PM), primarily from dust generating activities and heavy metals i.e. lead, silver, zinc, copper, iron, mercury, nickel, arsenic, manganese, cadmium and chromium, mainly from the vent shaft. Fugitive PM would be emitted at every stage of the mining process. PM is typically characterised in terms of its size fractions, with common metrics for health assessment being PM less than 10 micrometres in aerodynamic diameter (PM_{10}) and PM less than 2.5 micrometres in aerodynamic diameter ($PM_{2.5}$). From the point of view of impacts on human health and frequency of exposure, lead is the pollutant of greatest concern followed by PM. This HRA therefore focuses on assessing the health impacts of lead from the proposal to the surrounding community.

5.2 ASSESSMENT OF LEAD

5.2.1 Hazard Assessment

Lead is a naturally occurring element, making up about 0.0013% of the Earth's crust (**UNEP 2006**). There are three chemical forms of lead: metallic lead, inorganic lead compounds and organic lead compounds (containing carbon). Lead is usually obtained from sulphide ores, often in combination with other elements such as zinc, copper and silver. The main lead mineral is Lead Sulphide (Galena). Other common varieties include cerussite ($PbCO_3$), Lead oxide, also called minimum (Pb_3O_4), plattnerite (PbO_2) and angelsite ($PbSO_4$). Lead exists in three oxidation states: Pb (0) - the elemental form, Pb (II) and Pb (IV). Metallic lead, Pb (0), exists in nature, but its occurrence is rare (**UNEP 2006, IARC 2006, ATSDR 2007**).

Small amounts of lead reach the surface environment through natural weathering processes and volcanic emissions, thus giving a baseline environmental exposure. Globally, the main source of lead in air is exhaust from motor vehicles using leaded gasoline. Release of lead also occurs during lead smelting and refining, the manufacture of goods, and the incineration of municipal and medical wastes. It should however be noted that the abundant and widespread presence of lead in our current environment is largely a result of anthropogenic activity (**IARC 2006**). As a result of this activity, lead can enter the environment at any stage from its mining to its final use and it may contaminate crops, soil, water, food, air and dust. Almost all lead in air is bound to fine particles of less than 1 µm diameter, although some may be solubilized in acid aerosol droplets. The size of these particles varies with the source and with the age of the particle from the time of emission (**IARC 2006**).

In Australia, most of the lead released into the environment from emissions or as industrial waste is deposited in soil. Lead-containing wastes result from the processing of ores, the production of iron and steel, the various end-products and uses of lead, and the removal and remediation of lead paint (**IARC 2006**). People can absorb lead into their bodies by breathing air that contains very fine particles of lead or by swallowing dust, soil, water or food that is contaminated with lead. The average blood lead level among Australians today is not known, because few studies have measured levels in people who do not work in or live near lead mines, smelters, or workplaces that use lead. It is probably < 5µg/dL, based on limited evidence from Australian studies in small groups of children and on studies in other developed countries.

Broken Hill is considered a lead endemic area due to its history with lead mining which has left a legacy of widespread lead contamination and lead poisoning amongst the residents of the area (**NSW-FWLHD 2014**). Since 1991, all 1–4-year-old children in Broken Hill have been offered voluntary annual blood lead screening. A combination of reminder letters, promotions and advertising in the local media has been used to encourage attendance to the lead screening clinics. The NHMRC set a BLL goal of < 10µg/dL in 1993. In response to this, the NSW Department of Health along with the NSW Environmental Protection Authority set up the Broken Hill lead management program in1994 to address the high BLLs in Broken Hill children. This program ran over seven years until mid-2001. It incorporated five main activities i.e.

- monitoring and case-finding;
- case management;
- public education and health promotion;
- remediation of public land; and,
- evaluation, research and development.

In 1996, measurement of lead levels in pregnant women and neonates (via cord blood) was added to the list of the programmes monitored activities (**Lyle et al 2001, Boreland 2008, Balding et al 1997**). July 2006 marked the integration of lead management into the Broken Hill Child and Family Health Centre. Furthermore, several public health activities were recommended to minimize the impact of lead in Broken Hill children including:

- cord blood analysis offered for all babies born to women who reside in Broken Hill;
- blood lead level surveillance for children under 5 years;
- case management of children with lead levels above the recommended levels; and,
- educational and health promotion activities for families in the Broken Hill community.

The Broken Hill Community Reference Group, led by the Broken Hill City Council was founded in 2008. The group consists of community interest groups, mining companies and government agencies representing and advocating for the Broken Hill community regarding lead as a community issue. The Broken Hill Lead Steering Committee was also founded in the same year and was constituted to focus on the health issues related to elevated BLLs in children. In 2011, additional strategies were introduced to further improve the health outcomes of children in Broken Hill, including:

- alignment of lead testing with the childhood immunization clinics;
- introduction of SMS reminders to reduce 'did not attend' rates; and,
- development of a collaborative partnership with Maari Ma Health Aboriginal Corporation, an Aboriginal community controlled health service, where the Healthy Start team tests blood lead levels in children and provides follow-up care and case management of children with high lead levels (**NSW-FWLHD 2014**).

According to published information on the Health Stats NSW website[1], there has been a steady decline in BLLs in children between 1 and 4 years of age, from 1991 through to 2014, with >80% of the study population showing a BLL of <10µg/dL in 2014. Since 2000, the number of children with blood lead levels (BLLs) < 5µg/dL has increased from 13% to 52% in 2014. At the same time the population mean BLL has fallen from 8.4µg/dL to almost 5 µg/dL (**NSW-FWLHD 2014**). This reduction in BLLs is largely due to the management measures, described above, that have been and continue to be implemented in Broken Hill. In 2015, the NSW government released a ministerial announcement detailing its intention to invest into the Broken Hill Environment Lead program with the aim of further reducing lead levels in Broken Hill over 5 years. The lead abatement project team would be overseen by the Environment Protection Authority, Far West LHD and Broken Hill Lead Reference Group.

Considering >80% of the children in Broken Hill have a BLL of < 10µg/dL, it is reasonable to consider 10µg/dL as a representative background BLL for the children of Broken Hill.

[1] http://www.healthstats.nsw.gov.au/Indicator/env_pbhem/env_pbhem

5.2.1.1 KINETICS

5.2.1.1.1 Absorption

Lead absorption depends on the route of exposure, the physicochemical characteristics of the lead, the exposure medium, and the age and physiological status of the exposed individual (e.g. fasting, concentration of nutritional elements such as calcium, and iron status). Inorganic lead can be absorbed by inhalation of fine particles, by ingestion and, to a much lesser extent, trans dermally (**IARC 2006**).

Airborne lead may contribute significantly to exposure, depending on factors such as use of tobacco, occupation, proximity to busy roads, lead smelters, repair workshops, and leisure activities (e.g., arts and crafts, sports involving firearms) and also waste burning. Depending on the chemical speciation, particle size, and solubility in body fluids, up to 50% of inhaled Lead compounds may be absorbed (**UNEP 2010**). Smaller lead particles (< 1 μm) have been shown to have greater deposition and absorption rates in the lungs than larger particles. In adult men, approximately 30–50% of lead in inhaled air is deposited in the respiratory tract, depending on the size of the particles and the ventilation rate of the individual. The proportion of lead deposited is independent of the absolute lead burden in the air. The half-life for retention of lead in the lungs is about 15 hours. Once deposited in the lower respiratory tract, particulate lead is almost completely absorbed, and different chemical forms of inorganic lead seem to be absorbed equally (**IARC 2006**).

Approximately 95% of inorganic lead inhaled as submicron particles is absorbed orally. Rates and amounts of absorption of inhaled lead particles larger than 2.5 μm are determined primarily by rates of transport to, and absorption from, the gastrointestinal tract (**UNEP 2010**). For infants and young children, dust and soil often constitute a major exposure pathway due to behaviour patterns such as hand to mouth activities. The intake of lead is influenced by the age, and biological and behavioural characteristics of the child, and the bioavailability of lead in the source material (**UNEP 2010**). In adults, approximately 10% of dietary lead is absorbed (higher during fasting) However, in infants and young children, as much as 50% of dietary lead is absorbed. Absorption rates for lead from dusts, soils and paint chips may be lower, depending on its bioavailability. Most data on gastrointestinal absorption of lead are available for adults. Absorption of lead occurs primarily in the duodenum. The mechanisms of absorption have yet to be determined but may involve active transport and/or diffusion through intestinal epithelial cells (trans cellular) or between cells (Para cellular), and may involve ionized lead (Pb^{2+}) and/or inorganic or organic complexes of lead. The extent and rate of gastrointestinal absorption are influenced by physiological conditions of the exposed individual such as: age, fasting, the presence of nutritional elements including calcium, phosphorus, copper and zinc, iron status, intake of fat and other calories; and physicochemical characteristics of the medium ingested, including particle size, mineral species, solubility and lead species (**IARC 2006**).

Dermal absorption of inorganic lead is insignificant however organic lead may be readily absorbed through the skin. Absorbed lead is rapidly taken up by blood and soft tissue, and then slowly redistributed to bone. There is limited information available regarding absorption of lead in humans after dermal exposure (**IARC 2006, UNEP 2010**).

5.2.1.1.2 Distribution

Lead enters and leaves most soft tissues reasonably freely. The clearance from the blood into both soft tissues and bone dominates lead kinetics during the first few weeks after an exposure, with an apparent half-life of several weeks. Once an approximate equilibrium is reached between soft tissues and blood, the concentration of lead in blood is determined almost entirely by the balance among absorption, elimination, and transfer to and from bone. Lead enters and leaves bone by physiologically- distinguishable mechanisms, which include rapid exchange between blood plasma and bone at all bone surfaces, incorporation of lead into forming bone and its loss during bone resorption, and very slow diffusion of lead throughout undisturbed bone. The slow diffusion accounts for the gradual build-up of large quantities of bone-seeking elements such as lead in quiescent, largely cortical bone. Bone accumulates lead during much of the lifespan and may then serve as an endogenous source, releasing lead slowly back into the blood after the exposure stops. This is a concern especially during pregnancy, lactation and osteoporosis resulting in possible adverse effects. In the absence of continuing exposure, the whole-body half-life represents the loss of lead from bone (**IARC 2006, UNEP 2010**).

5.2.1.1.3 Metabolism

Lead in the body is not known to be metabolized or bio transformed. It does form complexes with a variety of proteins and non-protein ligands, for example, it binds to the sulfhydryl (SH) groups of proteins, altering their structure and function. Among other effects, lead substitutes calcium and zinc, affecting various biological processes, such as metal transport, energy metabolism, apoptosis, conduction of ions, cell adhesion and signalling, enzymatic processes, protein maturation, and genetic regulation. Lead has an affinity for the cell membrane, interferes with mitochondrial oxidative phosphorylation, and impairs the activity of calcium-dependent intracellular messengers and protein kinase C. Lead may inhibit DNA repair, have genotoxic effects, and affect sodium, potassium and calcium ATPase. The toxic effects of lead may, therefore, involve several organ systems and functions. (**IARC 2006, UNEP 2010**)

5.2.1.1.4 Excretion

The half-life of lead in blood is estimated to be 20–40 days. It is mainly excreted in urine (very slowly) however there are reports that comparable excretion in faeces occurs with values of from 1:1 to 3:1 being reported for the ratio of urinary lead clearance to endogenous faecal lead clearance in adult humans after injection, inhalation or ingestion of ^{203}Pb. Lead in the faeces includes both lead that has not been absorbed in the gastrointestinal tract and lead excreted in the bile (endogenous faecal excretion). Biliary clearance is a major route of excretion of absorbed lead (**IARC 2006, UNEP 2010**)

5.2.1.2 TOXICITY

The health effects of lead on an individual depend on the person's age, the amount of lead, and whether the person is exposed to lead short-term or over a long period. Lead is toxic to multiple organ systems, and effects may range from enzyme inhibition and anaemia to disorders of the nervous, immune and reproductive systems, impaired kidney and cardiovascular functions, and even death. Typical clinical manifestations of lead poisoning include weakness, irritability, asthenia, nausea, abdominal pain with constipation, and anaemia. Chronically exposed individuals may have a blue line on the gum margins and anaemia (**IARC 2006, NHMRC 2015a, UNEP 2010**).

The signs and symptoms of lead toxicity are variable in both adults and children. Children often appear asymptomatic even with elevated blood lead concentrations. Moderate-to-high exposure to lead (indicated by blood lead level 10 µg/dL and higher) can have harmful effects on many organs and bodily functions. Death can occur after very high exposure to lead i.e. above 70 µg/dL (**NHMRC 2015a, UNEP 2010**)

5.2.1.2.1 High exposure

There is a strong association between risk factors and health at BLLs between 10 – 100 µg/dL. A clear dose – response relationship was established at this level and there was no other likely explanation for the association. The following sections describe the health effects reported. Some of the early signs of lead poisoning can be non-specific and are usually gastrointestinal. Symptoms include abdominal pain, constipation, nausea, vomiting, anorexia and weight loss. Lead-induced colic may result from effects on the visceral autonomic nervous system, causing changes in smooth muscle tone, alterations in sodium transport in the mucosa of the small intestine, or lead-induced interstitial pancreatitis (**UNEP 2010**)

The effects of lead on the haematopoietic system result in decreased haemoglobin synthesis and anaemia. Lead affects the haem biosynthetic pathway in several ways. It inhibits δ-aminolevulinic acid dehydratase (also known as porphobilinogen synthase), probably through its high affinity for the zinc-binding site in the enzyme. It also causes an increase in zinc protoporphyrin, by a mechanism which is not fully established and inhibits pyrimidine- 5′-nucleotidase, resulting in accumulation of nucleotides, and subsequent haemolysis and anaemia (**IARC 2006**). In addition lead exposure increases coproporphyrin concentrations in the blood and disrupts mitochondrial enzymes that control the insertion of iron into protoporphyrin to form the haem component of haemoglobin and other haem-containing enzymes, such as cytochrome C. Basophilic stippling may occur as a result of the aggregation of undegraded or partially degraded ribosomes as the breakdown of ribonucleic acid (RNA) is reduced (**UNEP 2010**). **NHMRC 2015a** reports that raised blood pressure (hypertension) has occurred after short-term exposure in people with BLLs of approximately 50 µg/dL or more. Abnormally low levels of haemoglobin have also been measured after repeated or long-term exposure in people with BLLs of approximately 40 micrograms per decilitre or more.

Lead is known to cause proximal renal tubular damage, characterized by aminoaciduria, alteration in the elimination of phosphates, and glycosuria. The proximal tubular epithelial cells are altered (nuclear inclusion bodies, mitochondrial changes and cytomegaly), even after relatively short-term exposures; changes are generally reversible. Inflammation of the kidneys (acute interstitial nephritis) and abnormal kidney function (acute renal impairment) has been reported after short-term exposure in people with BLLs of approximately 40 µg/dL or more (**IARC 2006, NHMRC 2015a, UNEP 2010**). Chronic exposure to low concentrations of lead is associated with increased urinary excretion of low-molecular-weight proteins and lysosomal enzymes. Chronic exposure to high concentrations of lead results in non-reversible sclerotic changes, interstitial fibrosis, glomerular sclerosis, tubular dysfunction leading to decreased kidney function and ultimately chronic renal failure. Lead has also been implicated in the development of hypertension secondary to nephropathy (**IARC 2006, UNEP 2010**). Long-term kidney damage (chronic nephropathy) severe enough to cause death has occurred after short-term exposure in people with BLLs of approximately 60 micrograms per decilitre or more. Abnormal kidney function has also occurred after repeated or long-term exposure in people with BLLs less than 20 µg/dL, with more severe effects at higher BLLs (**NHMRC 2015a**).

Lead is a well-known neurotoxicant. Impaired neurodevelopment in children is one of its most critical effects, and may result from exposure in utero and during early childhood. Lead exposure in children is linked to a lower intelligence quotient (IQ), behavioural effects and learning disabilities. Although clinical symptoms of toxicity generally become apparent at blood lead concentrations of 70 µg/dL, epidemiological studies have shown that many important disturbances occur at blood lead concentrations of 10–15 µg/dL. These include electrophysiological anomalies of evoked brain potential in response to auditory stimuli and reduced peripheral nerve conduction. Extremely high BLLs in children (above 70 µg/dL) can cause severe neurological effects, leading to lethargy, convulsions, coma and death. Lead may also affect the nervous system in adults. Long-term exposure to lead at work has been found to decrease performance in some tests of nervous system function, and to cause weakness in fingers, wrists, or ankles (lead polyneuropathy)(**IARC 2006, UNEP 2010**). Recent reports indicate that lead is harmful even at blood lead concentrations below 10 µg/dL and that there may be no threshold. In addition, attention has shifted from the impact of lead on cognition to its effects on behaviour. Exposure to lead has been found to be associated with attention dysfunction, aggression and delinquency (**IARC 2006, UNEP 2010**).

In adults peripheral sensory nerve impairment has been reported for blood levels of about 30 µg/dL. Lead encephalopathy, which is rare and affects especially children, can occur at somewhat higher exposure levels (such as 100-120 µg/dL) and manifests as include agitation, drowsiness, poor attention span, vertigo, uncoordinated walking or movement (ataxia), headache, insomnia, restlessness, confusion, tonic–clonic convulsions and coma leading to death (due to severe cerebral oedema and raised intracranial pressure). Other problems with brain and nerves have occurred after long-term exposure in people with BLLs of approximately 40 µg/dL or more. These include problems with thinking, anxiety, mood changes, dizziness, fatigue, sleep disturbance, headache, irritability, lethargy, a general feeling of discomfort, slurred speech, convulsions, muscle weakness, sensation of burning, tingling or prickling in the skin, inability to control movement of the arms and legs, tremors and paralysis (**UNEP 2010, NHMRC 2015a**). The doubling of blood lead level from 10 to 20 µg/dL has been associated with an average loss of 1–3 points of IQ. In addition to reducing IQ, widespread exposure to lead is likely to have profound implications for a wide array of undesirable social behaviours. Social and emotional dysfunction and academic performance deficits have been correlated with lead exposure. (**UNEP 2010**)

Exposure to lead is associated with cardiovascular effects and with changes in endocrine and immune functions. The effect of lead on the heart is indirect and occurs mainly through the autonomic nervous system. It has been suggested that lead-induced hypertension and essential hypertension may have a common mechanism. The association between blood lead level and blood pressure is clearest for systolic blood pressure in adult males. A decrease in blood lead from 10 to 5 µg/dL has been associated with a decrease of 1.25 mmHg in systolic blood pressure (**UNEP 2010**). In women the association is weaker. However, women with BLLs from 4.0-31.1 µg/dL had increased risk of diastolic hypertension and a moderately increased risk for general hypertension (**IARC 2006, UNEP 2010**). Many of the effects of lead exposure in humans have been confirmed in experimental systems. At the cellular level, lead has mitogenic properties; it affects various regulatory proteins, including those that depend on the presence of zinc (**IARC 2006**).

Studies on the reproductive and developmental toxicity of lead do not show consistent effects, morphologically or quantitatively, on markers of male fertility. High BLLs (>40 µg/dL or >25 µg/dL for a period of years) in men appear to reduce fertility and to increase the risks for offspring of spontaneous abortion (pregnancy loss before the 20th week of gestation, but after the stage of unrecognized, sub-clinical loss), reduced foetal growth and preterm delivery. Maternal BLLs of approximately 10 μg/dL have been linked to increased risks of hypertension in pregnancy, spontaneous abortion, and impaired neurobehavioral development in the offspring. Higher maternal lead levels have been linked to reduced foetal growth; there is still uncertainty regarding links to malformations and the dose–response relationship. The effect on postnatal growth rate is apparent only in those children with continuing postnatal lead exposure. Overall it is not clear whether the effects are caused by a direct interaction of lead with the reproductive organs, or by modulation of the endocrine control of reproduction, or both (**IARC 2006, UNEP 2010**).

Humans occupationally exposed to lead show evidence of genotoxicity and these effects are correlated with blood lead concentrations. A lot of the evidence however involved co-exposure to lead and other compounds, making it difficult to attribute genetic and other effects to lead alone. In a limited number of studies on non-occupationally exposed individuals, no genotoxic effects were found that were correlated with blood lead concentrations (**IARC 2006**).

There is no proof that lead causes cancer in humans; however a few studies have suggested an association between lead exposure and lung cancer and, to a lesser extent, stomach cancer. Lead is hypothesized to be a co-carcinogen, allowing or augmenting the genotoxic effects of other agents and is classified as a “probable human carcinogen” (**UNEP 2010**).

5.2.1.2.2 Low exposure

As described above the health effects of lead at moderate to high exposure causes health conditions such as hematopoietic, neurological and reproductive effects to name a few. In contrast, the evidence from studies conducted in groups of people with low-level exposure to lead (indicated by BLLs less than 10 μg/dL) does not fulfil all these criteria (**NHMRC 2015a**). Specifically cross-sectional and prospective studies of children have found impairments in cognition, attention, and language function at concentrations of lead previously thought to be harmless i.e. below 10 μg/dL (**IARC 2006**).

The National Health and Medical Research Council (NHMRC) therefore carried out a review of the literature on low level lead exposure (i.e. BLLs less than 5 μg/dL and between 5 and 10 μg/dL) and presented a summary of findings on the effects in children and adults.

<u>Blood levels less than 5 μg/dL</u>: In children, exposure was associated with reduced average academic achievement and IQ. However, it is not possible to tell whether low-level lead exposure reduced children’s intelligence or whether children’s performance at school or on IQ tests were influenced by other factors such as socioeconomic status, education, parenting style, diet, or exposure to other substances in the groups of children studied. Overall it was difficult to ascertain whether average BLLs below 5 μg/dL resulted in meaningful health effects, but were in agreement that there is no ‘safe’ level of lead that has been proven not to cause any health problems.

<u>Blood levels between 5 – 10 μg/dL</u>: In children, exposure was associated with a higher occurrence of behavioural problems (poor attention, impulsivity and hyperactivity). However, it is not possible to tell whether low-level lead exposure caused behavioural problems in children or whether other factors affected behaviour or measurements of behaviour in the groups of children studied. In adolescent boys and girls exposure was associated with delay in physical sexual maturity or onset of puberty where as in adults exposure was associated with increased blood pressure. It was estimated that each doubling of blood lead level is associated with an increase in systolic blood pressure of 1 mm Hg.

Overall the authors found a strong association between risk factors and health at BLLs 5 – 10 µg/dl and < 5 µg/dl however no causal link was established at the lower BLLs. It is still unclear whether BLLs less than 10 µg/dL have meaningful health effects for individuals, because the available studies (cross-sectional studies) do not provide the type of reliable evidence that would enable public health experts and statisticians to make confident conclusions about cause and effect (**NHMRC 2015a**).

In May 2015, the NHMRC (**NHMRC 2015b**) released a statement recommending that if a person has a BLL greater than 5 µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman. This BLL is yet to be taken into account in the Australian lead air-quality guideline value therefore NHMRC recommends that Health authorities in Australian states and territories should continue to focus on identifying people who have been exposed to more lead rather than the background air concentrations. Should a person have a blood lead level > 5 µg/dL, their exposure to lead should be investigated and reduced (**NHMRC 2015b**).

5.2.2 Exposure Assessment

The Integrated Exposure Uptake Biokinetic Model (IEUBK) is a stand-alone personal computer software package recommended for modelling blood lead levels in the most sensitive age group, infants and children to age seven, (**NEPM, 2013**). IEUBKwin 32, version 1.1 Build 11 was downloaded in October 2016 for this study.

The model is used to assess site-specific risk for young children exposed to Pb from different media and through different pathways in their environment. In this study a combination of default and site specific values were used to provide:

1. A summary of exposure to lead by "hypothetical" children, relative to residences and schools, near the mine.
2. A best estimate of the Blood Lead Levels (BLLs) centred on a Geometric Mean (GMBLL) concentration for a typical child, aged 6 months to 84 months, assumed to live in the study area.
3. A basis for estimating the risk of BLL exceeding a BLL concentration of concern for a hypothetical child.

To estimate BLLs in children exposed to lead-contaminated media, the model uses four modules; biological, exposure, uptake and biokinetics and a statistical module that calculates blood lead levels and generates probability distributions, (**US-EPA, 2007**). The interrelationships between the first three (biological) modules are shown in **Figure 5-1**.

In this study the IEUBK model was setup using Australian values that were used in deriving the NEPM Health Investigation Level (HIL) and where applicable, site specific soil, water and airborne lead values to estimate exposure to lead, for a hypothetical population of children in residential areas close to the Mine. The model was also used to predict a plausible distribution of BLL concentrations centred on a GMBLL concentration. The focus for this assessment was on what changes to the BLLs that may occur due to the Proposal.

The probability that a population of children's BLL concentrations will exceed a certain level of concern was calculated by the model. In consideration of the existing elevated BLLs in Broken Hill, the level of concern is 10 µg/dL and compared to the aspirational 5 µg/dL (**NHMRC, 2016**).

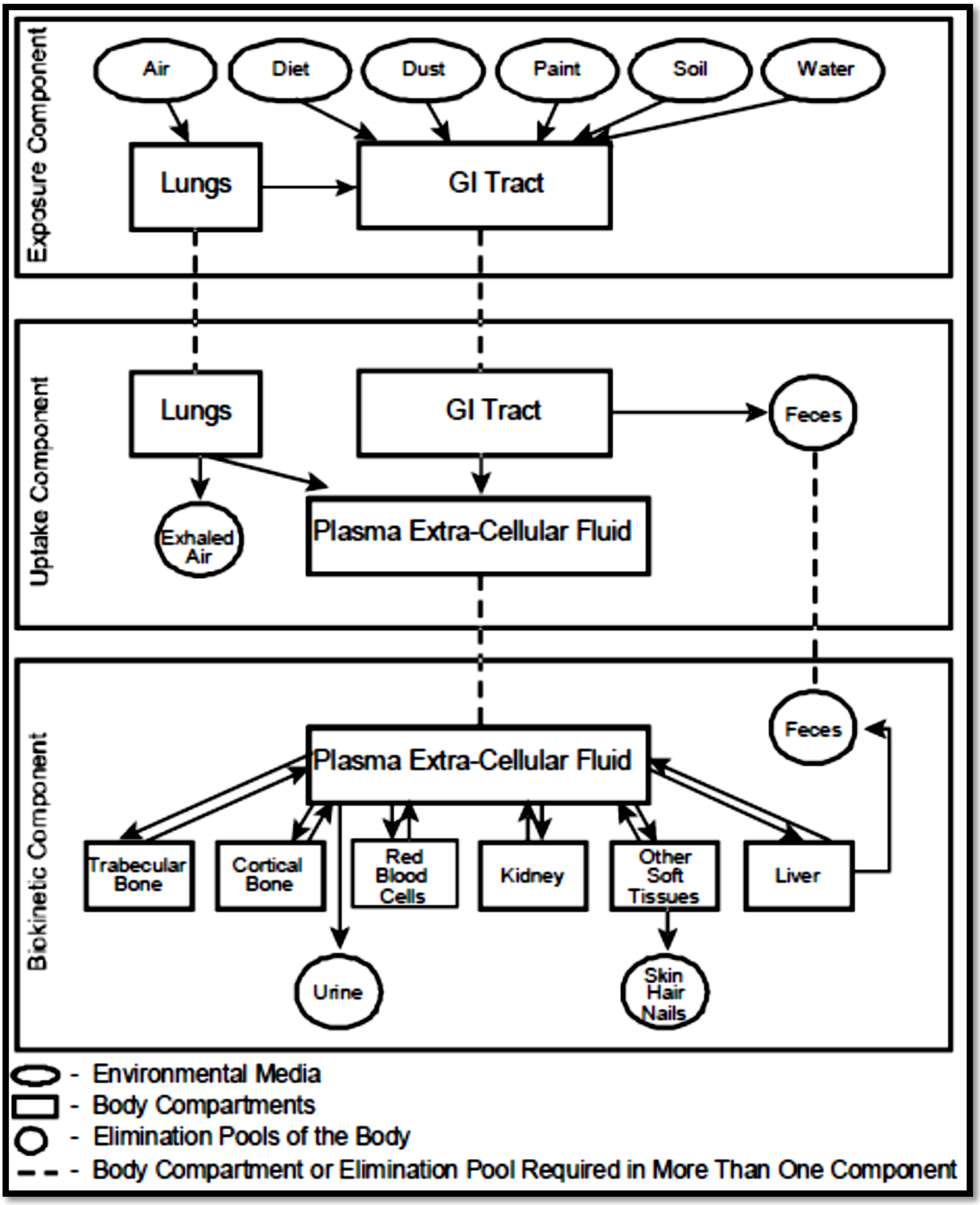


Figure 5-1: Biological Structure of the IEUBK model

5.2.2.1 Site selection and data collection

The sites used in this study were selected from the Perilya Broken Hill Mine monitoring program, consisting of two high volume samplers **Figure 4-1**; data used for this desktop study comprised of:

1. High volume samplers measuring total suspended particulates (TSP) and total lead (μg/m^3) at site LP26 and LP27;
2. Deposition gauges measuring lead in dust deposited at sites LP15 to LP25; and,
3. Total lead (μg/m^3) generated by PEL using an air shed lead model for ten residential receptors on the north-west boundary of the mine, located between LP24 and LP19.

In addition, the diffuse area including residences R1 to R10 (**PEL, 2016 b**) near the proposed mine were selected, **Figure 3-1**.

5.2.2.2 Model Scenarios

The study looked at with or without new mining activities the following scenarios:

1. BH6: Residence in Broken Hill north near the proposed mine, for this study the geometric mean soil concentration of lead (geometric mean 767 μg/g) for District 6 was selected (**Boreland, et al., 2002**) – *see section 5.2.2.3.1* - and the Broken Hill default outdoor lead concentration in air of 0.17 μg/m^3 (Air Quality Impact Assessment – Part 1 of the Specialist Consultant Studies Compendium). Sites R1 to R10 fell in soil District 6 and District 5 (geometric mean 521 μg/g).
2. LP26: Licence point LP26 using soil data from the Boreland study for District 6 and the average depositional lead in TSP monitoring program at this monitoring sites of 0.048 μg/m^3.
3. LP27: Licence point LP27 using soil data from the Boreland study for District 6 and the average depositional lead of 0.285 μg/m^3.
4. BH6 max: same as BH6 but using the maximum recorded soil lead in District 6 of 1011 μg/g

Model runs used the current soil and air lead data as the background situation, and the calculated cumulative soil and air values for the proposed mining actives.

5.2.2.3 IEUBK Model Parameters and Equations

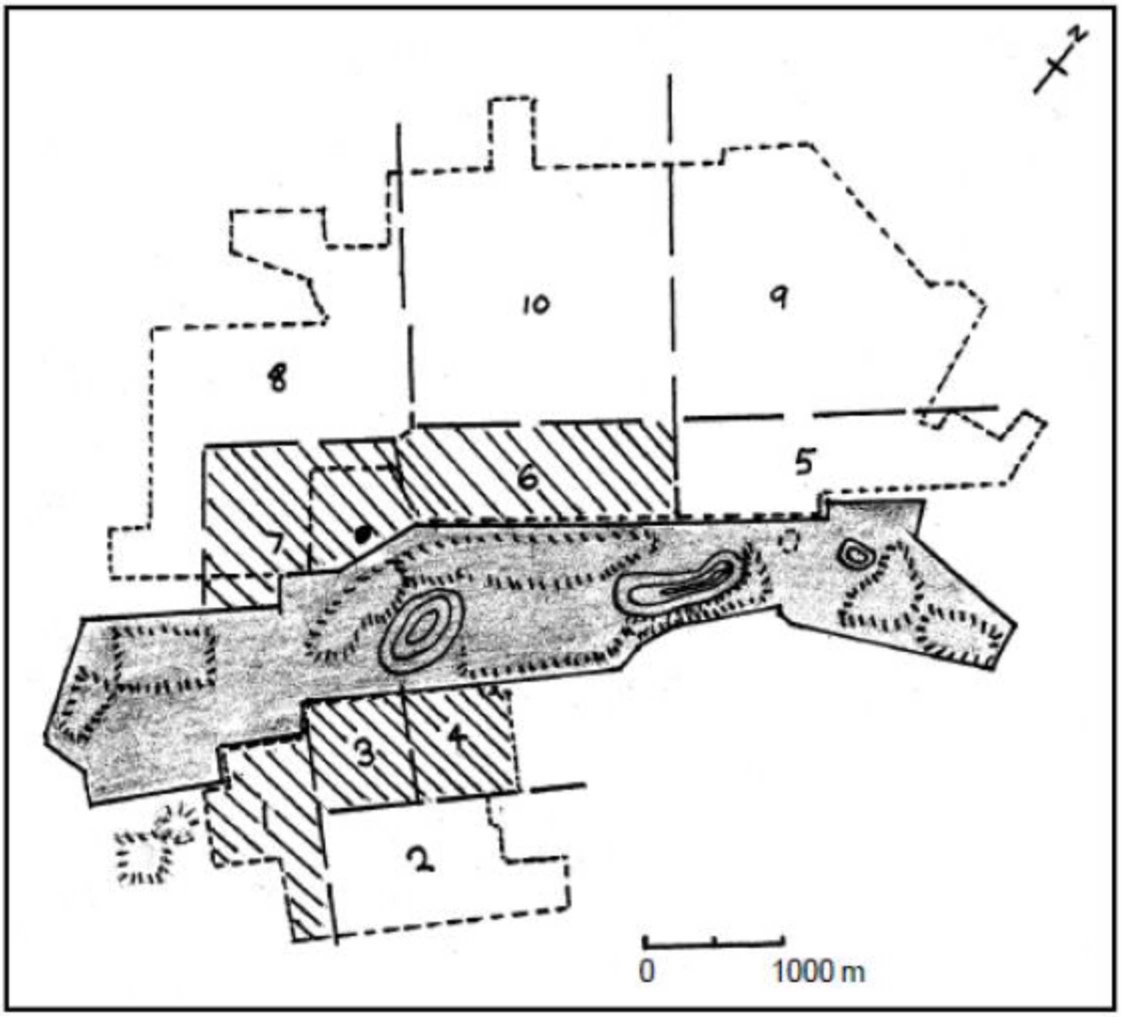
The IEUBK Model for lead in children was developed by the U.S. Environmental Protection Agency (US EPA), Technical Review Workgroup (TRW) for Metals and Asbestos (**US EPA, 2007**). There are five input data windows for each of the common sources of lead exposure; an additional window is available for consideration of alternative lead sources and a window to specify bioavailability for each of these sources. The model has default values that may be changed to reflect site-specific conditions. Site-specific data are most commonly used in place of the model default values for lead concentrations in soil, dust, air, and water.

In this study the default values provided in the IEUBK model were modified to Australian conditions, as outlined in the derivation of the HIL-A (**ERS, 2011**). Adjustments were made for Broken Hill north residence close to the Perilya mine, using site specific total lead concentration and depositional data, air-shed modelling, drinking water quality, and available literature, as cited. The Australian generic home with access to a garden was set up using soil set at the HIL-A and the default Australian values as described by NEMP in deriving the HIL-A (**ERS, 2011**).

It is important to note that the IEUBK model as set up in this study does not include any changes that relate to management measures that may be implemented by the community to minimize exposure to lead soil and dust, thus, the modelling of blood lead is conservative.

5.2.2.3.1 Soil/Dust Data

Soil and dust are the primary sources of lead exposure to children. No recent soil lead data were available for this study however data from historic detailed soil studies were available for modelling the site-specific blood lead – see appendix C (**Boreland, et al., 2002**) . The Boreland soil study divided the Broken Hill area into ten districts. Districts 5 and 6 are the nearest to the mine, **Figure 5-2.** The geometric mean and maximum soil lead values for district 6, with the highest lead levels of the two, were used in the model.



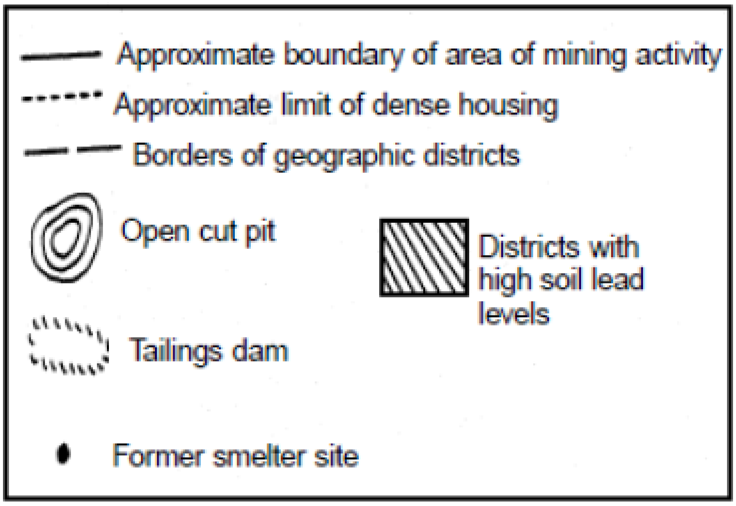


Figure 5-2: Map of Broken Hill showing district boundaries (Boreland et al 2002)

Notwithstanding the above, Perilya Broken Hill Limited provided a database comprising 1,935 soil samples collected over an unknown timeframe over an area approximately 17.5km long and 3km wide, orientated in a northeast – southwest direction. This database covers the Line of Lode and its extensions, including the Mine Site and the urban area of Broken Hill and was collected for mineral exploration purposes. The sample collection and analysis methodology is not known, with a range of methods presumed to have been used. Furthermore, as sampling was undertaken to identify areas of high lead in soils that may have reflecting underlying lead mineralisation, areas of higher lead values were preferentially sampled at a greater density than other areas. Results are reported in parts per million (ppm), with 1ppm = 1µg/g. In light of the above, the dataset was determined not to be adequate for the purposes of this assessment. Notwithstanding this, the mean lead value of all soil samples was 50.3ppm and the median is 9ppm, considerably lower than the assumed lead values. Indeed, of the 1,935 samples, only 79 recorded lead values <200ppm. As a result, the assumed soil lead levels are considered to be conservative.

To predict the impact on blood lead levels from the Proposal, the concentration of lead in soil, after twenty-five years of mining, was added to the background soil lead concentration, using site specific depositional soil lead (Pb-d) levels. The incremental concentration of soil lead was calculated using the formula (**Stevens, 1991**):

$$Cs = Pb\text{-}d \times [1-e\text{-}kt] \times 1000 / \partial \times D \times k$$

Where:

Cs = concentration of lead in soil after a given number of years of mine life (mg Pb/kg soil).

Pb-d = annual deposition of lead (mg Pb /m^2/yr)

k = Chemical specific soil loss constant (1/year) = $\ln(2)/T^{0.5}$

$T^{0.5}$ = Chemical half-life (Years) = 10^8 days for lead

t = Accumulation time (years)

∂ = soil bulk density (g/cm^3)

D = depth of soil mixing (m)

The predicted average annual deposition of lead (Pb-d) in the residential areas (R1-R10) from the Proposal is 3.1 x 10^{-6} mg Pb/m^2/year from (**PEL, 2016 b**). The half-life for lead is 10^8 days (**OEHHA, 2012**). The proposed mine life is 25 years[2] (**PEL, 2016 a**). The soil bulk density used in the equation is 1.4 g/m^3, assuming the soil is a sandy loam. The depth of soil mixing was assumed to be 2 cm as recommended by the US EPA for non-agricultural (untilled) soil. It should be noted that the Boreland study sampled the top 10 cm of soil. The calculated concentration of incremental lead in soil after 25 years of mining is 2.78 Pb mg/kg (same as µg/g) of soil.

The concentration of indoor dust lead (µg/g) is derived from the outdoor soil concentration using the multiple source analysis feature of the IEUBK model. In deriving the HIL-A NEPM used a 0.7 conversion factor for the contribution of soil lead to household dust lead. The conversion factor recommended by NEPM for site specific assessments the IEUBK default value of 100 is used (**ERS, 2011**). NEPM used a low conversion factor of 0.5 in deriving the HIL-A for lead, suggesting that there is a very low contribution to indoor dust derived from ambient air. The model is not sensitive to this parameter, when HIL-A is calculated using 0.5 the result is 306 mg/kg, compared to using 100, which gives an HIL-A of 302 mg/kg (**ERS, 2011**).

5.2.2.3.2 Air data

As a default, the model calculates indoor air Pb concentration as 30 % of the outdoor air Pb concentration. The model allows the user to vary the value of each parameter by age. In this study the default ventilation rate by age was updated to conform to those used in deriving HIL-A (**ERS, 2011**). The outdoor air dust lead concentrations are changed for each model scenario as outlined below.

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[2] The Applicant anticipates that Phase 1 to Phase 3 mining operations (*see Section 2.3 of Air Quality Impact Assessment – Part 1 of the Specialist Consultant Studies Compendium*) would, based on known ore reserves, require approximately 16 years to complete. However, the Applicant anticipates that additional ore would be identified during mining operations. As a result, the Applicant proposes to undertake mining operations for a period of 25 years from the date of granting of development consent, with rehabilitation and mine closure activities expected to require a number of years following the completion of mining operations.

Table 5-1: Soil/ Dust data parameters

Parameter in IEUBK Model (units)	Value used in study	Reason for change / Reference
Soil/dust ingestion weighting factor	50%	Australian Exposure Factor Handbook (**enHealth, 2012, IARC, 2006**)
Outdoor soil lead (µg/g)	767	(1 to 3) Geomean, District 6, (**Boreland, et al., 2002**).
	812.62	(1 to 3) Cumulative District 6. Calculation of soil lead in the top 0.02 m after 25 years of mining, using PEL depositional lead model incremental values.
	1011	(4) Maximum soil lead District 6, (**Boreland, et al., 2002**).
	1056.64	(4) Maximum soil lead District 6. Calculation of soil lead in the top 0.02 m after 25 years of mining, using PEL depositional lead model incremental values.
Amount of soil + dust ingested daily (g/day)	(0-1yr) | 0.032 (1-2yr) | 0.1 (2-3yr) | 0.1 (3-4yr) | 0.1 (4-5yr) | 0.1 (5-6yr) | 0.1 (6-7yr) | 0.1	Australian Exposure Factor Handbook (**enHealth, 2012**)
Contribution of outdoor soil lead to indoor dust lead (conversion factor)	0.7	The conversion factor used in deriving the HIL-A, (**ERS, 2011**).
Contribution of outdoor airborne lead to indoor dust lead (conversion factor)	100	The conversion factor recommended by NEPM for site specific modelling (**ERS, 2011**).

Table 5-2: Air data parameters

Parameter in IEUBK Model (units)	Value used in study	Reason for change / Reference
Ratio of indoor dust lead concentration to corresponding outdoor concentration (%)	30	Schedule B7 Appendix D (**NEPM, 2013**, **US EPA, 1998**).
Outdoor air lead concentration (µg/m^3)	0.17 0.1731 0.1217 0.1251 0.2273 0.2308	(1 & 4) Background. Average air-borne lead near mine data provided by PEL. (1 & 4) Cumulative lead in air from PEL Model. (2) average background LP26 (2) Cumulative LP26 (3) average background LP27 (3) Cumulative LP27 Air-shed model (**PEL, 2016 b**)
Time spent outdoors (hr/day)	(0-1yr) | 1 (1-2yr) | 2 (2-3yr) | 3 (3-4yr) | 4 (4-5yr) | 4 (5-6yr) | 4 (6-7yr) | 4	Schedule B7 Appendix D (**NEPM, 2013, US EPA, 1998).** Previous studies (**Toxikos, 2010**) used half these values based on a South Australian study by (**Brinkman, et al., 1999**). This approach was superseded in deriving the NEPM HIL-A (**ERS, 2011**)
Ventilation Rate (m$_3$/day)	(0-1yr) | 5.7 (1-2yr) | 8.77 (2-3yr) | 9.76 (3-4yr) | 10.64 (4-5yr) | 11.4 (5-6yr) | 12.07 (6-7yr) | 12.25	Schedule B7 Appendix D (**NEPM, 2013, US EPA, 2008**)
Lung absorption (%)	32	Schedule B7 Appendix D (**NEPM, 2013, US EPA, 2008**)

5.2.2.3.3 Dietary data

The dietary data input window includes information on that portion of total lead intake which enters the body through the consumption of food. The default daily dietary lead intake values for each age group were modified to the Food Standards Australia and New Zealand (FSANZ) (**ERS, 2011**). NEPM adopts the view that mineral lead (lead sulphide) is not soluble in water and therefore not taken up by home grown produce (**pers. com., ERS 2016**).

Table 5-3: Dietary data parameters

Parameter in IEUBK Model (units)	Value used in study	Reason for change / Reference
Dietary lead intake (µg/day)	(0-1yr) | 5.1 (1-2yr) | 5.8 (2-3yr) | 6.7 (3-4yr) | 3.2 (4-5yr) | 3.6 (5-6yr) | 4.1 (6-7yr) | 4.7	Calculation of dietary lead intake based on the mean daily intake reported in the 20th Australian total diet survey for infants in 2003 and the average age group body weight from the USEPA Child-Specific Exposure Factors Handbook 2008, (**US EPA, 2008**)
Use of alternate dietary intake	Not used	This feature of the model allows the user to input site specific lead in food grown and consumed locally.

5.2.2.3.4 Drinking water data

The drinking water data input window is divided into two sections: water consumption rates and environmental concentrations. The default consumption rates are age-dependent and based on Australian national averages.

Table 5-4: Drinking Water Data Parameters

Parameter in IEUBK Model (units)	Value used in study	Reason for change / Reference
Water Consumption (L/day)	(0-1yr) | 0.49 (1-2yr) | 0.308 (2-3yr) | 0.356 (3-4yr) | 0.417 (4-5yr) | 0.417 (5-6yr) | 0.417 (6-7yr) | 0.48	Calculation of dietary lead intake based on the mean daily intake reported in the 20th Australian total diet survey for infants in 2003 and the average age group body weight from the USEPA Child-Specific Exposure Factors Handbook 2008.
Lead concentration in drinking water (µg/L)	4.2	Average lead levels in Broken Hill drinking water (**essential water, 2016**).

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5.2.2.3.5 Maternal data

The mother's BLL (µg/dL) is used to determine BLLs in a child's blood at birth. The current IEUBK default value of 1 µg/dL has been adopted in deriving the HIL-A. The maternal blood lead value used in this study is based on adult BLLs for maternal BLL reported in Broken Hill is 1.36 µg /dL (**Toxikos, 2010**). Sensitivity testing of this value found that the net change to the model output was negligible.

5.2.2.3.6 Bioavailability

The bioavailability lead from ingested soil, dust, water and food is a significant contributor to BLLs. The IEUBK model provides default bioavailability values but site-specific values can be substituted. Lead in water and food is assumed to be in a soluble form and therefore 100% bioaccessibility from the gastrointestinal tract. The bioavailability of soil lead is influenced by numerous characteristics of the soil-lead matrix, and is therefore site specific. The chemical form of lead in soil has a great bearing on solubility and therefore bioavailability. Other important characteristics that influence bioavailability include particle size, pH and redox potential and organic matter content. It is therefore difficult to infer the appropriate Relative BioAvailability (RBA) value to use in the IEUBK model.

The study area is near a lead-zinc mine where the predominant form of lead is the sulphide, galena (PbS). Galena and its weathering product anglesite ($PbSO_4$) potentially have lower RBA values then lead oxides, phosphates or slag, which in turn are less bioavailable than lead carbonates, acetates and oxides of manganese. The TRW suggest that the RBA for lead sulfide and sulphates may be less than 25%, (**US EPA, 1999**).

Studies for the Rasp mine in Broken Hill found that the average bioaccessibility of lead from surface dust was 7.3% and just 1.4% from mine ore, (**Toxikos, 2010**). Rounding up this value to 10% bioaccessibility and multiplied by the 50% absorption fraction from soil and dust to obtain a gastrointestinal absorption coefficient for soil and dust of 5% (**pers. com., ERS 2016**). This lower absorption fraction is adopted for all IEUBK model scenarios.

5.2.2.3.7 Statistical Module

The IEUBK model addresses variability in blood lead concentrations among exposed children. Children having the same exposure to concentrations of environmental lead can develop very different BLLs due to differences in behaviour, household characteristics, and individual patterns of lead uptake and bio kinetics, (**US EPA, 2007**). The IEUBK model uses a log-normal probability distribution to characterize this variability.

The biokinetic component output provides a central estimate of blood lead concentration, which is used to provide the Geometric Standard Deviation (GSD). The GSD is a measure of relative variability in BLLs of children of a specific age or a hypothetical population of children whose lead exposure is known. The GSD in IEUBK encompasses biological and behavioural differences, measurement variability from repeat sampling, variability because of sample locations, and analytical variability (**US EPA, 2007**). In this study the default GSD of 1.6 is used.

5.2.2.3.8 Input data

The input data described in the preceding section are summarised in **Appendix A**, which also shows how the default values have been modified with site-specific values.

5.2.2.4 IEUBK Model Outputs

The IEUBK was used to generate:

1. GMBLL, by age group.
2. Percentage of children with BLLs more than the specified level(s) of concern (5 and 10 µg/dL)
3. Soil lead concentrations to meet the target level, without altering other model inputs.
4. Predicted BLLs with increasing soil lead concentrations.

Model outputs showing each medium's contribution to blood lead levels are provided in **Appendix B**. The average of the geometric mean BLL concentrations for children in sequential 1-year age intervals for eight scenarios is presented in **Table 1**. The soil and air input values are shown in the first column.

Table 5-5: GMBLL (µg/dL) for seven age groups

Scenario	Input		GMBLL by age group						
	soil (µg /g)	air (µg/m$_3$)	.5-1	1-2	2-3	3-4	4-5	5-6	6-7
BH6 background	767	0.17	2.5	2.8	2.7	2.2	2.0	1.9	1.9
BH6 cumulative	812.64	0.1734	2.5	2.8	2.7	2.3	2.1	2.0	1.9
LP26 background	767	0.1217	2.5	2.7	2.7	2.2	2.0	1.9	1.9
LP26 cumulative	812.64	0.1251	2.5	2.8	2.7	2.2	2.0	2.0	1.9
LP27 background	767	0.2251	2.5	2.8	2.7	2.2	2.0	2.0	1.9
LP27 cumulative	812.64	0.2308	2.5	2.9	2.8	2.3	2.1	2.0	2.0
BH6 max background	1011	0.17	2.3	3.1	3.0	2.5	2.3	2.2	2.2
BH6 max cumulative	1056.64	0.1734	2.7	3.2	3.1	2.6	2.4	2.3	2.2

5.2.3 Risk Characterisation

The main finding is that the background and cumulative GMBLLs in all age groups are lower than the 5 µg/dL target level, for all soil lead scenarios. Modelling shows a very small increase in the GMBLL in children exposed to the proposed mining activities.

Estimates of a plausible distribution of BLLs centred on the calculated GMBLL are plotted by the IEUBK model. The probability that children will have BLLs exceeding the level of concern is an important consideration for risk assessors. The percentage of children with a probability of having a BLL that will exceed a target BLL is also calculated by the IEUBK model. The portion of the upper tail of the probability distribution exceeding the target BLL provides an estimate of the risk of exceeding that level for a hypothetical child living with the same exposure history. **Figure 5-3** and **Figure 5-4** show the probability density curve around the geometric mean of

2.265 μg/dL of the population that have a 5% probability of exceeding the target BLL. The percentage of hypothetical children living near the Broken Hill Perilya mine, with a 5% probability of exceeding the 10 μg /dL, is 0.079%, and the 5 μg /dL target is 4.599%.

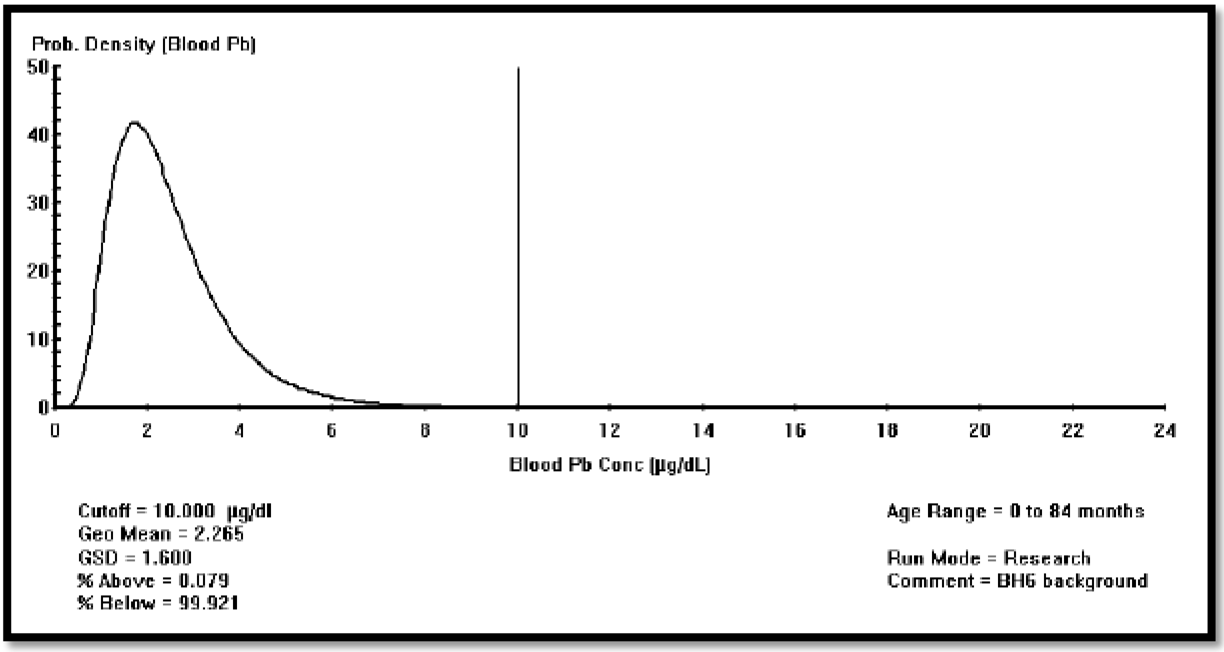

Figure 5-3: Probability distribution around the GMBLL for the BH Scenario at 10 μg /dL cut-off

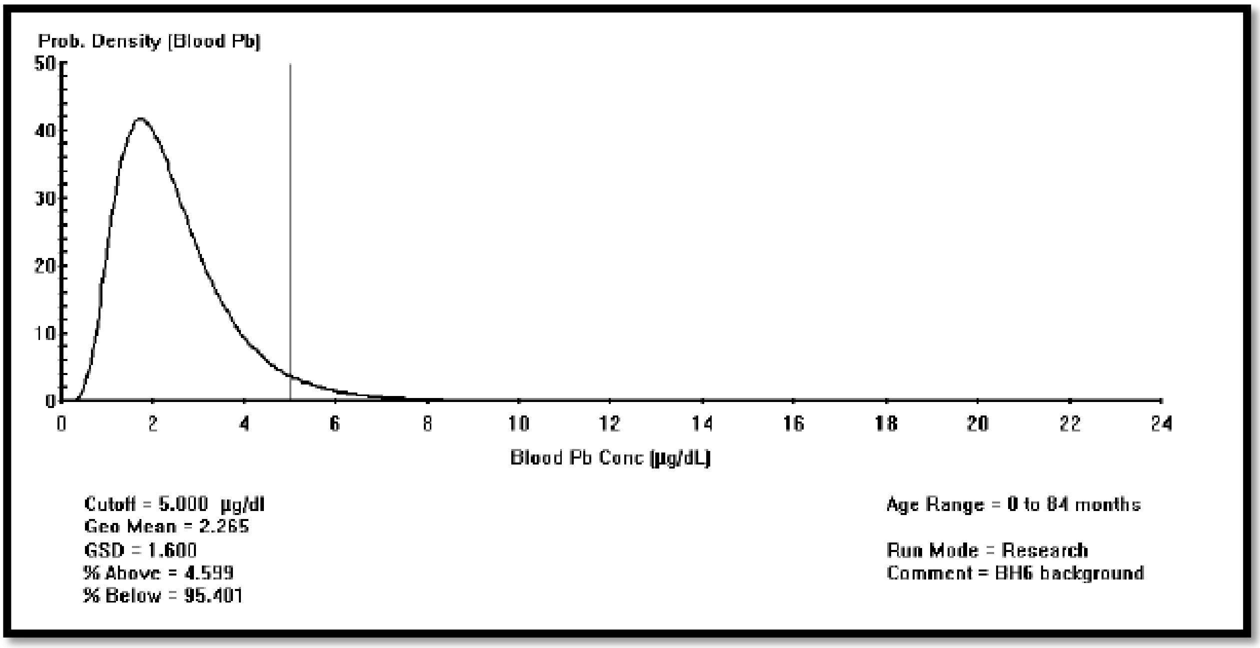

Figure 5-4: Probability distribution around the GMBLL for the BH Scenario at 5 μg /dL cut-off

The geometric means and probable percentage of children exceeding target values for all scenarios investigated are presented in Table 2. This table shows the soil and air lead values used in the model run, the GMBLL and the percentage that have a 5% probability of being higher than the 10 μg/dL or 5 μg/dL target level.

Table 5-6: Calculated GMBLL and percentage of children level of concern

Scenario	Input		Geometric Mean	% children above BLL target	
	soil (µg /g)	air (µg/m3)		10 µg/dL	5 µg/dL
BH6 background	767	0.17	2.265	0.079	4.599
BH6 cumulative	812.64	0.1734	2.322	0.094	5.131
LP26 background	767	0.1217	2.24	0.073	4.381
LP26 cumulative	812.64	0.1251	2.297	0.088	4.899
LP27 background	767	0.2251	2.294	0.087	4.866
LP27 cumulative	812.64	0.2308	2.351	0.103	5.416
BH6 max background	1011	0.17	2.558	0.186	7.696
BH6 max cumulative	1056.64	0.1734	2.614	0.216	8.386

All scenarios based on the soil geometric mean for District 6 had less than 0.1% of children at risk of exceeding 10 µg/dL level and less than 5.5% of exceeding 5 µg/dL level. The scenarios using the maximum soil lead in District 6 had less than 0.22% of children risk of exceeding 10 µg/dL level, and less than 8.5% of exceeding 5 µg/dL level. The percentage of children above the target values increases slightly if the proposed mining activities go ahead.

The model was also used to generate soil lead concentrations associated with the target BLLs. A soil lead concentration of 2,815 µg Pb /g is associated with the 10 µg/dL target, and 801 µg Pb/g with the 5 µg/dL target. This information is instructive when developing management tools to reduce the BLLs in a population.

Comparisons of BLL concentrations with varying soil lead concentration provide a measure of the sensitivity of increasing soil lead concentrations on blood lead. Using the input data for BH6 cumulative scenario, IEUBK calculated the blood lead concentrations for incremental soil lead concentrations from 0 to 2,500 µg Pb /g. The data is presented in **Table 5-7** and graphically in Figure 7.

Table 5-7: Broken Hill background conditions for residences close to the Perilya mine

Soil Concentration (µg lead/g)	Blood Concentration (µg/dL)
0.0	1.3
357	1.8
714	2.2
1071	2.6
1429	3.1
1786	3.5
2143	3.9
2500	4.3

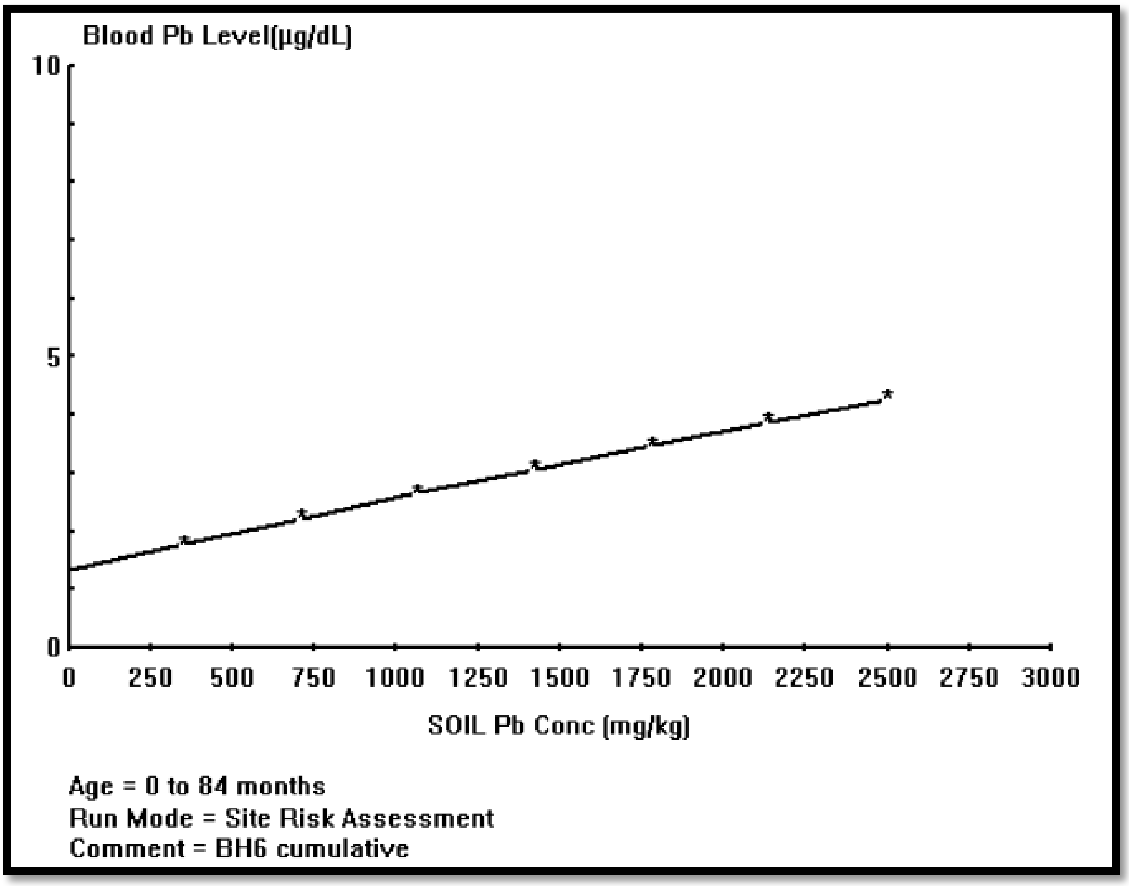

Figure 5-5: Soil lead concentrations against BLLs for residences close to the Perilya mine

The model was used to explore the sensitivity to various exposure assumptions. The effect of reducing the soil and dust lead absorption fraction from 50% to 30% had a significant effect on the percentage of children with a 5% probability of being higher than 5 µg /dL BLL; from 41.9% down to 17.0% using the input values for deriving the HIL-A.

5.2.3.1 Sensitivity Analysis

Sensitivity analysis of the soil and dust lead absorption fraction had a significant effect on blood lead levels. The effect of increasing the relative absorption fraction from 5% through to 50% on blood lead with increasing soil concentrations is presented in **Figure 5-6** and **Table** 5-8**.**

This analysis shows that soils with lead concentrations above 1,000 for an absorption fraction of 50% or 1,400 µg Pb/g for an absorption fraction of 30% have geometric means higher than the 10 µg /dL target if the relative absorption fraction is increased from the values derived from the Toxikos study to the default IEUBK values.

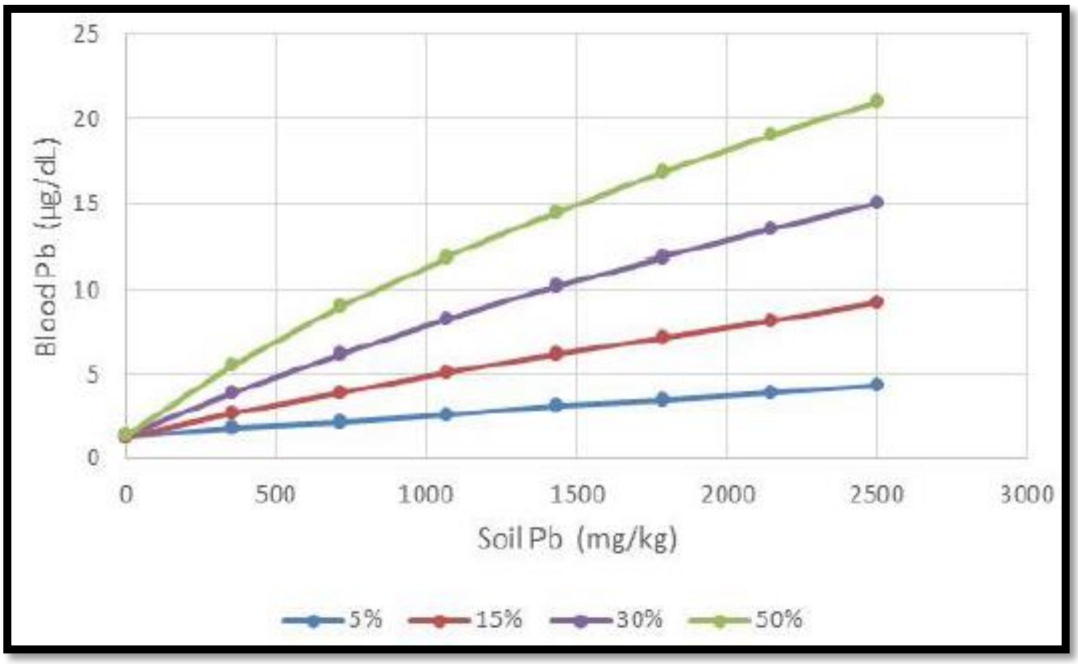

Figure 5-6: Sensitivity to soil and dust absorption percentage

Table 5-8: Sensitivity of blood lead modelling to the absorption fraction

Soil Concentration (µg lead/g)	**Blood Concentration (µg/dL)**				
Absorption Factor	5%	10%	15%	30%	50%
0.0	1.3	1.3	1.3	1.4	1.4
357	1.8	2.2	2.7	3.9	5.5
714	2.2	3.1	3.9	6.2	9.0
1071	2.6	3.9	5.1	8.3	11.9
1429	3.1	4.7	6.2	10.2	14.5
1786	3.5	5.4	7.2	11.9	16.9
2143	3.9	6.2	8.2	13.5	19.0
2500	4.3	6.9	9.2	15.0	21.0

6. CONCLUSIONS

The modelled outputs from the Air Quality Impact Assessment – *Part 1 of the Specialist Consultant Studies Compendium* as well as data from the Applicants monitoring network were used to evaluate the potential BLLs, using the IEUBK model, for children between the ages of 6 months and 48 months, the most susceptible population group. Site specific information was compiled from the data provided and a literature review on information relevant to evaluating BLLs in Broken Hill and the broader Australian community. From this information, the IEUBK model was set up to run eight scenarios. These consisted of:

- Broken Hill residences near the proposed Perilya Mine (BH6), background and cumulative;
- Compliance air and dust monitoring sites LP26 and LP27, background and cumulative; and,
- Broken Hill residences near the mine but with the maximum recorded soil lead concentration in District 6 (BH6 max), background and cumulative.

Input values consisted of a combination of IEUBK and NEPM default values, and site specific values. The site-specific values consisted of soil lead concentrations from the Boreland study in 2002, background air lead concentrations from monitoring data near the mine, cumulative air lead and depositional dust outputs from the PEL air-shed modelling, maternal blood lead in Broken Hill and average drinking water lead concentrations from the Broken Hill drinking water supplier. The Absorption factor used in this study was derived from the Toxikos study for Rasp Mine.

The model outputs were intended for comparative purpose and to explore the effect of mining activity on BLLs. BLL concentrations in children between the ages of 6 months and 48 months:

1. The GMBLL for all age groups in all scenarios was below 5 µg/dL.
2. The percentage of children with a 5% probability of exceeding the 10 µg/dL target was between 0.07% and 0.22%. The lowest result in LP26 background and highest in BH6 max cumulative.
3. The GMBLL in children living near the mine after 25 years of operations (BH6 cumulative) is less than 5 µg/dL exposed to soil lead connections of less than 2,500 µg Pb/g.

The model shows a very small increase in the GMBLLs in children with the proposed mining activities. Similarly, the percentage of children above the target values increases slightly with the proposed mining activates over the next 25 years. The IEUBK model calculated that a soil lead concentration of 2,815 µg Pb /g is associated with the 10 µg/dL target, and a concentration of 801 µg Pb /g with the 5 µg PbB /dL target.

Sensitivity analysis of the relative absorption fraction found, that increasing the adopted value from 5% through to 50% would result in elevated blood lead levels in children. Those living on soils at more than 1,000 µg Pb/g for 50% relative absorption or 1,400 µg Pb/g for 30% have a 5% probability of exceeding the 10 µg Pb/dL target value.

Based on the foregoing, the Proposal is not expected to result in a significant change of the current background BLL of the Broken Hill north area. It is recommended that lead monitoring and bioavailability studies at receptors that represent the most exposed parts of the Broken Hill population. This data should then be used to refine the IEUBK modelling, making the outputs specific to the Proposal[3].

[3] Site specific soil, dust and bioavailability information would be required in order to use the model outputs for risk management purposes.

7. LIMITATIONS

The IEUBK modelling is not intended as a stand-alone risk assessment for BLLs in children. The outputs of the model as set up in this study are intended to apply to a hypothetical population of children between 6 months and 48 months of age. It is not appropriate to extrapolate the probability BLL outcomes to older persons or an individual or neighbourhood risks.

The quality of information generated by the IEUBK model is dependent on the quality of the input data and default values used. This desktop assessment relied on data available to PEL at the time of this assessment, supplemented by site-specific information. Where available, Australian default values were used to replace the North American values, in addition Broken Hill values were used where sufficient confidence in their source was found. This desktop study relied on third party verification of all input data. All input data and their source have been documented to provide the reader a better understanding of the model output and limitations in interpretation.

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APPENDICES

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Appendix A

IEUBK Model Input Data

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These tables highlight modified data Australian/NEPM values in grey and light blue for site specific data.

Parameter	units	age <	BH6	BH6 cumulative	LP26	LP26 cumulative	LP27	LP27 cumulative
1. AIR DATA								
Indoor air Pb Conc %	%	all	30	30	30	30	30	30
Outdoor air concentration (TSP annual average)	µg/m³	all	0.17	0.1734	0.1217	0.1251	0.2273	0.2308
Time spent outdoors	h/day	1	1	1	1	1	1	1
	h/day	2	2	2	2	2	2	2
	h/day	3	3	3	3	3	3	3
	h/day	4	4	4	4	4	4	4
	h/day	5	4	4	4	4	4	4
	h/day	6	4	4	4	4	4	4
	h/day	7	4	4	4	4	4	4
ventilation rate	m^3/day	1	5.7	5.7	5.7	5.7	5.7	5.7
	m^3/day	2	8.77	8.77	8.77	8.77	8.77	8.77
	m^3/day	3	9.76	9.76	9.76	9.76	9.76	9.76
	m^3/day	4	10.64	10.64	10.64	10.64	10.64	10.64
	m^3/day	5	11.4	11.4	11.4	11.4	11.4	11.4
	m^3/day	6	12.07	12.07	12.07	12.07	12.07	12.07
	m^3/day	7	12.25	12.25	12.25	12.25	12.25	12.25
Lung Absorption	%	all	32%	32%	32%	32%	32%	32%

2. DIET								
Dietary Pb intake	µg Pb/g	1	5.1	5.1	5.1	5.1	5.1	5.1
	µg Pb/g	2	5.8	5.8	5.8	5.8	5.8	5.8
	µg Pb/g	3	6.7	6.7	6.7	6.7	6.7	6.7
	µg Pb/g	4	3.2	3.2	3.2	3.2	3.2	3.2
	µg Pb/g	5	3.6	3.6	3.6	3.6	3.6	3.6
	µg Pb/g	6	4.1	4.1	4.1	4.1	4.1	4.1
	µg Pb/g	7	4.7	4.7	4.7	4.7	4.7	4.7
3. DRINKING WATER								
mean Pb water conc	µg/L	all	4.3	4.3	4.3	4.3	4.3	4.3
water intake	L/day	1	0.49	0.49	0.49	0.49	0.49	0.49
	L/day	2	0.308	0.308	0.308	0.308	0.308	0.308
	L/day	3	0.356	0.356	0.356	0.356	0.356	0.356
	L/day	4	0.417	0.417	0.417	0.417	0.417	0.417
	L/day	5	0.417	0.417	0.417	0.417	0.417	0.417
	L/day	6	0.417	0.417	0.417	0.417	0.417	0.417
	L/day	7	0.48	0.48	0.48	0.48	0.48	0.48
4. SOIL/DUST								
soil/dust ingestion weighting factor	%	x	50	50	50	50	50	50
outdoor soil Pb geo mean conc’	µg/g	x	**767**	**812.64**	**767**	**812.64**	**767**	**812.64**
Or Outdoor soil Pb (max conc.)	µg/g	x	**1011**	**1056.64**				
soil+dust ingestion	g/day	1	0.032	0.032	0.032	0.032	0.032	0.032
	g/day	2	0.1	0.1	0.1	0.1	0.1	0.1
	g/day	3	0.1	0.1	0.1	0.1	0.1	0.1
	g/day	4	0.1	0.1	0.1	0.1	0.1	0.1

	g/day	5	0.1	0.1	0.1	0.1	0.1	0.1
	g/day	6	0.1	0.1	0.1	0.1	0.1	0.1
	g/day	7	0.1	0.1	0.1	0.1	0.1	0.1
Soil/dust multiple source analysis								
contribution of soil lead to indoor household dust lead (Conversion Factor)			0.7	0.7	0.7	0.7	0.7	0.7
contribution of outdoor airborne lead to indoor household dust lead (Conversion Factor)			100	100	100	100	100	100
7. Bioavailability for all gut absorption pathways								
Bioavailability soil absorption	%		5	5	5	5	5	5
Bioavailability dust absorption	%		5	5	5	5	5	5
Diet	%		50	50	50	50	50	50
drinking water	%		50	50	50	50	50	50
alternate source	%		0	0	0	0	0	0
5. Maternal Data								
mothers blood lead conc at childbirth	µg/dL		1.3	1.3	1.3	1.3	1.3	1.3

Appendix B

IEUBK Model Output Data

(Total No. of pages including blank pages = 5)

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CALCULATED BLOOD LEAD AND LEAD UPTAKES: 1. BH6 background

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.102	2.425	0.000	1.002
1-2	0.171	2.740	0.000	0.626
2-3	0.206	3.179	0.000	0.726
3-4	0.241	1.544	0.000	0.865
4-5	0.258	1.744	0.000	0.869
5-6	0.274	1.991	0.000	0.871
6-7	0.278	2.283	0.000	1.003

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.005	4.533	2.5
1-2	3.120	6.657	2.8
2-3	3.134	7.245	2.7
3-4	3.187	5.838	2.2
4-5	3.199	6.070	2.0
5-6	3.207	6.341	1.9
6-7	3.208	6.772	1.9

****

CALCULATED BLOOD LEAD AND LEAD UPTAKES: 2. BH6 cumulative

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.104	2.423	0.000	1.001
1-2	0.174	2.736	0.000	0.625
2-3	0.210	3.175	0.000	0.725
3-4	0.246	1.543	0.000	0.864
4-5	0.264	1.742	0.000	0.868
5-6	0.279	1.989	0.000	0.870
6-7	0.283	2.281	0.000	1.002

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.063	4.592	2.5
1-2	3.299	6.834	2.8
2-3	3.314	7.425	2.7
3-4	3.371	6.024	2.3
4-5	3.384	6.258	2.1
5-6	3.393	6.530	2.0
6-7	3.395	6.961	1.9

****
CALCULATED BLOOD LEAD AND LEAD UPTAKES: 3. LP26 background
****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.073	2.425	0.000	1.002
1-2	0.122	2.740	0.000	0.626
2-3	0.147	3.179	0.000	0.726
3-4	0.173	1.544	0.000	0.865
4-5	0.185	1.744	0.000	0.869
5-6	0.196	1.991	0.000	0.871
6-7	0.199	2.283	0.000	1.003

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.001	4.501	2.5
1-2	3.109	6.597	2.7
2-3	3.123	7.176	2.7
3-4	3.176	5.758	2.2
4-5	3.188	5.985	2.0
5-6	3.195	6.252	1.9
6-7	3.197	6.682	1.9

****

CALCULATED BLOOD LEAD AND LEAD UPTAKES: 4. LP26 cumulative

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.075	2.423	0.000	1.001
1-2	0.126	2.736	0.000	0.625
2-3	0.151	3.175	0.000	0.725
3-4	0.177	1.543	0.000	0.864
4-5	0.190	1.742	0.000	0.868
5-6	0.201	1.989	0.000	0.870
6-7	0.204	2.281	0.000	1.002

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.060	4.559	2.5
1-2	3.288	6.775	2.8
2-3	3.303	7.355	2.7
3-4	3.360	5.945	2.2
4-5	3.373	6.173	2.0
5-6	3.381	6.441	2.0
6-7	3.383	6.871	1.9

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CALCULATED BLOOD LEAD AND LEAD UPTAKES: 5. LP27 background

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.136	2.425	0.000	1.002
1-2	0.229	2.740	0.000	0.626
2-3	0.275	3.179	0.000	0.726
3-4	0.322	1.544	0.000	0.865
4-5	0.345	1.744	0.000	0.868
5-6	0.366	1.991	0.000	0.871
6-7	0.371	2.283	0.000	1.003

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.009	4.572	2.5
1-2	3.133	6.727	2.8
2-3	3.147	7.327	2.7
3-4	3.201	5.933	2.2
4-5	3.213	6.170	2.0
5-6	3.220	6.447	2.0
6-7	3.222	6.879	1.9

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CALCULATED BLOOD LEAD AND LEAD UPTAKES: 6. LP27 cumulative

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.139	2.423	0.000	1.001
1-2	0.232	2.735	0.000	0.625
2-3	0.279	3.175	0.000	0.725
3-4	0.327	1.542	0.000	0.864
4-5	0.351	1.742	0.000	0.868
5-6	0.371	1.989	0.000	0.870
6-7	0.377	2.281	0.000	1.002

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.068	4.630	2.5
1-2	3.312	6.904	2.9
2-3	3.328	7.507	2.8
3-4	3.385	6.119	2.3
4-5	3.398	6.358	2.1
5-6	3.406	6.636	2.0
6-7	3.409	7.068	2.0

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CALCULATED BLOOD LEAD AND LEAD UPTAKES: 7. BH6 max background

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.102	2.416	0.000	0.998
1-2	0.171	2.718	0.000	0.621
2-3	0.206	3.157	0.000	0.721
3-4	0.241	1.535	0.000	0.860
4-5	0.258	1.735	0.000	0.864
5-6	0.274	1.981	0.000	0.866
6-7	0.278	2.273	0.000	0.998

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.316	4.833	2.6
1-2	4.066	7.576	3.1
2-3	4.089	8.173	3.0
3-4	4.163	6.799	2.5
4-5	4.181	7.038	2.3
5-6	4.194	7.315	2.2
6-7	4.197	7.747	2.2

****

CALCULATED BLOOD LEAD AND LEAD UPTAKES: 8. BH6 max cumulative

****

Year	Air (µg/day)	Diet (µg/day)	Alternate (µg/day)	Water (µg/day)
.5-1	0.104	2.415	0.000	0.998
1-2	0.174	2.714	0.000	0.620
2-3	0.210	3.153	0.000	0.720
3-4	0.246	1.533	0.000	0.859
4-5	0.264	1.733	0.000	0.863
5-6	0.279	1.979	0.000	0.866
6-7	0.283	2.271	0.000	0.997

Year	Soil+Dust (µg/day)	Total (µg/day)	Blood (µg/dL)
.5-1	1.374	4.891	2.7
1-2	4.243	7.750	3.2
2-3	4.267	8.351	3.1
3-4	4.345	6.983	2.6
4-5	4.365	7.224	2.4
5-6	4.378	7.502	2.3
6-7	4.382	7.934	2.2

Appendix C
Boreland et al 2002, study

(Total No. of pages including blank pages = 5)

Lead dust in Broken Hill homes – a potential hazard for young children?

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Abstract

Objective: To determine the potential hazard posed by indoor lead dust to young children in Broken Hill, a silver-lead-zinc mining town in outback Australia, and the degree to which lead flux is influenced by factors such as geographical location, house construction type and condition.

Methods: 116 homes were selected and 93 (80%) studied from 10 localities in Broken Hill during the spring of 1995. Lead flux was measured using 85 mm diameter polystyrene petri dishes. Dishes were placed in four rooms of each house to collect dust over a six-to-eight-week period. Data on the location, condition and construction type of each house were recorded. Multiple linear regression was used to determine predictors of lead flux. Flux data were log transformed for the analysis.

Results: Average household lead flux varied nearly seven-fold across districts from a low of 166 (distant from the mines), to a high of 1,104 μg/m²/30-day period (adjacent to the mines). Houses that were 'adequately sealed' had 2.9 times the lead flux, and 'poorly sealed' houses 4.3 times the flux, of 'very well sealed' houses. Construction material did not significantly affect these flux levels, and no statistically significant interactions were found between house condition and location or house type.

Conclusions: Many Broken Hill homes have high levels of lead flux that pose a potential risk to young children. Quantification of this hazard provides useful information for the community that can help focus efforts on actions required to minimise lead dust in the home.

Implications: Household dust is a potential source of lead for young children in at-risk communities. Information on lead flux in homes can assist these communities and public health agencies to better understand and deal more effectively with the problem.

(Aust N Z J Public Health 2002; 26: 203-7)

In 1991, a blood-lead survey of preschool-aged children in Broken Hill found that one in five children had a blood-lead level in excess of 25 μg/dL, the then National Health and Medical Research Council (NHMRC) level of concern.[1] A major public health program has since been implemented to deal with the lead problem.[2] This program has been based on an understanding of the sources and pathways by which children are exposed to lead in this community.

In Broken Hill, isotope studies indicate that much of the lead in both children's blood and house dust originated from the local ore body.[3] The ore body has been mined since 1883, with smelting on site until 1898.[4] Lead is spread throughout the city; the semi-arid climate and paucity of vegetation exacerbate dispersal of lead by wind and water erosion.

House dust is a potential source of lead for children; behaviour-related ingestion of contaminated dust is thought to be the primary route of exposure.[5-7] Lead levels in house dust are related to numerous factors, including lead levels in soil and paint, proximity to sources of contamination, and house repair and construction type.[5,8,9]

Although Broken Hill homes encompass a wide range of construction materials and building repair, the majority are 50-100 years old and built of wood and corrugated iron, or stone. Large amounts of fine lead-bearing dust is trapped in the wall and ceiling cavities of older homes, and can migrate into the living space through poorly sealed cornice and wall joints. It was unclear what hazard this posed to young children in Broken Hill.

This paper reports a study that aimed to determine the potential hazard caused by indoor dust and the degree to which indoor lead flux (the amount of lead falling on a surface over a given time period, measured as μg lead/m²/30 days) is influenced by factors such as geographical location, house construction type and house condition.

Methods

Study population

Broken Hill was divided into 10 districts according to soil lead level and proximity to the mining lease (see Figure 1), based on a soil lead survey undertaken by Broken Hill City Council in 1992. One sample of the top

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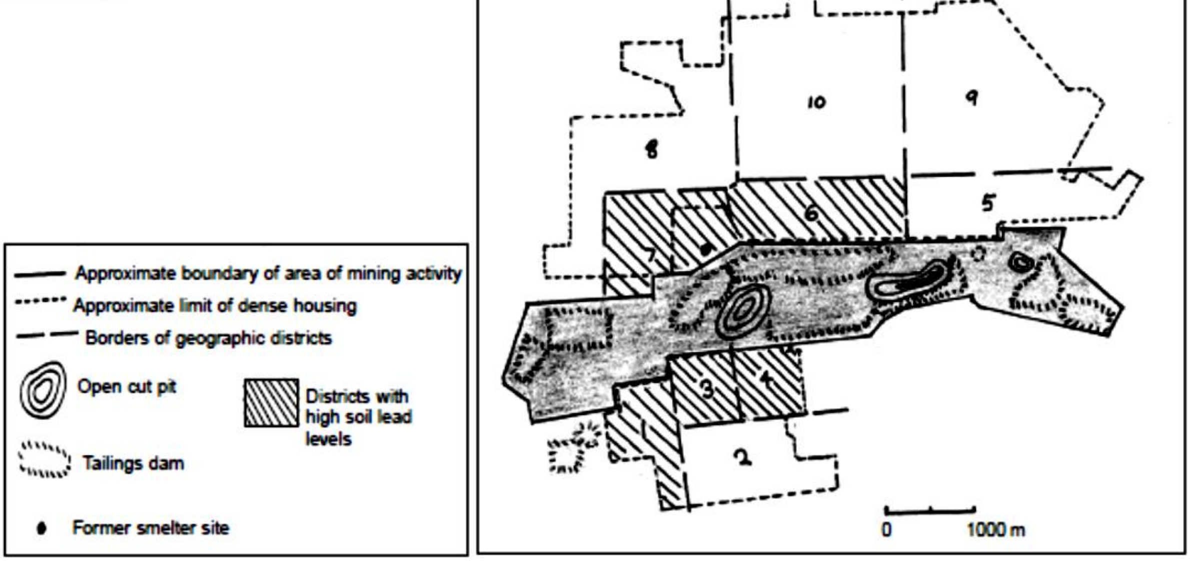
Figure 1: Map of Broken Hill showing district boundaries and other relevant information.



10 centimetres of natural soil was collected from each city block. Samples were collected from undisturbed vacant land (54%); where this was not possible, samples were collected from nature-strips. Geometric mean soil lead concentration was calculated for each district, and districts ordered from highest to lowest according to mean lead concentration. Districts were rank ordered then divided into two groups about the median value: that is those districts with high (mean soil lead level 1,220 µg/g, range 708-2,305 µg/g), or lower (mean soil lead level 361 µg/g, range 245-521 µg/g) concentrations (see Table 1).

The study was conducted between September-November 1995. Homes were purposively chosen to provide a consistent mix of house type and condition sampled across each district, and to ensure that a significant proportion contained preschool-aged children so that the relationship between blood lead level and lead flux could be tested.

Initially, 150 of 310 families with children who were due for an annual blood lead test in November were sent invitations to join the study. Families were chosen sequentially from a list ordered by family number (a unique identifier assigned the first time a child receives a blood lead test), without reference to the child's blood lead level or the house type and condition. This process was continued until 15 families had been chosen for each district. Sixty-one of the 150 families agreed to participate in the study. We then reviewed the type and condition of each of these homes, and recruited another 55 homes from the general community selected specifically to achieve an even mix of house type and condition within each district.

Sampling

Lead flux was measured using 85 mm diameter polystyrene petri dishes, based on the method developed by Gulson et al. 1995.[10]

Four petri dishes were placed in each home, one in each of the four rooms most used by children. If no children lived in the home, dishes were placed in the four most used rooms. Dishes were placed between 0.5 and 2.5 metres above floor level (average height 1.79 m) where they would not be disturbed or obstructed from dust fall, and secured in place with 'Blutak' (plasticine).

Identification number, location, height above floor level, quality of room seal and house construction material were recorded for each dish. In a minority of houses where more than one type of construction material was used, the primary material was recorded. Rooms were considered very well sealed if there were no cracks along the cornices, wall joins, around windows, etc; as adequately sealed if minor cracks were present; and as poorly sealed if there were large cracks along cornices or walls, or where the room had louvre windows. This assessment was carried out by one of us (FB), and was made prior to measuring lead flux or the children's blood lead levels.

Dishes were placed from the end of September 1995 to the first week of November 1995 and exposed for around six weeks. At collection, residents were asked whether any unusual dust generating activity had occurred during dish exposure, or if the dishes had been disturbed. During the study period there were two days of high wind and visible dust.

Collected dishes were sealed into individual air tight plastic bags and taken to Royal Newcastle Hospital Biochemistry for analysis. Lead content was assayed in accordance with Australian standards (ISO/DIS 9855). This procedure is based on nitric/hydrochloric acid digestion and final determination by graphite atomic absorption spectrometry.

Lead content was reported as loading (µg/m^2), which was then converted to flux (µg/m^2/30 day period). Flux was standardised to a 30-day period; e.g. if the dish was exposed for 60 days,

Table 1: Soil lead levels (1992 Broken Hill City Council survey), lead flux and house condition by district.

	District by location code										
	1	2	3	4	5	6	7	8	9	10	Total
Soil lead concentration (µg/g)											
Geometric mean	866	509	1454	2305	521	767	708	261	245	271	–
95% CI	684-1,098	435-597	1,136-1,861	1,642-3,235	435-624	581-1011	508-986	229-298	204-295	238-309	–
	n=17	n=31	n=11	n=21	n=24	n=20	n=13	n=31	n=27	n=51	
Lead flux/house (µg/m²/30 days)											
Mean	1,180	315	1,129	1,795	396	1,012	1,008	764	216	284	865
SE	397	67	309	523	106	292	315	405	66	45	117
Min-max	165-4,883	62-650	119-2,666	158-6,640	129-981	117-2,158	179-2,474	0.7-4,244	77-601	33-528	0.7-6,640
Geometric mean	784	256	758	1,104	330	727	643	185	166	234	442
95% CI	452-1,361	159-411	382-1,501	614-1,983	206-529	350-1,510	327-1,263	42-814	100-276	143-382	340-576
	n=11	n=9	n=9	n=13	n=7	n=7	n=9	n=10	n=8	n=10	n=93
House condition											
% adequately sealed	27	67	44	31	43	43	22	10	50	40	37
% poorly sealed	27	0	22	46	43	29	22	40	0	20	26

standardised flux was calculated at half of that measured. Results were not standardised for height, as linear regression indicated no significant relationship between log(flux) and height (p=0.12, R^2=0.007). Average height of dish placement was 1.79 m. Results are reported as µg lead/m²/30-day period.

Statistical analysis

Twenty-two homes were excluded from analysis because residents reported unusual dust generating events during dish exposure (renovation, excavation, etc). A further home was excluded because three of the four dishes placed were disturbed or not retrieved. Thus, of 116 homes initially sampled, data from 93 (80%) were included in the analysis. Four valid dishes were retrieved from 77 (83%) of the homes. Three valid dishes were retrieved from each of the remaining 16 homes (four dishes were not retrieved, 11 had been tipped over or covered during the sampling period, and one was excluded after graphical review showed it to be an extreme outlier).

Lead flux values were positively skewed and so were $\log_{10}$-transformed before analysis. Mean $\log_{10}$ values were transformed back to the original scale to give geometric means.

To assess the effect of house condition on lead flux it was necessary to summarise overall house condition, as the adequacy of seal varied between rooms in 52% of homes, with 16% having rooms across the range from 'very well' to 'poorly sealed'. This summary was developed as follows. First, the overall geometric mean lead flux was calculated for each 'room seal' category, using all valid dishes for that category. Next, we used these means to calculate a hazard ratio for each level of seal, using 'very well sealed' rooms as the referent group. Then, we estimated for each house a hazard score by summing the hazard ratios for each of the four rooms sampled. The hazard scores ranged between 4 and 17.6 and were categorised into three groups: 'very well sealed' (4-5.3); 'adequately sealed' (5.4-11.3); or 'poorly sealed' (11.4-17.6) houses.

Multiple linear regression was used to investigate the effect of house condition and construction type on lead flux after controlling for locality. Household lead flux levels were estimated by calculating the arithmetic mean of the standardised flux found in each of the rooms sampled. These values were then $\log_{10}$ transformed. Simple linear regression was also used in an ecological analysis to describe the relationship between average soil lead level and average indoor lead flux for each district. Statistical analysis was undertaken using Microsoft Excel 97 and SAS System for Windows v6.12.

Results

Average household lead flux varied nearly seven-fold across districts from a low of 166, to a high of 1,104 µg/m²/30-day period (see Tables 1 and 2). The higher the average soil lead level found in a district, the higher the mean indoor lead flux (R^2=0.80, p=0.0004) (see Figure 2).

Houses in districts with high soil lead concentrations had indoor lead flux levels three times higher than houses from districts with lower soil lead levels (see Table 3). House condition was correlated with indoor lead flux (see Tables 2 and 3). The lowest levels were observed in 'very well sealed' houses. The 'adequately sealed' houses had 2.9 times the lead flux, and 'poorly sealed' houses 4.3 times, of 'very well sealed' houses. Construction material did not further affect the flux levels, and no statistically significant interactions were found between house condition and location, or house type.

Discussion

This study gives a clear picture of the distribution and determinants of lead flux in Broken Hill homes and its potential importance as a hazard to young children.

Not surprisingly, we found a sizeable variation in lead flux based on location and condition of homes. Houses close to the mine lease and in poor condition had lead flux levels nearly 13 times higher than 'very well sealed' houses further away. Interestingly,

Table 2: Effect of quality of sealing on observed geometric mean lead flux per house (µg/m²/30 days) in districts with high or lower soil lead concentration in Broken Hill.

Quality of house seal	Districts with lower soil lead concentrations				Districts with high soil lead concentrations			
	n	GM mean	95% CI of GM	Hazard ratio	n	GM mean	95% CI of GM	Hazard ratio
Very well	17	112	54–233	1.0	18	338	239–479	1.0
Adequate	18	252	194–329	2.3	16	1,278	930–1,758	3.8
Poor	9	655	347–1,236	5.8	15	1,442	948–2,194	4.3
Total	44	224	154–327		49	814	616–1,076	

house construction material was relatively unimportant, once the house condition and location were taken into account. These findings are consistent with earlier studies of indoor lead dust from Broken Hill and elsewhere.[9,10]

On closer inspection, the flux levels appear to be influenced by specific past mining and related activities in addition to proximity to the mine lease. Districts adjacent to the mine and down-wind of specific lead sources had the highest flux and soil lead concentrations. One district downwind of and close to the former open cut mine had approximately double the soil lead concentrations and lead flux of an adjacent district, which was close to but upwind of the open cut. Districts close to and downwind of a small tailings dam and the former smelter also had high soil lead levels.

The observation that specific districts in Broken Hill pose a greater hazard with regard to lead has implications for families with young children living or visiting there. However, the data suggest that efforts to maintain a house in those districts in very good condition can offer benefits by keeping the indoor lead flux down to less than one-quarter of that in 'poorly sealed' houses, a level that is more reflective of that recorded in adequately sealed houses away from the mine lease.

These findings confirm that only small amounts of lead and dust enter from the ceiling and wall cavities into the living space of 'very well sealed' homes. This occurs even when large amounts of fine lead-bearing dust are trapped in the building cavities of the older homes close to the mines, and can be contrasted with the large amounts of dust entering 'poorly sealed' homes.

While community-based data on lead flux are limited, information from Newcastle, a large urban centre in Australia, and nearby North Lake Macquarie, where the country's second-largest lead smelter is located, provides a useful point of comparison.[8] It indicates that the Broken Hill experience is not unique.

Table 3: Results of multiple regression on factors affecting household lead flux in Broken Hill.

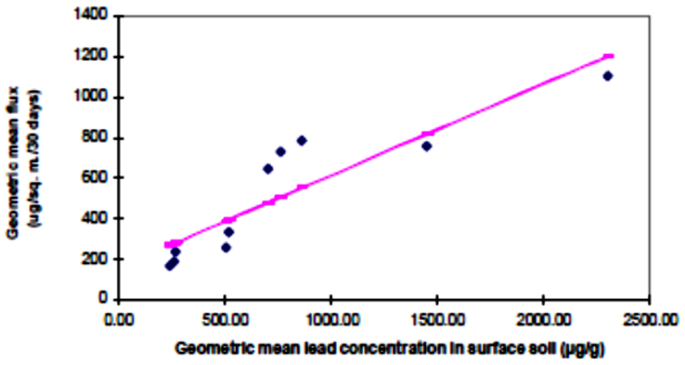
Factor	Ratio measure	95% CIs	*p*
Location			
Low soil lead	1		
High soil lead	3.4	2.26–5.01	.0422
House seal			
Very well	1		
Adequate	2.9	1.81–4.51	.0386
Poor	4.3	2.41–7.66	.0029
House type			
Corrugated iron	1		
Brick	0.9	0.50–1.72	.2966
Stone	0.9	0.44–1.82	.1789
Other	0.8	0.46–1.29	.5953

Note:
For all factors combined, $R^2 = 0.5$, $p<0.0001$

The Newcastle data support our finding that well maintained Broken Hill homes (with 'very well or adequately sealed' ceilings) in the least affected districts, away from the mine lease, have flux levels similar to houses in a large urban centre that does not have a major environmental lead problem (see Table 4). Furthermore, the very high levels of flux in Broken Hill homes in areas adjacent to the mine lease are similar to those found in homes from the high risk zone adjacent to the Boolaroo lead smelter at North Lake Macquarie.

Consideration of potential sources of bias in the study is warranted. Selection bias was possible due to the refusal of some

Figure 2: Relationship between mean indoor lead flux and soil lead concentrations by district in Broken Hill, 1995.



families to participate in the study and the exclusion of study homes that reported disturbances. While it was difficult to determine the likely impact of these issues, we were able to examine the effect of excluding homes that reported disturbance. The 22 excluded homes were distributed between districts with high and lower soil lead levels (41% and 59% respectively) and very well, adequately and poorly sealed homes (30%, 48% and 22% respectively) consistent with the ratio of study houses in each of those groups. However, 80% of the disturbances in high soil lead areas were classed as major (e.g. replacement of wall and ceiling linings) compared with 33% in areas with lower soil lead level. Homes reporting 'major' disturbances were much more likely to have average flux exceeding the upper 95% confidence interval for their location and condition class than were homes reporting minor disturbances (58% cv 20%), either reflecting the additive effect of the major disturbance or an underlying high level. Thus, the net effect of excluding these homes would be to avoid a potential over-estimate of the difference in flux between areas of high and lower soil lead levels.

We were also limited due to our recruitment strategy and sample size, to report estimates of lead flux in 'very well', 'adequately' and 'poorly' sealed homes in broadly defined regions, rather than individual districts. The estimate of average lead flux obtained for individual districts may not be accurate, as varying proportions of very well, adequate and poorly sealed homes were sampled from each district and the actual proportion of homes in each condition class by district is not known.

Furthermore, the impact of other potential influences on indoor lead flux such as the amount of time windows and external doors were open were not considered in this investigation and would be worthwhile including in a future study.

Contaminated house dust is a potential source of lead uptake by children via ingestion or inhalation.[5-7,11,12] This study indicates that in many, but not all, Broken Hill homes high levels of lead flux constitutes a significant potential hazard for young children.

Quantification of this hazard, both in terms of the amount of lead flux predicted for houses based on their condition and locality, and relative measures such as hazard ratios provide useful information for the community that can help focus efforts on actions required to minimise lead dust in the home. Children living in homes near the mines will continue to be exposed to higher levels of indoor lead dust, although these levels would be significantly lower if the home is 'very well sealed'. These data will also help inform decisions about the role of interventions aimed at improving the quality of ceilings and walls and help set realistic targets for reductions in lead flux when such a course of action is taken. The study also provides a valuable reference point from which to measure temporal trends in lead flux in Broken Hill homes as mining practices and activities change and the quality of the housing stock changes both in response to, and independent of, a concern about lead.

In conclusion, this study has quantified the extent to which household dust is a potential source of lead for young children in Broken Hill. Through access to information on lead flux in their homes, the community is now in a position to better understand and deal more effectively with this component of the lead problem.

Table 4: Comparison of lead flux (arithmetic means) in Broken Hill homes with Newcastle and North Lake Macquarie.

Broken Hill (µg/m²/30 days)		Other locations[a] (µg/m²/4 weeks)	
Least affected areas		Newcastle	
Overall	405	Overall	237
Very well sealed	193		
Adequately sealed	294		
Poorly sealed	1,026		
Most affected areas		North Lake Macquarie	
Overall	1,278	Overall	1,148
Very well sealed	444		
Adequately sealed	1,570		
Poorly sealed	1,969		

Notes:
(a) Data from Wlodarczyk et al. 1997.[9]

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