NSW GOVERNMENT | Chief Scientist & Engineer

Reducing the health and environmental impacts of lead contamination in Broken Hill.

January 2026

Acknowledgement of Country

The Office of the NSW Chief Scientist & Engineer acknowledges the Traditional Custodians of the lands where we work and live. We celebrate the diversity of Aboriginal peoples and their ongoing cultures and connections to the lands and waters of NSW.

We pay our respects to Elders past, present and emerging and acknowledge the Aboriginal and Torres Strait Islander people that contributed to the development of this Report.

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Reducing the health and environmental impacts of lead contamination in Broken Hill – Preliminary Report

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Mr Simon Draper PSM
Secretary, Premier's Department
52 Martin Place
SYDNEY NSW 2000

28th January 2026

Dear Mr Draper,

In July 2025, the then acting Secretary, Premier's Department asked that I provide advice on **minimising the human and environmental impacts of lead contamination in Broken Hill.**

A long history of lead mining in Broken Hill has left a legacy of widespread contamination and human exposure. While some progress has been made in reducing environmental lead levels and community exposure, improvements have slowed in recent years. Aboriginal children remain disproportionately affected, with comparatively higher exposure risks.

In preparing this preliminary advice, the Office of the NSW Chief Scientist & Engineer (OCSE) Reviews and Committees team, led by Dr Darren Saunders (Deputy NSW Chief Scientist & Engineer), relied primarily on stakeholder consultation and desktop research. OCSE engaged with stakeholders from government, industry, allied health groups, and community organisations and also visited Broken Hill to gain a firsthand understanding of the issue and discuss concerns directly with local stakeholders.

In short, we found that a centralised, coordinated approach deploying timely, evidence-based decision making is required to reduce BLL in the children of Broken Hill. This includes integrated, whole-of-system data, ongoing expert guidance and a robust and transparent MERI framework to be implemented. An improved focus on environment lead mitigation through targeted zonal remediation that uses best available information on lead exposure sites is required and a greater focus on public health is required and that this ultimately is treated as a 'public health issue'.

Many of the issues highlighted in this report have been documented in prior studies and reports. However, previous recommendations remain unimplemented, and new data and insights have emerged. The purpose of this report is not to delay progress but to realign current efforts toward minimising community exposure to lead, particularly in children.

Addressing elevated blood lead levels of children in Broken Hill is an urgent public health priority. The development window from birth to 5 years old is critical and delays in effective intervention risks irreversible impairment and potential lifelong complications to successive generations.

Finally, I thank the Reviews and Committees team within OCSE for their dedication and hard work in bringing this report together.

Yours sincerely

H. Durrant-Whyte.

Professor Hugh Durrant-Whyte
NSW Chief Scientist & Engineer

Contents

Acronyms

AAQ	Ambient Air Quality
AQC	Air Quality Control
ARTC	Australian Rail Track Corporation
ASC	Assessment of Site Contamination
BHCC	Broken Hill City Council
BHELP	Broken Hill Environmental Lead Program
BHELRG	Broken Hill Environmental Lead Response Group
BHELS	Broken Hill Environmental Lead Study
BHM	Broken Hill Mines Limited
BHP	Broken Hill Proprietary Company
BHUDRH	Broken Hill University Department of Rural Health
BLL	Blood Lead Level
CBH	CBH Resources Ltd
CFH	Child and Family Health
CSE	NSW Chief Scientist & Engineer
DDG	Dust Deposition Gauge
DPC	Department of Premier and Cabinet (NSW)
D-HVAS	Directional High-Volume Air Samplers
EIP	Environmental Improvement Plan
EPA Tasmania	Environment Protection Authority Tasmania
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
EPL	Environment Protection Licence
FWLHD	Far West Local Health District
HIL	Health Investigation Limit
HVAS	High-Volume Air Samplers
IEUBK	Integrated Exposure Uptake Biokinetic
LiA	Lead-In-Air
LiDAR	Light Detection and Ranging
MERI	Monitoring, Evaluation, Reporting and Improvement
MMHAC	Maari Ma Health Aboriginal Corporation
MoU	Memorandum of Understanding
NAAQ	National Air Ambient Quality
NEPC	National Environment Protection Council

NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NPI	National Pollutant Inventory
NPWS	National Parks and Wildlife Service
NSW EPA	NSW Environment Protection Authority
OCSE	Office of the NSW Chief Scientist and Engineer
OEH	Office of Environment and Heritage
PM	Particulate Matter
POEO	*Protection of the Environment Operations Act 1997* (NSW)
RSL	Regional Screening Level
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SA EPA	SA Environment Protection Authority
TDP	Total Deposited Particulates
TGC	Total Ground Control
THEP	Trail Area Health and Environment Program
TLAP	Targeted Lead Abatement Program
TSF	Tailings Storage Facility
TSP	Total Suspended Particulates
US EPA	US Environmental Protection Agency
XACT	X-ray-induced Acoustic Computed Tomography
XRF	X-ray Fluorescence

Executive summary

In July 2025, the then Acting Secretary of the Premier's Department requested the Office of the NSW Chief Scientist & Engineer (OCSE) to provide independent expert advice on the human and environmental impacts of lead contamination at Broken Hill. This Report builds on the work of Taylor, Isley, Lyle, et al. (2019, updated 2022) and provides the most up-to-date information and evidence on the ongoing impacts of environmental lead to human health, particularly in children, and methods to minimise community exposure. Working with the Premier's Department as Chair of the Broken Hill Environment Lead Response Group (BHELRG), OCSE refined a preliminary workplan into the first phase of a broader review for the Government's consideration. Many of the issues highlighted in this report have been documented in prior studies and reports. However, previous recommendations remain unimplemented, and new data and insights have emerged. The purpose of this report is not to delay progress but to realign current efforts toward minimising community exposure to lead, particularly in children.

Through stakeholder consultation and research, OCSE has collated existing data, identified current programs and knowledge gaps, reviewed national and international approaches, and provided preliminary findings and recommendations for managing lead contamination and improving community health. This Report was delivered under tight time constraints, and as such should be considered as a preliminary review that presents a series of findings and recommendations, many of which inform more extensive future evaluation. Where relevant, the Report identified significant data or knowledge gaps that should be filled prior to making additional decisions.

There is no safe level of lead in blood. Lead exposure early in life poses long-term health risks through neurodevelopmental, cardiovascular, renal and other effects, with lifelong cognitive and behavioural consequences. These effects are observed even at moderate exposure levels, such as those measured in many children in Broken Hill.

A long-term commitment to the Broken Hill Environmental Lead Program (BHELP) or similar program is critical to enable key partners/stakeholders in government and the community to implement actions to achieve long-term, multi-generational reduction in lead exposure across Broken Hill, particularly for children. Adequate and long-term commitment to resourcing the program will underpin continuity of results and is critical to achieving long-term change. This includes effective monitoring and outcome reporting.

An effective Monitoring, Evaluation, Reporting and Improvement (MERI) framework is critical for successful program implementation and progress towards program goals. A MERI framework that promotes adaptive management in response to progressive monitoring and evaluation should be an integral part of program implementation. This includes the development of meaningful evaluation metrics and the provision of easily accessible data, e.g. metrics that focus on measuring outcomes rather than tracking activities.

The MERI framework should be supported by the adoption of an open-data framework alongside a communication plan on what information is collected and why. This will ensure greater government transparency, giving stakeholders and the community a clear appreciation of the progress towards outcomes. Ongoing Expert Panel input will further contribute to the continual improvement of programs related to reducing blood lead level (BLL) of children in Broken Hill.

Addressing the impacts of lead in Broken Hill requires a public health-centric response, with the aim of minimising exposure to lead in those most susceptible (i.e. children aged 5 or less) while supporting people that may be at high risk of lead exposure. Targeted remediation and emissions control measures to minimise dispersion and lower environmental exposure should be implemented alongside public health initiatives that support community members in understanding risk and taking steps to minimise their exposure. Coordinated program design and evaluation should consider significant equity challenges in Broken Hill.

OCSE has provided the following preliminary recommendations for consideration in implementing actions and programs to mitigate environmental lead contamination and exposure in Broken Hill. These recommendations are presented in no order of importance, but some indication of timeframe/priority is flagged where appropriate.

Findings

Lead contamination in Broken Hill

- There is no safe level of lead in blood. Lead exposure early in life poses long-term health risks through neurodevelopmental, cardiovascular, renal and other effects, with lifelong cognitive and behavioural consequences.
- Early childhood (from birth to five years) represents a critical developmental window. Delays in effective intervention risk irreparable impairment and potential lifelong complications to entire generations of children residing in Broken Hill.
- Redistribution of environmental lead contamination from legacy mining practices may be a key contributing factor to elevated BLL in children.
- A complex set of community attitudes to the health, economic, social, cultural and heritage implications of environmental lead exist in Broken Hill.
- Current interventions to mitigate lead contamination are not always focused on human health outcomes.

BHELP: Lead management programs

- Coordination of different aspects of lead management appears fragmented, without a standardised program logic, evaluation framework or data repository for all lead programs in Broken Hill. Evaluation metrics are not consistent and often focus on tracking activity relating to program delivery, as opposed to measuring outcomes or program efficacy.
- Marginal reductions in the mean BLL over time have slowed in recent years. Reliance on reporting the geometric mean of BLL may mask more subtle but important information about BLL distributions and specific subpopulations.
- Inherent equity issues within the community present ongoing challenges in exposure risk, program delivery and effectiveness. Aboriginal children continue to present with a higher mean BLL than those of non-Aboriginal children.
- There is a clear relationship between annual geomean BLL and mean lead dust deposition rates in Broken Hill. However, the relationship between individual BLL and lead in dust and soil at place of residence is not clear, suggesting that household exposure is not the only driver of elevated BLL.
- Evidence supporting the effectiveness of home remediation for lowering BLL in Broken Hill or other locations with environmental lead contamination is limited. There is no formal evaluation process or centralised collection of data to evaluate effectiveness.
- Accessibility to home remediation by the NSW Government is limited by the current allocation of funds. Priority is currently given to those with high BLL.
- International limits for lead in soil may not be applicable to Broken Hill due to differences in bioavailability and other factors used in the Integrated Exposure Uptake Biokinetic (IEUBK) model. A site-specific target lead-in-soil level in Broken Hill might be appropriate.
- Until further information is available, the current National Environmental Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM) Health Investigation Limits (HILs) are appropriate for managing soils at Broken Hill.
- There is a potential role of stormwater in migration or dispersion of lead in soils from known contaminated sites at legacy mining areas and the railway corridor.
- Epidemiological evidence suggests that underlying nutritional deficiencies (particularly iron) are associated with elevated BLL. The evidence for nutritional interventions in children without deficiencies remains anecdotal.

Lead emissions and dispersion

- Lead in air and dust depositions is being monitored and managed at both mining sites and at community level. The current mine operators, Perilya and Broken Hill Mines, are required to have emissions controls in place, monitor emissions, and report results publicly.

- Preliminary analysis of emissions by OCSE suggests that the average lead air emissions from operations are below the Environment Protection Licence (EPL) limits but lead in deposited dust levels are above the limit recommended by Taylor, Isley, Lyle, et al. (2019, updated 2022)
- It is difficult to determine the relative contribution to lead emissions from legacy and current mining activities. However, some studies suggest that lead in air concentrations are higher when the wind direction originates from areas used predominantly for mining than from non-mining areas (i.e. communities and residential).
- Lead in air levels are consistently below the AAQ NEPM limit, however both mines frequently report values above the more stringent US Environmental Protection Agency's (US EPA's) National Air Ambient Quality (NAAQ) standard. Airborne lead in Broken Hill falls below the AAQ NEPM, however levels remain significant and warrant intervention measures.
- Considering a number of inherent monitoring limitations and assumptions, the AAQ NEPM may not be the appropriate regulatory mechanism to monitor and control lead levels in Broken Hill. Analysis of other complementary data is required (i.e. lead in deposited dust, particulate matter and meteorological data).
- Lead in air high-volume air sampler (HVAS) monitoring may be systematically underestimating community lead exposure due to decreased sampling efficiency at higher particle sizes. Lead in deposited dust measurements can meet this gap as it better reflects lead exposure through ingestion. However, the monthly sampling period limits timely action and response.

Recommendations

Recommendation 1: Coordination, data and program evaluation

The NSW Government, alongside key partners and stakeholders, should implement these recommendations as the future lead program to address lead contamination and exposure in Broken Hill. This should include establishing a centralised resource in Broken Hill to act as the responsible entity for coordinating activities and communication to enable timely, transparent and evidence-based decision making.

a. Ensure individual **recommendations are not considered in isolation**; progress those that can be advanced immediately, while gathering further information to inform others.
b. The centralised resource should be supported by **ongoing Expert Panel guidance,** independent of the BHELRG and the future lead program, to provide evidence-based guidance that informs decision-making on a continuous basis.
c. Establish an integrated, transparent and whole-of-system approach to **data and information collection storage and analysis** to support timely, evidence-based decision-making and strengthen community trust.
d. Develop a **Program Logic** for the future lead program that includes clear outcomes and targets to reduce lead in the environment.
e. Design and implement a robust, effective and transparent **MERI framework** that facilitates adaptive management of the future lead program, reflects the Program Logic and measures progress towards outcomes.
f. Use **technology** to better understand lead contamination across Broken Hill. Mapping of lead across Broken Hill to assist in targeted remediation works and using sensors and associated technologies to provide real-time monitoring of lead in air and dust levels would support timely, informed decision-making.
g. Align to **other government funding** and leverage existing strategic initiatives to efficiently advance the objectives of the future lead program.

Recommendation 2: Public health initiatives

Strengthen the public health response to lead exposure through a more comprehensive education and access program, supported by an approach that considers all relevant risks

a. Continue the current blood testing program**,** ensuring that there is consistent screening of age groups, consistent data collection, and a **standardised/structured statistical analysis approach** that seeks to understand trends in BLL data and potential links to causal environmental factors.
b. Link zonal remediation data and a risk-based approach to remediation to inform and enhance a **targeted approach for additional BLL screening of at-risk children**. Data can be used to identify others at high risk of lead exposure, for example siblings of children with high BLL or newborns in affected homes and develop consistent 'trigger criteria' for screening of children outside of the standard screening age group.
c. Strengthen the **community reach program** and revamp initial BHELP programs that identified lead exposure as a public health concern, such as hand washing and Lead Ted.
d. Promote **nutritional knowledge** on lead and diet across the community and improve access to health foods by continuing to incorporate nutrition messages in the LeadSmart program and establish community programs to assist access.

Recommendation 3: Remediation

Continue to manage lead in soil through the development of a co-ordinated and strategic remediation program.

a. Pivot to a **zonal remediation program** that utilises the best available information on lead exposure sites across Broken Hill. This should include:
    - developing a high-resolution geospatial map of lead exposure across Broken Hill based on existing data including BLL and lead in soil.
    - identifying high-risk areas where BLL exceed 5 µg/dL and with soil values above 300 mg/kg. Values are based on current criteria and should be revised by an Expert Panel.
    - within high-risk areas, prioritising places and premises where children aged 5 or less are likely to be present, as well as other high-risk groups (e.g. families expecting newborns or Aboriginal families).
    - developing and implementing a zonal remediation program (based on previous remediation programs) focused on mitigating lead in high-risk areas, places and premises.

b. Develop **evaluation measures and timeframes** for remediation activities to assess effectiveness. This should include both health and environmental monitoring and should be coordinated across the different groups in Broken Hill.

c. Undertake further work to **better understand dispersion of lead** across Broken Hill including investigation into potential stormwater pathways and strategies to minimise runoff and dispersion of lead from key areas (e.g. the railway corridor).

d. Develop a **strategy that considers heritage value** while meeting human health outcomes.

e. **Engage experts** to explore site-specific investigation criteria and remediation strategies for Broken Hill. Experts should consider whether targeting a lead-in-soil concentration after remediation of <150 mg/kg can meet health outcomes.

Recommendation 4: Emissions control

Continue efforts to reduce emissions (lead in air and lead in deposited dust) from mining operations and at the community level.

a. Continue efforts to reduce lead and dust emissions from mining operations by **implementing a continuous improvement approach** informed by monitoring data and trigger levels for response. If new targets are introduced, identify and address major contributors, and explore technologies or processes that can assist in meeting these targets. Further investigation, guided by an Expert Panel, is needed to determine specific criteria appropriate to the unique conditions in Broken Hill.

b. **Assess how monitoring results can inform remediation programs**, including evaluation. For all air and dust monitoring, ensure there is a clear understanding of the method utilised, its limitations and interpretation.

c. Incorporate **dust dispersion management** strategies, such as revegetation and street sweepers into remediation and dust mitigation activities for places and premises.

d. Understand the **limitations of current AAQ NEPM standards and monitoring** techniques to ensure risk of lead exposure is interpreted appropriately and informs further action. Inclusion of other complementary data (e.g. lead in deposited dust, particulate matter and meteorological data) may assist responses to minimise lead exposure.

1. Lead Contamination in Broken Hill

1.1 Introduction

Broken Hill, located in far-western NSW, has a prominent place in the mining, industrial relations and economic history of Australia, with mining continuing to be a primary driver of economic and social outcomes for the community. Broken Hill sits on one of the world's largest lead, zinc and silver ore deposits, with extensive lead contamination present in the town's environment from both natural sources and extensive mining and processing operations over more than a century. As such, the population of Broken Hill is subject to significant lead exposure in various contexts. This exposure is reflected in elevated blood lead levels (BLL) in the Broken Hill community, particularly among children (WNSWLHD Public Health Unit, 2025).

Ongoing management efforts (including remediation, improved emissions controls and close monitoring) have seen an overall downward trend in BLL in children in Broken Hill. However, this decline has plateaued in recent years, with the majority of Aboriginal children (68%) aged 1 year to less than 5 years still recording levels above the threshold national standard (5 µg/dL), with 6% of Aboriginal children in this age range exceeding 20 µg/dL blood lead concentrations (WNSWLHD Public Health Unit, 2025).

The Broken Hill Environmental Lead Response Group (BHELRG) was established in June 2023 in response to advocacy from the Broken Hill Mayor and community, following correspondence with the NSW Premier. The Department of Premier and Cabinet (DPC) led the Group from its inception in mid-2023. In August 2023, leadership of the BHELRG was transferred to the then Department of Regional NSW.

In July 2025, the Office of the NSW Chief Scientist & Engineer (OCSE) was asked by the then Acting Secretary of the Premier's Department to provide independent advice on the human and environmental impacts of lead contamination in Broken Hill. A preliminary workplan was developed in consultation with the Premier's Department as BHELRG Chair, to undertake the first phase of a broader review for the Government's consideration. Following feedback from the BHELRG, OCSE revised the approach and this Report builds on the 2019 Broken Hill Environmental Lead Program (BHELP) paper by Prof. Mark Taylor and colleagues (2019), updated in 2022 with more recent information pertaining to lead in Broken Hill.

This Report outlines initial findings and recommendations for managing lead contamination and improving community health outcomes based on available data and stakeholder input. It collates existing data, identifies current programs and knowledge gaps, reviews national and international approaches where appropriate, and provides preliminary findings and recommendations for consideration. Due to time constraints, this Report should be viewed as a guide for further work rather than a comprehensive analysis.

OCSE developed this Report using available data and targeted stakeholder consultation (see Appendix 1 and Appendix 2). As part of this process, OCSE visited Broken Hill to engage with key local stakeholders, including mining companies (Broken Hill Mines Limited (BHM) and Perilya Limited (Perilya)), Maari Ma Health Aboriginal Corporation (MMHAC), Far West Local Health District (FWLHD), Broken Hill City Council (BHCC), and NSW Government agencies such as Aboriginal Affairs, Public Works, the NSW Environment Protection Authority (NSW EPA), and Transport for NSW.

Further, OCSE recommends reading Taylor, Isley, Lyle, et al. (2019, updated 2022) alongside this Report for context on the historical issue of lead contamination. Rather than revisiting previous findings, this Report focuses on progress since 2019 and incorporates new evidence to assess current environmental contamination and health outcomes in Broken Hill as of 2025.

1.1.1 Environmental lead

Lead contamination is well established as an ongoing issue in Broken Hill and is documented in the review undertaken by Taylor, Isley, Lyle, et al. (2019, updated 2022) that considers both historical (legacy) and current sources of lead contamination in Broken Hill. A number of studies have reported detection of lead in air, dust and soil in Broken Hill across a range of settings and locations, including residential properties, workplaces, parks and other public settings (Boreland et al., 2008; Cattle & Wimborne, 2017; Juhasz, 2018; Taylor, Isley, Lyle, et al., 2019, updated 2022). Transportation of ores through Broken Hill has also resulted in contamination of the railway corridor. Taylor, Isley, Lyle, et al. (2019, updated 2022) concluded that both past and present mining operations contribute to lead contamination.

The historical significance of mining in Broken Hill is recognised by National Heritage listing of the city under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act). Protection under this listing dictates that changes that might impact heritage significance should be consistent with overarching values. However, a Commonwealth decision-making process exists to address competing risks to heritage versus human health risks whereby impacts on heritage sites must be considered with respect to the EPBC Act, the *Heritage Act 1977* (NSW) and the *Broken Hill Local Environmental Plan 2013* (NSW).

Broken Hill's semi-arid climate, with prolonged dry spells and sparse vegetation, provides conditions that may favour dust dispersion across the city. Climate change is projected to further increase temperatures (by 1.4-4.2°C by 2090) and reduce spring rainfall by ~30%, intensifying droughts (NSW DCCEEW, 2024). How these changes will affect future dust dispersion in Broken Hill remains uncertain.

Both proximity to the Line of Lode and age of house can be predictors of household dust concentration (Taylor, Isley, Lyle, et al., 2019, updated 2022) . However, lead concentration in dust in Broken Hill does not correlate well with total dust deposition, which is likely related to monthly rainfall (OEH, 2018). There is not a strong relationship between BLL in children and lead concentration in the soil at their residential address, suggesting that there are other non-soil and/or non-residential sources of lead exposure (Taylor, Isley, Lyle, et al., 2019, updated 2022). Although some data indicates a reduction of both lead in air and BLL, coincident with the halting of some lead-emitting mining and processing operations at other sites (Taylor, Isley, Lyle, et al., 2019, updated 2022), there is no recent geospatial data mapping of any potential relationship between BLL in children and lead in soil or dust, or proximity to Line of Lode.

1.2 Broken Hill Lead Management Programs

Despite the introduction of environmental controls on mining and smelting activities in the early 1990s, lead contamination is persistent in Broken Hill and requires ongoing management. These controls include the capping of the Line of Lode, remediation of contaminated areas and emissions reduction measures at mine sites. Programs to address the ongoing issue of lead exposure in Broken Hill have been implemented since the first iteration of the BLL screening program in 1991. A comprehensive timeline of programs until from 1991 until 2013 can be found in Boreland & Lyle (2014).

In 2015, the NSW EPA allocated ~$13 million in funding (over five years to 2020) for programs in response to the concern of ongoing detections of elevated BLL in local children in Broken Hill (BHELP, 2018). These programs became the basis for the BHELP and form the foundation of contemporary lead management programs in Broken Hill. These programs are detailed in the *Broken Hill Environmental Lead Program – Steering Committee Annual Reports* (2015-2020).[1]

This section provides a snapshot of programs, research and activities undertaken to address environmental lead contamination and human lead exposure in Broken Hill from 2015 to the present day. The information presented here builds on the work of Taylor, Isley, Lyle, et al. (2019, updated 2022), draws from academic research, a desktop review of the available data and literature, program information, and data from mines. The OCSE team also draws insights from a site visit made in September 2025. This visit involved consultations with key stakeholders (Appendix 1) and informal tours of areas of interest. During these consultations and site visits, the OCSE team gained valuable insights to inform this report, mainly centred on the community's concerns about lead and possible barriers to program success. These findings have been combined with examples from research and prior reports to shape the content, scope and findings of this Report.

This Report is not intended to be a comprehensive evaluation of lead management programs in Broken Hill. Instead, this section draws significantly on programs and projects undertaken or commissioned by the

[1] The reports and other resources are available at the LeadSmart website https://leadsmart.nsw.gov.au/resources/, accessed on 17 December 2025.

BHELP (including some initiatives discussed in Taylor, Isley, Lyle, et al. (2019, updated 2022), their progress to date, mining operations and relevant research published since Taylor, Isley, Lyle, et al. (2019, updated 2022) to provide an updated snapshot of lead management programs and activities in Broken Hill.

The BHELP was allocated ~$13 million funding over 5 years (2015-2020) by the NSW Government to address lead exposure at Broken Hill and the detection of elevated BLL in children (BHELP, 2020). An independent Steering Committee provided oversight of the program, and included representatives from NSW EPA, NSW Health and key stakeholders including BHCC, MMHAC, Broken Hill University Department of Rural Health (BHUDRH), Office of Environment and Heritage (OEH), NSW Department of Planning, Industry and Environment, Aboriginal Affairs and others. The following were also established:

- Broken Hill Reference Group – to provide guidance and feedback to BHELP
- Aboriginal Lead Reference Group – to provide engagement between the BHELP and the local Aboriginal community
- BHELP project team – to coordinate work priorities across three key focus areas:
    - research and monitoring
    - consultation, education and funding
    - remediation.

While this section focusses on work performed under BHELP, OCSE are aware that other remediation activities on residential and public areas are being undertaken by other parties across Broken Hill. These actions should be consolidated under a more coordinated approach in any future lead program in Broken Hill.

1.2.1 BLL screening program

There is no safe level of lead in blood. Lead exposure early in life poses long-term health risks through neurodevelopmental, cardiovascular, renal and other effects, with lifelong cognitive and behavioural consequences (Wigg, 2001). These effects are observed even at moderate exposure levels, such as those measured in many children in Broken Hill. Frequent hand-to-mouth contact of children in the cohorts of 1 to under 5 years old make them particularly vulnerable to lead ingestion.

Blood lead levels (BLLs) are considered a key indicator of lead exposure, with well-documented links to adverse health effects. The BLL screening program aims to monitor the BLL of Broken Hill children aged less than 5 years, including newborns (via umbilical cord screening). The BLL screening is aimed to be both preventative (i.e. for early intervention cases) and responsive (i.e. to enable further interventions) in reducing the elevated BLL of individuals.

The FWLHD's Child and Family Health team (CFH) and MMHAC's Primary Heath Care Service conduct voluntary BLL screenings for all children aged less than 5 years and offer appropriate case management interventions where BLL are above 5 µg/dL.[2] Aboriginal children can attend either service for their healthcare checks, however most attend MMHAC. Whichever organisation identifies an elevated BLL is required to undertake interventions, which can include education packages, risk management strategies (including home visits and counselling), environmental assessments and, in cases of extreme toxicity (above 45 µg/dL), medical treatments such as chelation therapy (NSW Health, 2018). Where the BLL is greater or equal to 10 µg/dL, retesting is recommended with the frequency dependent on the level detected. For children who have BLL greater or equal to 10 µg/dL, assessments of lead exposure risks at home are conducted and depending on the risk exposure level, cases may be referred for home remediation.[3] The FWLHD, in partnership with Western NSW Health Intelligence Unit and BHUDRH, reports BLL trends in the

[2] This value is based on the NHMRC guideline released on 19 May 2015 (NHMRC, 2015).

[3] Initially, children with elevated BLL ≥ 15 µg/dL and significant risk identified in home assessment were referred for home remediation. In 2020, BHELP approved extension of home remediation program for children who have BLL between 10 – 15 µg/dL who live in high-risk zone and age less than 2 years old.

Broken Hill population in annual lead health reports (e.g. BHELP, 2018) for the specific purpose of public health monitoring and protection.

As the BLL screening program is designed to monitor the BLL of children in Broken Hill, one of the other primary metrics reported is participation rate. From 2015-2024, the estimated BLL screening participation rate ranged from 73% to 90% in newborns, with a 10-year annual average of 85% for children aged 1 year to less than 5 years (WNSWLHD Public Health Unit, 2025). Efforts have been made to increase the participation of Aboriginal children in this program, due to their over-representation in elevated BLL categories. However, as mentioned in NSW EPA's *Health Check* report,[4] there is uncertainty with the estimated participation rate from population data due to the high proportion of transient residents and issues with under-reporting of Aboriginality in the census (NSW EPA, 2020). From community consultations, some suggestions to improve Aboriginal community engagement and impacts are community vouching of home remediation and unified engagement with the MMHAC. Other recommendations are to include broader health providers outside CFH and the MMHAC such as general practitioners, midwives, paediatricians or dietitians in delivering lead health education (NSW EPA, 2020).

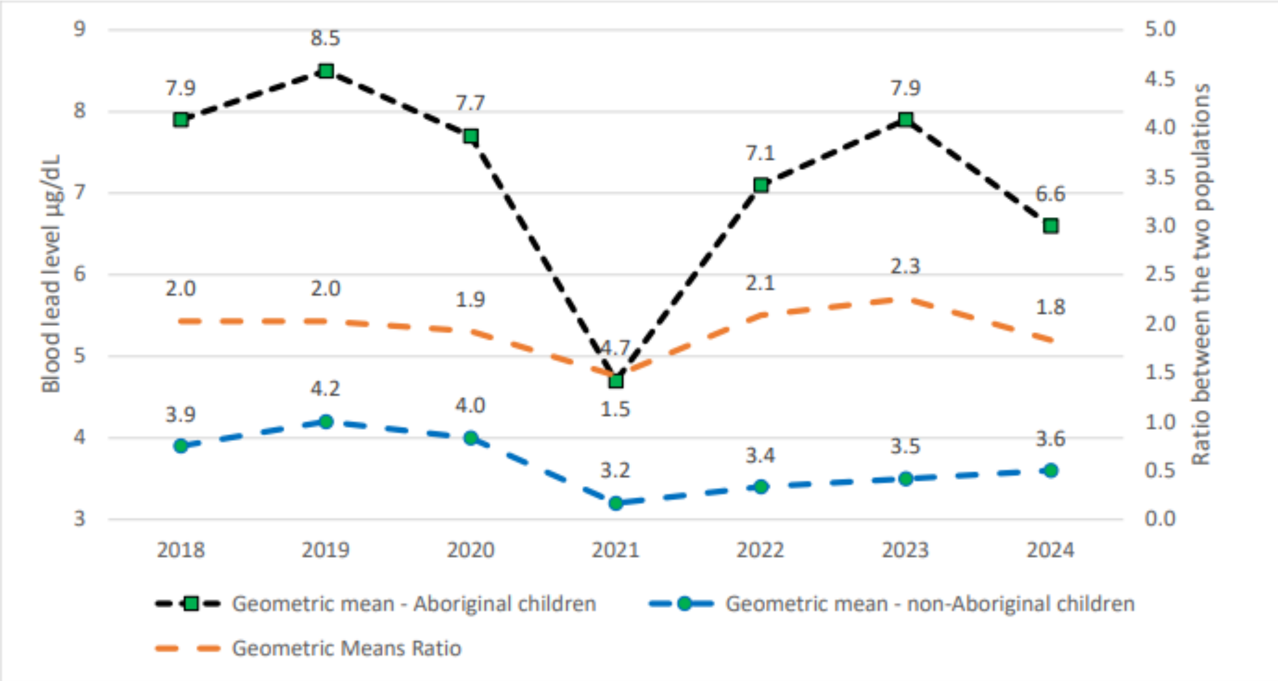
Key indicators of population exposure are the geometric mean blood lead concentration and the proportion of children below and above the 5 µg/dL guideline value.[5] The geometric mean of BLL in children aged 1 to less than 5 years has decreased from 5.8 µg/dL in 2015 to 4.3 µg/dL in 2024 (WNSWLHD Public Health Unit, 2025) (Figure 1, top). However, around 40% of children aged 1 to less than 5 years in the city have BLL above the national standard of 5 µg/dL, despite ongoing management efforts (WNSWLHD Public Health Unit, 2025) (Figure 1, bottom).

Aboriginal children consistently exhibit average BLL 1.8 times higher those of non-Aboriginal children, and it has been suggested that this disparity is due to socio-economic disadvantages faced by the Aboriginal community including inadequate housing access (Maari Ma, 2017). Although the age-standardised geometric mean BLL for Aboriginal children aged 1 to less than 5 years fell by 29% between 2015 and 2024, from 9.3 µg/dL to 6.6 µg/dL, persistent disparity between Aboriginal and non-Aboriginal children remains (WNSWLHD Public Health Unit, 2025).

BLL shifts occurring around the COVID-19 pandemic have raised some questions. In 2021, for non-Aboriginal children, the geometric mean of BLL (4.7 µg/dL) fell slightly below the National Health and Medical Research Council (NHMRC) recommended guideline. This was not the case for Aboriginal children. It has been suggested that the decrease in BLL is due to a decrease in screening rates during the COVID-19 lockdown, as the total number of children screened aged 1 to less than 5 years remained steady (689 tests in 2020 compared to 681 tests in 2019) (WNSWLHD Public Health Unit, 2021). The BLL results in 2022 suggest the opposite, with the BLL geometric mean returning to the higher level of 7.1 µg/dL, with even less screening.

[4] The *Health Check* report was done to assess confidence in the BHELP and assess whether they had delivered services in-line with their stated objectives (NSW EPA, 2020).

[5] The geometric mean is used to report to BLL as opposed to an average or arithmetic mean. The majority of children will have BLL at lower range while a small number will have a very high BLL. The arithmetic mean is strongly affected by very high values. As such, using geometric mean can prevent extreme values to dominate the weighting and normalise the values being average (WNSWLHD Public Health Unit, 2025).



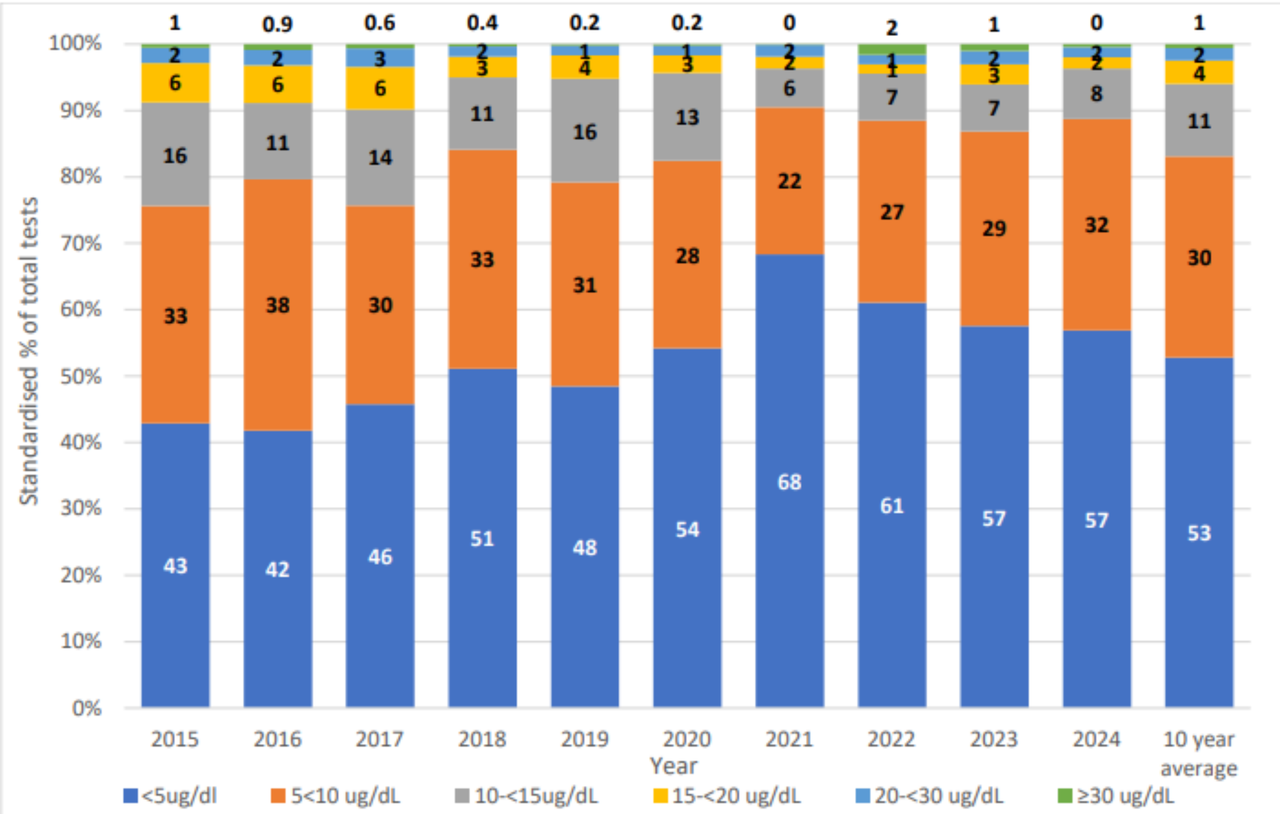


Figure 1. *Top:* Age-sex standardised geometric means BLL and ratios for Aboriginal children and non-Aboriginal children ages 1 to less than 5 years. Dates from 2018 to 2024. Source: (WNSWLHD Public Health Unit, 2025). *Bottom:* Blood lead levels of all children aged 1 to less than 5 years by category as a percentage of total annual tests, (age-sex standardised percentage). Dates from 2015-2024. Source: (WNSWLHD Public Health Unit, 2025).

1.2.2 Home assessment and remediation program

As noted above, children with BLL exceeding 10 µg/dL referred to the home assessment and remediation program for an assessment to identify lead exposure risks and targeted interventions, which may include delivery of education and incentives (e.g. cleaning kits and sandpits, and if required, further referral for home remediation. Both CFH and MMHAC are involved in the assessment, with assistance from NSW EPA.

As part of the assessment process, lead concentrations are collected using a portable X-Ray Fluorescence (XRF) device[6] to identify the lead exposure risk and inform potential risk management strategies. Home environments analysed include internal surfaces including walls, ceiling, curtains rugs, toys, etc., external walls and surfaces including soils, paths, sandpits and gardens. Between 2015/16 and 2024/25, 305 total home assessments for the purpose of supporting potential remediation were performed at residences of children with elevated BLL, with 291 (95%) having lead risk above health investigation limits (HIL) of 300 mg/kg lead in soil.[7]

The targeted home remediation is risk-based and informed by the children's BLL and lead concentrations in dust/soil. Initially, home remediation referral was prioritised based on children's BLL ≥15 µg/dL and soil lead concentrations above 1,000 ppm (NSW EPA, 2020). In, 2020 it was extended to children with BLL of 10-14 µg/dL who live in "high-risk zones for exposure"[8] and who are less than 2 years of age (BHELP, 2020). Approximately 182 home remediations due to elevated BLL and home assessment results were delivered from 2016/17 to 2024/25.[9]

NSW EPA contracts NSW Public Works to project manage contractor-delivered remediation activities aiming to reduce or eliminate lead exposure sources (NSW Public Works, 2024a). The remediation activities include:

- replacing or capping contaminated soils
- encapsulating interior and exterior lead-based paints, and
- sealing of cracks and joints to prevent lead dust build-up.

There are some challenges in home remediation activities. These include managing environmental risk due to housing age, poor construction and the presence of asbestos-containing products. OCSE stakeholder consultation identified concerns that the condition of some houses is so poor (e.g. no floors, overcrowding) that remediation is not viable. Securing a workforce presents additional challenges, as a vendor can be contracted for a year without knowing how many houses they will be asked to remediate. Nonetheless, NSW Public Works can deliver the projects without the need to relocate residents. Regardless, funding constraints remain the limiting factor on the number of homes remediated (NSW EPA, 2020).

1.2.3 Public land remediation

Over 20 hectares of public land was remediated between 2015 and 2025 – primarily through surface capping – under a Memorandum of Understanding (MoU) between BHELP and BHCC (BHELP, 2020; Ramboll, 2024). Remediation was carried out specifically on the sites that were identified as the highest priority (i.e. Patton Park in 2019, O'Neil Park in 2017) informed by Cattle & Wimborne (2017) and Green et al., (2016). Remediation activities have taken place on 22 public sites.[10] Additionally between 2015 and 2025, 24 daycares, family daycares, preschools, and primary schools (K-2) were tested a combined total of

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[6] Portable XRF devices can be used to immediately and non-destructively measure dust, paint and soil lead levels.

[7] NSW EPA, pers. comm., 2025. Note that the sampling of homes was undertaken by NSW EPA, NSW Health and MMHAC. Other sampling of homes has been undertaken by NSW Health and MMHAC for the purpose of educational risk screening that is not reported here. The results are not representative of the distribution of lead risks across Broken Hill as they are skewed towards children with high blood lead levels.

[8] It is not described the criteria for "high risk zones for exposure".

[9] NSW EPA, pers. comm., 2025.

[10] NSW EPA, pers. comm., 2025.

38 times, with 28 (74%) having lead risks identified. Of these, 13 (34%) were very high risk.[11] Not all sites were remediated.

Since 2015, the MoU between the BHELP and BHCC has focused on remediating public sites and land to effectively minimise exposure to lead in the local environment, particularly in children. In this context, remediation is a catch-all phrase that includes one-time solutions, such as replacing the existing front yard dirt surface of a community hub with synthetic grass, and ongoing efforts, such as weekly high-pressure cleaning at public parks.

The aim of the program is to deliver targeted, cost-effective and sustainable lead remediation works based on research, monitoring and risk assessments. Actions taken through the program focus on removing or mitigating lead exposure and providing a safer environment for local children and the community into the future. Works include:

- surface capping and fencing of high-lead areas, including public parks and tailings dams
- ongoing annual maintenance of council parks and playground equipment
- installation of handwashing facilities and playground shelters.

Remediation efforts are prioritised according to risk of exposure (NSW EPA, 2020):

- residential – prioritise based on children's BLL > 15 µg/dL and lead in soil concentration> 1,000 ppm
- public area – prioritise by high soil lead concentration rather than location.

Remediation priorities have been informed through monitoring and research. In 2016, a monitoring survey of 10 parks and ovals in Broken Hill was conducted (Cattle & Wimborne, 2017). Data from a portable XRF device was used to generate a model to predict topsoil lead contamination. Findings indicated that parks and ovals furthest from the Line of Lode had the lowest topsoil lead concentrations, while those closer (i.e. Patton Park, O'Neil Park) had sections with lead concentrations above the HIL for public recreational spaces.[12]

Additional investigation also used a portable XRF device to determine environmental lead concentrations in four publicly accessible sites of interest. In 2017, AJ Keast Park was identified as a priority site based on frequency of use and overall risk (Green, et al., 2016) and in 2017 was remediated through capping with loam, installing mulch, planting trees and ground cover, and erecting a concrete boundary around the bare dirt areas with elevated lead concentration. The effectiveness of remediation efforts in areas that had previously been remediated was variable, with elevated lead concentrations recurring at some sites that had been previously capped (BHELP, 2018).

Green et al. (2016) also found that the grassed area southwest of AJ Keast Park separated by the drainage line and levee had a low to moderate risk level,[13] suggesting that the drainage line and levee are preventing the migration of higher lead concentrations from reaching the grassed area (Figure 2). More research is required to understand the potential migration or dispersion of lead in soils through stormwater, as the impacts of stormwater on human exposure to lead was identified as a data gap in the *Preliminary Conceptual Site Model – Lead in Broken Hill*.

[11] NSW EPA, pers. comm., 2025. All early childhood services are offered free environmental testing of their services each year, with participation voluntary. This data is more representative of lead risks across Broken Hill as it is not driven by blood lead data.

[12] The lead concentration HIL for recreational public spaces is 600 mg/kg, NEPM 2013, Schedule B1.

[13] In the research, risk level is defined by soil concentration and percentage of ground cover.

AJ Keast Park and Surrounds: Overall Risk Levels and Soil Lead Concentrations

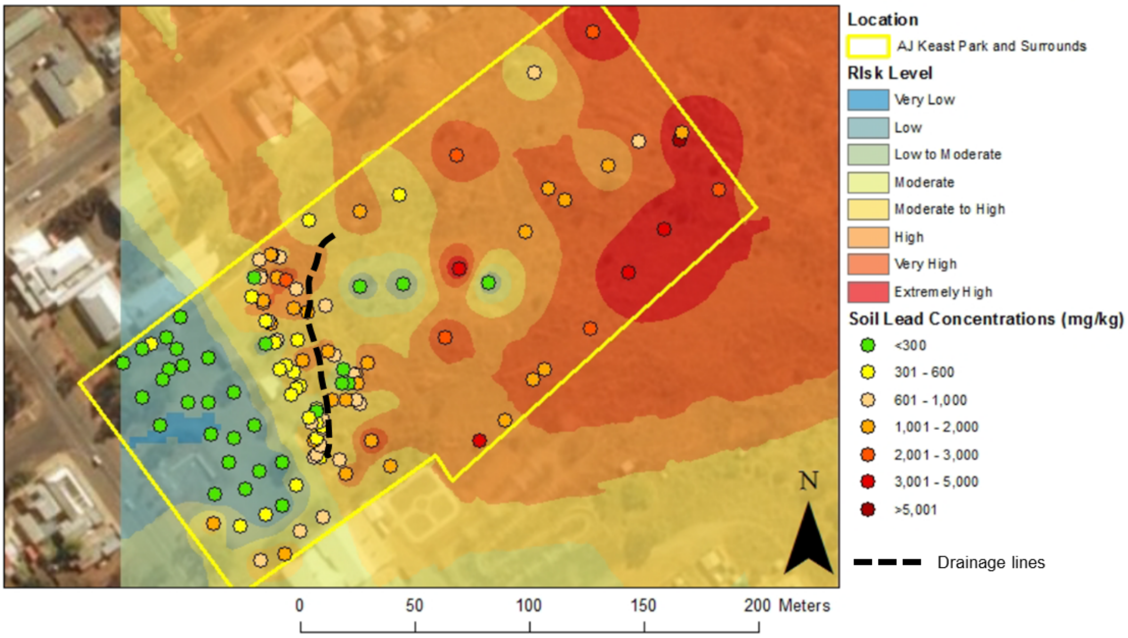

Figure 2: Adapted soil lead concentrations and overall risk at AJ Keast Park and surrounds, superimposed with the approximate location of the drainage lines (bold, black dotted lines) (Green, et al., 2016).

1.2.4 Public health initiatives

Community engagement through lead health awareness and education programs (i.e. LeadSmart) aims to provide sustainable communications and encourage practical skills to minimise lead exposure into the future. The LeadSmart program provides knowledge about lead exposure, including health risks, healthy eating, pathways of exposure, and exposure prevention strategies to all Broken Hill residents, especially the families and caregivers of children aged less than 5 years and those expecting newborns.[14] It is embedded through different types of engagement, including:

- public announcements, events and parks signage
- formal education in school and e-learning, and
- personalised communications during immunisation visits, house assessments and after home remediation is done.

Since 2015, communication of lead awareness and education has spanned the LeadSmart website and resources, media campaigns on television and on Facebook, health communication (education packs) and participation in community events.

An assessment of online lead health communications in Australia has outlined the need to provide consistent, accurate and comprehensive information on lead health risks, along with specific primary practical intervention such as how often to clean interior spaces (Sullivan & Green, 2016). Additional online resources for preventative behaviour include information around health and nutrition, pregnancy, hygiene and ways to protect community members from lead in backyards, the workplace and during renovations.

According to the LeadSmart program survey (n = 200) in 2017, the community found the materials had influenced lead awareness, with more than 77% remembering three or more key messages and almost half making positive changes in their life to reduce lead exposure for themselves or others (ABC, 2017; BHELP, 2017).

The LeadSmart program was later extended to include formal education in curriculum-aligned programs in preschool and primary schools, with the possibility of developing e-learning modules for Broken Hill

[14] The education packs for families expecting newborns are increased based on the exposure studies in 2017 – check annual report – and early intervention for 6 months old.

contractors and transient workers (Art of Multimedia, n.d.; BHELP, 2020).[15] The *Health Check* report suggests that a more formal and strategic evaluation considering behaviour change would be beneficial for community engagement strategies, including providing information for visitors and newcomers (NSW EPA, 2020).

Stakeholder consultation during the OCSE site visit to Broken Hill identified several challenges to effective community engagement. A complex set of community attitudes to the health, economic, social, cultural and heritage implications of environmental lead exist in Broken Hill. While some residents are highly concerned, there is a more general sense of acceptance or complacency around lead contamination as an inherent part of living in Broken Hill. Some community members feel strongly that the issue of lead contamination for residents needs to be fixed to a level that doesn't impact mining. Others identified that high BLL in children can be stigmatised and seen as the parents' fault, which can create a barrier to parents seeking help when needed. Additionally, there are equity issues within the community that need to be considered when recommending behavioural and nutritional interventions. Stakeholder engagement also identified significant knowledge gaps among residents who are new to Broken Hill, non-mining tradespeople and employers, existing residents and parents/carers, further highlighting areas for improvement in community programs.

1.3 Monitoring and management of lead emissions and dispersion

1.3.1 Past and present mining operations

A succession of companies has undertaken mining and processing of silver, lead and zinc along the Line of Lode since initial prospecting in 1883. Hence, cumulative environmental and health impacts within Broken Hill reflect the actions of generations of companies rather than any single operator. Mining and processing techniques have changed over time, with open cut mining, smelting and transport of crushed ore via unsealed and public roads for processing (Ramboll, 2024) no longer taking place. Rail transport of lead and zinc concentrate to Port Pirie, South Australia now takes place using sealed containers but legacy contamination along transport routes such as roads, rail lines and surrounding areas in Broken Hill is well known.

Today, two major mining companies remain operational: Perilya and BHM. Perilya operates the Southern Operations, North and Potosi Mines (the latter currently under care and maintenance), and has significantly increased production since acquiring the sites in 2002. BHM owns the Rasp and Pinnacles Mines, with current Rasp underground operations and processing overlaying significant historical operations.

Broken Hill's long and ongoing history of lead mining and dispersion of lead from naturally occurring sources (i.e. the Line of Lode), has caused lead contamination at varying concentrations throughout the entire town. The introduction of environmental measures in the 1990s has decreased emissions and dispersion from mining activities over time, however many areas remain contaminated by lead from legacy mining activities, including contaminated land on or near the current mining leases (Taylor, Isley, Lyle, et al., 2019, updated 2022). This lead can be remobilised contaminating other areas around Broken Hill. Importantly, controls on contemporary mining emissions alone will not eliminate remobilised lead dispersion from legacy mining-related land contamination.

Minimising the ongoing lead contamination in Broken Hill requires a multi-faceted approach that addresses the multiple sources of lead emissions and dispersion, including both contemporary mining emissions as well as resuspension and dispersion from legacy contamination, including on mine sites.

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[15] In 2019, lead health education was provided to 180 employees from the National Broadband Network (NBN) rollout and Water2Broken Hill pipeline projects. The e-learning module was commissioned but not completed.

1.3.2 Lead emission monitoring, reporting and limits

There are two ways lead emissions and dispersion are commonly measured and reported:

- Lead in Total Deposited Particulates (TDP-Pb) (also referred to as lead in deposited dust) – typically measured with units μg/m^2 or g/m^2 – measures lead particulate deposition per unit area and is often reported per specified unit of time (e.g. μg/m^2/day or μg/m^2/month).
- Lead in Total Suspended Particulates (TSP) (also referred to as Total Solid Particles or lead in air) – typically measured with units μg/m^3 – measures the volumetric concentration of lead particles in the air and is used to report ambient air lead concentrations. The National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) threshold is 0.5 μg/m^3. In addition to TSP, PM10-Pb refers to only particulate matter with a size fraction smaller than 10 micrometres.

While lead in deposited dust can be resuspended (therefore increasing lead in air), the two values are different measures and have differing recommended exposure limits.

Lead in deposited dust/TDP

At present, there is no NSW-wide established standard or limit for lead in deposited dust. Rasp Mine's development consent specifies a maximum project contribution of 2 g/m^2/month for deposited dust (yearly average) (NSW DPIE, 2011). This value includes lead, but there is no limit specifically for lead dust deposition.

Taylor, Isley, Lyle, et al. (2019, updated 2022) plotted the annual geometric mean of BLL against concentrations of lead in deposited dust in Broken Hill,[16] showing that if lead in deposited dust exceeds 90 μg/m^2/day, the annual geometric mean of children's BLL is likely to exceed 5 μg/dL. Further investigation by an Expert Panel will be needed to determine a Broken Hill-specific limit, target or goal that considers human health outcomes and practical actions for response.

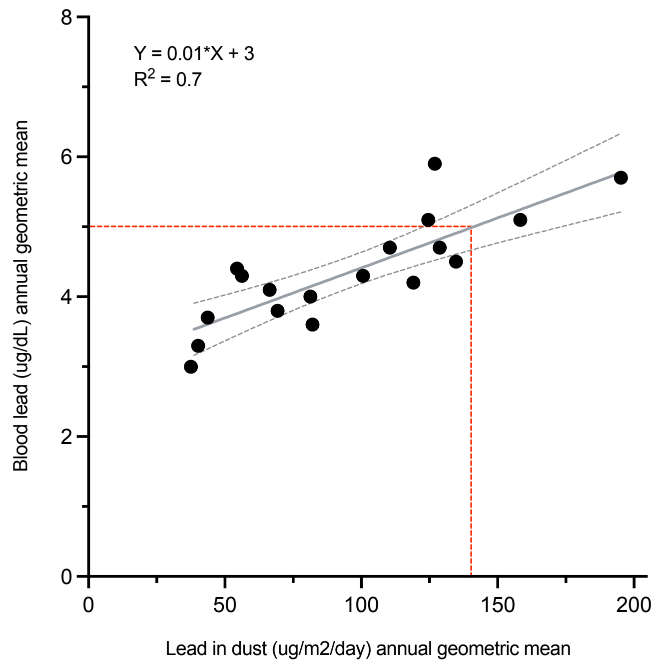

Figure 3: Lead in deposited dust vs BLL (2017-2024). Relationship between annual mean BLL and annual mean lead in deposited dust using data from (BHELP, 2017, 2018, 2020; Dong et al., 2019; WNSWLHD Public Health Unit, 2025) and

[16] See Figure 12 in (Taylor, Isley, Lyle, et al., 2019, updated 2022).

TDP-Pb values for BHM and Perilya's Environmental Protection Licence Dust Deposition monitoring points and the NSW EPA's dust deposition gauges in residential areas of Broken Hill.

The Queensland Government imposes a trigger value of 100 µg/m^2/day for lead compounds in Mount Isa, adapted from German guidelines (TA Luft, 2002). Exceeding this value initiates an investigation to identify the potential cause of the exceedance and actions to minimise environmental harm (QLD DETSI, 2025a). However, while the Mount Isa trigger value is represented as a daily limit, it is calculated as an annual average and does not consider short-term exceedances.

Lead in Air/TSP

Ambient lead levels in air are nationally regulated by the Ambient Air Quality (AAQ) NEPM with a limit of 0.5 µg/m^3 (yearly average), and a stated outcome of "ambient air quality that minimises the risk of adverse health impacts from exposure to air pollution".[17] The AAQ NEPM does not apply directly to individual polluters, but instead requires individual jurisdictions within Australia (including NSW) to monitor and report on compliance to the air quality standards and issue yearly air quality reports. For lead, ambient lead monitoring in NSW under the AAQ NEPM ceased in 2004, as the introduction of unleaded petrol meant ambient lead concentrations fell consistently below the AAQ NEPM standard (NSW DCCEEW, 2023).

A list of national and international lead in air quality standards can be found in Table 9 (Appendix 3).

Under the AAQ NEPM, lead air quality measurements are to be carried out on TSP "or its equivalent", using either high- or low-volume gravimetric sampling[18] for a period of 24 hours every sixth day.[19] The AAQ NEPM's objective is to provide an "average" representation of general air quality and population exposure, and it "does not apply to monitoring and controlling peak concentrations from major sources such as … major industries" (NEPC, 1998). The 0.5 µg/m^3 limit for lead was determined based on "reducing and maintaining blood lead levels below 10 µg/dL" in accordance with the (now rescinded) NHMRC guidance.[20] A lower air quality limit of 0.3 µg/m^3 was rejected in view of the "small increase in indicative averted health impact … debate regarding the blood lead IQ loss threshold, blood lead correlation with lead in air (and) declining lead in air levels" (National Environment Protection Council, 1998). As a yearly average, the NEPM limit also does not consider short-term exceedances of lead in air levels above 0.5 µg/m^3.

In an article examining smelter emissions in Port Pirie, Taylor, Isley and Glover (2019) conclude that "lead in air needs to be approximately 80% lower than the current national [NEPM] standard (0.5 µg/m^3) to ensure that the geometric mean of blood lead levels of children under 5 years is less than or equal to 5 µg/dL." Taylor and Isley (2014) note that the NEPM limit and 1-in-6-day monitoring regime "ignores days when short-term, high levels of pollution occur", and that yearly averages "would appear to downplay the damaging exposure effect that can result from elevated short-term exposures."

Several studies have also found that the sampling effectiveness of High Volume Air Samplers is dependent on factors such as particle size, wind speed and sampler orientation (Krug et al., 2017; Wedding et al., 1977; Watson et al., 1983; Van Der Meulen et al., 1984). Generally, HVAS are effective for sampling smaller particle sizes such as PM10 particulate matter, however sampling effectiveness declines significantly as particle size increases.

In 2017, the US EPA performed a comprehensive study examining the effectiveness of High Volume Air Samplers depending on these factors, including particle size, wind speed and sampler orientation (Krug et al., 2017). Aerosols characteristic of large atmospheric particulate matter were generated in a wind tunnel and collected with a high-volume air sampler (HVAS), with two isokinetic reference samplers installed on either side of the HVAS. Pairwise non-parametric analyses were performed to evaluate the statistical significance of the distributions between the various test scenarios. Their results found that sampling

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[17] *National Environment Protection (Ambient Air Quality) Measure* ('AAQ NEPM') clause 5.

[18] AAQ NEPM Schedule 3.

[19] AAQ NEPM Schedule 2.

[20] The AAQ NEPM impact statement notes that "*both the level of concern and the lowest observed adverse effect level for the effects of lead on intelligence has been determined to be 10 µg/dL*" (NEPC, 1998).

effectiveness for particles of size 5–10 µm was approximately 80% and decreases to as low as 42% for particles of size 30–35 µm depending on wind speed and sampler orientation.

In a study on geochemical signatures of atmospheric dust in Broken Hill, galena particles observed in dust collected at a site adjacent to mining operations were on the order of 20–50 µm in size (Dong & Taylor, 2017). Particles collected from more distal sites were on the order of ~5 µm in size, which is expected given the increased atmospheric transport ability of smaller size particles. Similarly, a study incorporating outdoor dust loading data from six dust deposition gauges positioned in residential areas of Broken Hill found that for locations closer to mining areas, 24–52% of lead-bearing particles were larger than 10 µm, compared to 15–24% for locations further away (Gillings et al., 2022). The same study also reported that sites closer to mining areas had a lead dust deposition rate of 99–289 $\mu g/m^2/day$, compared to 5–39 $\mu g/m^2/day$ for sites further away.

Unlike the smaller inhalable ambient lead-bearing particulate matter (of size below 10 µm), ingestion through hand-to-mouth contact is the predominant exposure pathway of larger soil and dust particles (US EPA, 2024a). Accordingly, lead associated with particles > 10 µm is an important contributor to lead exposure, and so the degradation in sampling efficiency associated with High Volume Air Samplers for particles larger than 10 µm has been described as a "serious concern" by the US EPA in their use for Pb-TSP sampling (US EPA, 2024a).

This concern was also noted by Morrison et al. (2017) in a pilot study of lead phases in deposited particles in Broken Hill, with the authors noting that large lead-containing particles captured by deposition "will inevitably make up a high proportion of the mineral/elemental mass but may not be captured by a high-volume air sampler … due to their large aerodynamic diameter, a result of the large physical size (~50 µm) and high mass density of the Pb phases."

Recently, EPA Tasmania has re-examined the issue of lead in dust from the Nyrstar zinc smelter in Hobart and the MMG mine at Rosebery on Tasmania's west coast, where both sites currently include HVAS monitoring of lead in air (TSP) as part of the regulatory environment. The work considered the potential exposure to lead via ingestion from deposited dust. After assessment of historical data as well as new on-ground measurements, the EPA Tasmania study concluded that relying on HVAS monitoring alone, without accompanying dust deposition measurement, would be insufficient for instances where significant lead-in-dust is present in particles greater than approximately 30 µm. This is due to the reduced sensitivity of HVAS instruments to particles of aerodynamic diameters greater than approximately 30 µm, and also because particles of this size and larger rapidly fall-out (deposit) after being emitted to air.[21]

Taken together, these findings suggest that reliance on HVAS monitoring (and associated regulatory Pb-TSP limits) may systematically underestimate community lead exposure near mining sources, especially for children for whom the hand-to-mouth ingestion exposure pathway predominates. Dust deposition measurements may provide a more reliable indication of compliance with air quality standards, however they are poorly time-resolved (typically being monthly reported values) and are inherently reactive, being ill-suited for real-time or proactive monitoring of lead exposure.

1.4 Emissions from current mining operations

In general, emissions from lead mines are fugitive in nature and result mainly from ore processing operations (US EPA, 1998). Current BHM and Perilya mining operations in Broken Hill are conducted underground and as such their mining emissions are largely contained or controlled through defined emission sources at ventilation points. Active suppression includes the application of water sprays on stockpile areas, the use of vacuum trucks and wheel washers on haulage trucking fleets. In contrast, ore processing operations (loading, crushing, grinding etc) are not typically contained underground. Hence, preventing lead particulate matter from ore processing operations from becoming airborne mostly relies on dust-suppression techniques (e.g. watering, equipment washing) or by otherwise capturing the particulates

[21] EPA Tasmania, pers. comm., 2025.

using appropriate ventilation and capture (e.g. air filtration, negative pressure buildings). Both mines are required to monitor emissions and implement controls by their Environment Protection Licences (EPLs).

1.4.1 Mining emissions controls

The EPLs for both mines in Broken Hill contain a general requirement that dust emissions from the premises are "minimised", and also contain provisions detailing specific controls (such as covering loads of ore trucks, immediately suppressing visible dust emissions, and requiring negative pressure on crusher enclosures) (NSW EPA, 2024b, 2024a, 2025b).[22] Rasp Mine's development consent contains a long-term criterion for TSP of 90 µg/m^3 (annual average), 25 µg/m^3 (annual average) for particulate matter < 10 µm (PM_{10}), and a short-term 24-hour criterion of 50 µg/m^3 for particulate matter < 10 µm (PM_{10}) (NSW DPIE, 2011). These limits include lead but are not lead-specific. The development consent for Perilya's North Mine requires that "all reasonable and feasible avoidance and mitigation measures are employed" so that particulate matter emissions do not exceed an air quality criterion of 0.5 µg/m^3 lead (annual average) at "any residence on privately owned land" (NSW DPIE, 2021c). Perilya's South Mine did not require a development consent.

The EPL for BHM's Rasp Mine imposes a point source air concentration emission limit of 20 mg/m^3 for TSP, and 1 mg/m^3 for "type 1 and type 2 substances" (including lead) at both the ventilation shaft and process enclosure/baghouse stack (NSW EPA, 2025b). The EPA's online POEO register includes three non-compliances for this licence condition since 2012.[23] In March 2024, BHM reported an exceedance at the Crusher Baghouse of emissions of type 1 and type 2 substances but could not identify the source of the exceedance (BHOP, 2024b). In April 2024 BHM again reported an exceedance but attributed it to high levels of manganese, again without being able to identify the source (BHOP, 2024a). No such limits could be found in Perilya's EPLs. Over the years, the NSW EPA has imposed several additional licence conditions on both Perilya and BHM in relation to lead pollution management. In 2016, the NSW EPA required additional dust reduction strategies at Perilya following a December 2015 Environmental Audit Report which identified that additional pollution studies and reduction programs were required to ensure the mining operation complied with the EPL (NSW EPA, 2016). The changes to Perilya's EPL required them to engage an expert to undertake a "comprehensive assessment of dust monitoring and management at the Perilya mine site". Following this, the EPA reviewed Perilya's submitted dust monitoring and management plan and found the information provided was "insufficient" to facilitate an improved evaluation of emission management from the premises (NSW EPA, 2017). The EPA then required Perilya to seek an additional independent dust monitoring and management assessment, dust management plan, and air quality management plan, and subsequently required implementation of their recommendations in a 2018 licence variation (NSW EPA, 2018).

Following a recent (2025) inspection of BHM's Rasp Mine, the EPA noted "concerns with emissions controls" (NSW EPA, 2025c), including the "absence of emission controls" along Federation Road and Delprats Mine site. As a result, the Rasp Mine EPL was varied on 1 July 2025 (NSW EPA, 2025b) to incorporate additional emissions controls, including additional requirements for:

- the use of the green-dyed Total Ground Control (TGC) dust suppressant on all free areas
- a sediment pond and drainage maintenance
- repairs to eroded slopes and trial of dust suppressant use on high-risk slopes
- management of the BHP Slag Dump
- emission control at Delprats Mine
- a proactive dust management program including a real-time air quality monitoring network and pre-emptive dust mitigation measures based on weather forecasts.

The 2025 variations to the EPL also stipulated that BHM must ensure that any required heritage applications are submitted, should these be required to complete the works.

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[22] Perilya has two EPLs (North and Southern operations), BHM has one EPL (Rasp mine).

[23] The public register of EPLs is available under section 308 of the *Protection of the Environment Operations Act 1997* (NSW) at https://apps.epa.nsw.gov.au/casesapp/searchcases.aspx, accessed on 17 December 2025.

1.4.2 Mining emissions monitoring

Per the *Protection of the Environment Operations Act 1997* (NSW) s 66(6), the mines must publish their monitoring data obtained per the conditions of each EPL within 14 days of obtaining the data. Both mines publish monthly environmental reports containing emissions data in PDF format on their respective websites. While this is standard practice, the publication of data in PDF format makes it difficult to access, analyse and track trends in the raw data. Additionally, changes in mine ownership over time have resulted in historical emissions reports and data no longer being publicly accessible.

Accordingly, to facilitate our preliminary analysis, the OCSE requested that BHM and Perilya provide data in a machine-readable format. BHM provided the requested data for Rasp Mine (including HVAS results for 2015-2025, dust deposition data for 2007-2025, water quality data for 2019-2025 and weather data for 2018-2025). Perilya provided anonymised data regarding their BLL monitoring program, as requested. However, Perilya did not supply OCSE with the emissions data contained in their environmental reports. Accordingly, OCSE manually extracted the emissions data for Perilya's mines from their publicly available monthly environmental reports. While all attempts have been made to verify the accuracy of the extracted data, there is some risk of human error due to inconsistent formatting of results in the reports and the manual extraction of the data.

In addition to the monitoring conducted by the mines, the DCCEEW's Science and Insights Division operates ambient air HVAS monitors and dust deposition gauges to produce a report for the NSW EPA, monitoring lead levels around the Broken Hill community as part of the Broken Hill Environmental Lead Study Phase 2.

High Volume Air Sampler (HVAS) monitoring

Both mines perform ambient air quality monitoring of TSP with HVAS monitors. BHM also operates HVAS monitoring of PM10 and PM10-Pb. OCSE's analysis of the ambient air emissions monitoring indicates that the yearly TSP-Pb averages for both mines (Figure 4, top) are well below the NEPM yearly average limit of 0.5 µg/m^3.

However, the annual geometric means for both mines (Figure 4, bottom) are almost always above the recommended limit of 0.11 µg/m^3 posited by Taylor, Isley and Glover (2019) to keep BLL for children under the age of 5 below 5 µg/dL, and always above the more stringent limit of 0.082 µg/m^3 to keep the BLL of children aged less than 24 months under 5 µg/dL.

The TSP-Pb values for Perilya decreased slightly after additional dust reduction strategies were imposed in 2018 via a licence variation by the NSW EPA, suggesting that these strategies may have been effective. The data for BHM's Rasp Mine predates the implementation of the 2025 dust reduction strategies.

The quarterly TSP-Pb averages are consistently above the US EPA's more stringent National Air Ambient Quality (NAAQ) standard of 0.15 µg/m^3 (3-month average) (Figure 5).

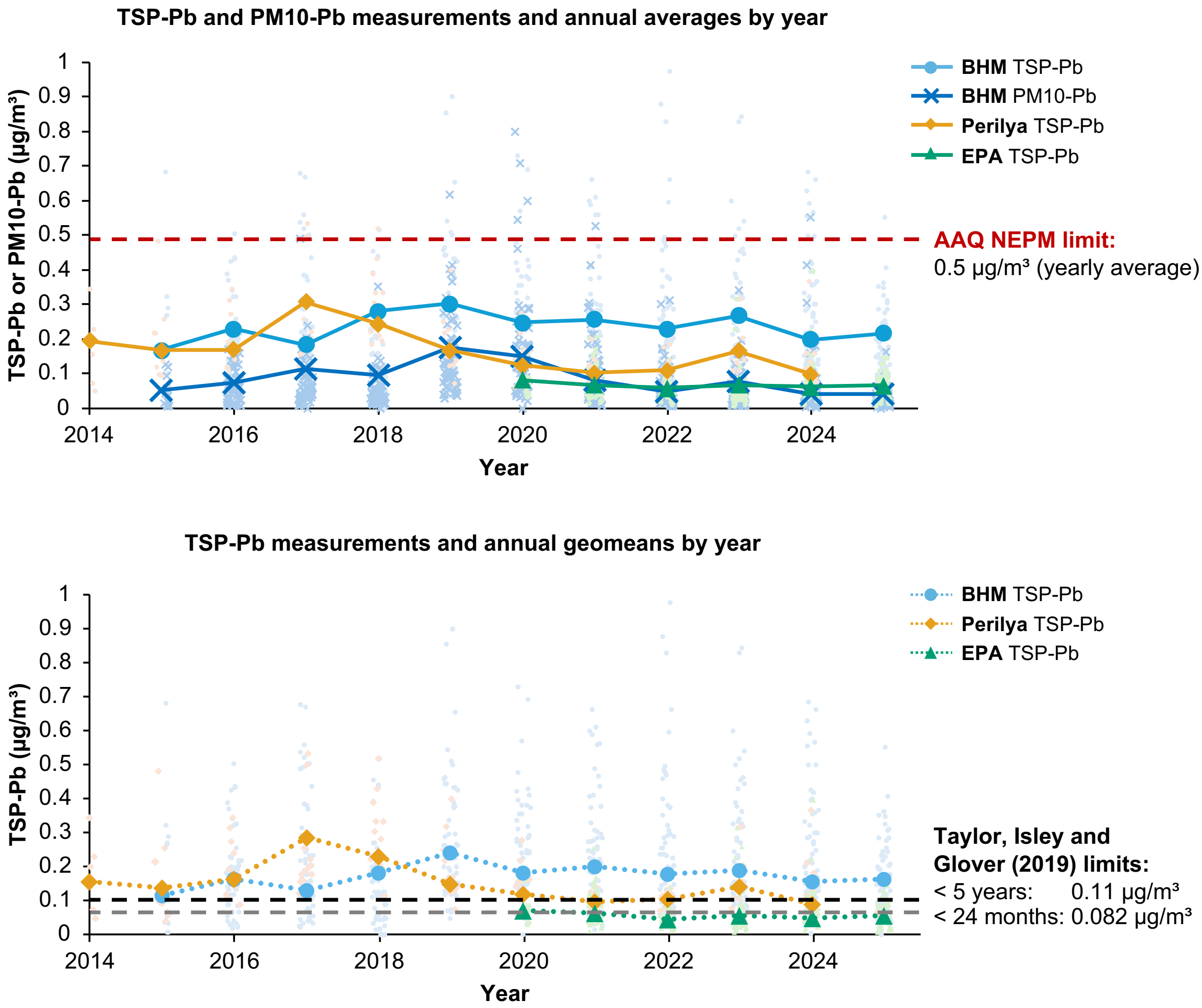

Figure 4: Top: Annual averages of TSP-Pb and PM10-Pb for BHM and Perilya's Environmental Protection Licence HVAS monitoring points, and the NSW EPA's HVAS monitoring points (excluding directional HVAS instruments), with the AAQ NEPM limit of 0.5 µg/m^3 superimposed. Bottom: Annual geometric means of TSP-Pb for the monitoring points, with limits from Taylor, Isley and Glover (2019) of 0.11 µg/m^3 (for children < 5 years) and 0.082 µg/m^3 (for children < 24 months) superimposed. Y-axis for both plots limited to 1 µg/m^3.

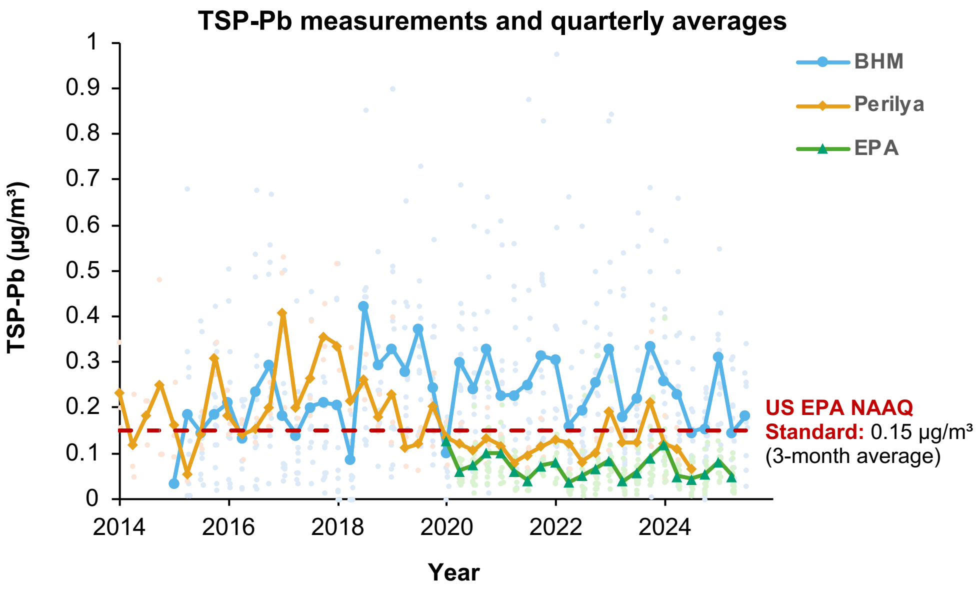

Figure 5: Quarterly averages of TSP-Pb for BHM and Perilya's EPL monitoring points, and the NSW EPA's HVAS monitors (excluding directional HVAS instruments), with US EPA NAAQ standard of 0.15 µg/m^3 superimposed.

Dust Deposition monitoring

BHM and Perilya monitor both total deposited particulates (TDP) as well as Pb in deposited particulates (TDP-Pb or DD-Pb). These values are reported as total monthly values (g/m^2/month), meaning that the minimum temporal resolution is monthly. As mentioned above, there is no lead-specific limit in BHM's EPL for lead dust deposition. Figure 6 shows TDP-Pb or DD-Pb is consistently above the recommended short-term exposure limit of 90 µg/m^2/day proposed by Taylor, Isley, Lyle, et al. (2019, updated 2022) and the similar trigger value of 100 µg/m^2/day imposed by the Queensland Government for Mount Isa, when both are converted to equivalent monthly limits.[24]

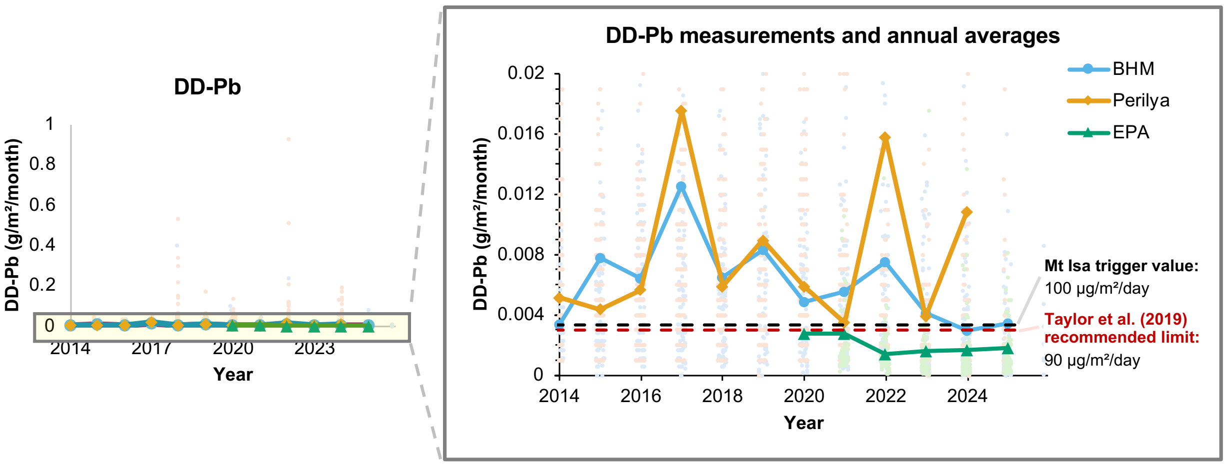

Figure 6: Annual averages of TDP-Pb for BHM and Perilya's Environmental Protection Licence Dust Deposition monitoring points, and the NSW EPA's dust deposition gauges, with Mount Isa trigger value of 100 µg/m^2/day and recommended limit from Taylor, Isley, Lyle, et al. (2019, updated 2022) of 90 µg/m^2/day superimposed (both converted to equivalent monthly limits). Left: all measurements; right: y-axis limited to 0.02 µg/m^2/month.

[24] As the available dust deposition data is only available with a monthly temporal resolution, the trigger values were converted to equivalent monthly limits by multiplying the value by 30 days.

1.4.3 Contemporary lead contamination attributable to active mining

Numerous studies have found that a significant proportion of contemporary lead contamination within the Broken Hill community originated from mining areas. A smaller number of studies conclude that at least some proportion of this contamination can be attributed specifically to recent active mining activity (i.e. not only from resuspended historical mining contamination located on or near the mine leases and Line of Lode).

D-HVAS studies

In 2016, a network of directional high-volume air samplers (D-HVAS) was installed at five community sites in Broken Hill[25] as a part of the five-year Broken Hill Environmental Lead Study (BHELS) Phase I. The study aimed to better understand the relative concentration of airborne lead sourced from active mining areas compared to non-mining areas. Pairs of D-HVAS units were set up with one unit in each pair operating when winds originated from mining areas (i.e. legacy and current mining areas at the Line of Lode – Sector A), and the other when winds originated from non-mining areas (i.e. residential or community –Sector B) (BHELP, 2020; NSW DPIE, 2021a, 2021b).

The results of the BHELS Phase I indicated that ambient lead concentrations (µg/m^3) across the three-year sampling period for all five sites were consistently higher when winds came from Sector A than Sector B. The Silver City Highway site, which is located 600 m south of Perilya Southern Operations, consistently recorded the highest median ambient lead concentrations from both sectors. A separate monthly dust deposition gauge (DDG) (g/m^2/month) at the Silver City Highway site also measured the highest lead levels compared to other sites, supporting the D-HVAS results (NSW DPIE, 2021a, 2021b).

Isotopic analyses, particle morphology, mineralogy

Another study by Dong and Taylor (2017) used isotopic analysis, scanning electron microscopy and energy-dispersive X-ray spectroscopy to characterise the nature of dust deposits around Broken Hill. The authors studied the particle morphology, mineralogy and isotopic composition of dust lead collected across six sampling sites in residential areas of Broken Hill. The authors concluded that “contemporary dust lead contamination in Broken Hill is sourced primarily from current mining activities and not from weathering or legacy sources”.

This finding was somewhat supported by a 2017 pilot study exploring whether spectrographic analytical and scanning electron microscopy techniques were able to determine the proportion of environmental lead that is sourced from more recently mined or milled material (Morrison et al., 2017). While only a proof-of-concept study, and warning that the results need to be interpreted cautiously, the study reported that 44-96% of lead in deposited dust samples underwent significant alteration from an original galena product, suggesting that those materials had been in the environment for “some time” and “may be derived from their liberation and exposure during historical mining operations”. The authors also reported that “initial results … suggest the possibility of increased deposition of more recently mined/concentrated material to the north of current mining and processing operations under the influence of prevailing southerly winds during the sampling period.”

1.5 Resuspended emissions from legacy contamination

Lead is retained in soil until it is resuspended, mechanically mixed (for example, from tilling, landscaping and animals), or leached (which is “known to be a slow process”) (US EPA, 2006). Lead retained in soil can be readily resuspended and can be a significant source of additional airborne lead in areas near major sources of lead emissions (US EPA, 2006). This represents a major confounding factor in the analysis of lead emissions in Broken Hill, as contemporary lead emissions caused by resuspension of lead in soil from historical mining activity cannot be controlled by emissions controls on contemporary mining activity (and vice versa).

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[25] Three sites north of the Line of Lode (Wetlands, National Parks and Sewerage Pumping Station) and two sites south of Line of Lode (Silver City Highway and Waterboard).

1.5.1 Contaminated land on mining leases

The 'Line of Lode' in Broken Hill refers to the rich ore body that extends through the city, and the elevated slag and waste heap that resulted from the legacy mining operations. The area has several owners (e.g. mining companies, Crown Lands, private owners etc.) and encompasses both mining and non-mining land, including publicly accessible land and transport infrastructure. Given the number and changing of owners, it is difficult to get a single historical picture of lead remediation or suppression at the Line of Lode, and where information is available, it is presented generically. While it is known that 'capping' of the Line of Lode occurred in 1990s, there is no clear documentation of the capping measures and its boundaries.

Remediation of the Line of Lode

Within the publicly accessible area, recent redevelopment of the Line of Lode Miner's Memorial in 2023 removed and contained over 2,000 m^3 of lead-contaminated soil (NSW Public Works, 2024b).

Under the mining lease area of North Mine, Potosi and South Operations, the land was rehabilitated and revegetated by the previous mine operators. This includes:

- Preliminary *Waste Rock Embankment* slope rehabilitation at Potosi by Pasminco in 2000 following substantial problems with erosion and rainfall runoff (RWC, 2023). Some activities undertaken included profiling batter slopes, placement of waste rock and spreading of growth medium.
- The existing Tailings Storage Facility (TSF) at the North Mine is capped, and the decommissioned TSF receiving tailing materials from 1956-1990 was stabilised (through battered slope and placement of waste rock) and partially rehabilitated (RWC, 2023). The top surface is layered with coarse oxidised waste rock material to prevent dust generation and provide a growth medium for revegetation (RWC, 2023).

Ongoing rehabilitation trials have been conducted and monitored against analogue target sites. Some success has been observed at South Operations TSF landform matching the ecosystem function level of the undisturbed target sites. It is possible that incorporation of waste rock into topsoil has assisted the development of vegetation through minimisation of wind erosion and run-off and facilitated water retention to support seed germination (RWC, 2023).

This is consistent with OCSE site visit observation that waste rock and passive dust suppression methods being used at mining lease zones including on non-operational areas. However, there is limited information on the frequency and methodology behind these measures both at the mines and across Broken Hill in general. There is a need for a registry of remediation works that is openly accessible, permitting evaluation and improvements.

Lead contamination on mining lease areas

The 2017 assessment of soil areas (stockpiles, dams and contaminated contact zones) at North Mine site found that "lead (in soil) exceeded guideline values for all land use classes – with concentrations in approximately 29% of samples exceeding the (1,500 mg/kg) Commercial/Industrial Health-Based Investigation Levels (HIL)" (RWC, 2023). The assessment also found that "the soil properties indicate that soils are nutrient deficient and pose a risk of erosion and dispersion" (RWC, 2023).

It is well established that high lead-in-soil concentrations are likely in areas in close proximity to the Line of Lode due to legacy mining contamination and decommissioned smelting activity. These were discussed in Taylor, Isley, Lyle, et al. (2019, updated 2022), with high lead concentrations detected in the topsoil and subsoil within approximately 0.4 km north and 0.8 km south of the Line of Lode with mean subsoil lead value of 805 mg/kg (range 24-6507 mg/kg) (Yang & Cattle, 2017, 2018).

Contribution of lead in soil to lead in TSP emissions measurements and its off-site impact

Perilya's *Air Quality Management Plan* for North Mine estimates lead in TSP emissions of 66 kg/year from "free areas wind erosion"[26] if no controls are applied, and virtually no emissions if controls are applied (RWC, 2022a). The controlled "free areas wind erosion" lead dust lift-off risk is considered as the least significant compared to lead dust lift off coming from mining activities (e.g. baghouse stacks, road haulage, upcast vents and transfers). This is based on the results of completed dispersion modelling (RWC, 2022a).

In contrast, in estimations of Rasp Mine emissions from the existing "free area"[27] of 22.3 ha, the annual controlled emissions of lead in TSP is 6,343 kg/annum (assuming conservative 80% control efficiency using chemical suppression) (Environ Australia, 2010), and the lead dust emissions from "free areas" constitutes 95% of all lead dust emissions and only 5% from mining activity (BHM, 2023).

While D-HVAS studies show high lead levels downwind from the Line of Lode (NSW DPIE, 2021a, 2021b), it is difficult to distinguish legacy or current mining activities as the source of lead in air and dust. Overall, the study concluded that the lead is predominantly sourced from the Line of Lode (NSW DPIE, 2021a, 2021b).

1.5.2 Railway corridors

The rail corridor to Port Pirie, SA, has been used to transport processed ore from Broken Hill since smelting activities were relocated in 1897. This has resulted in a large amount of lead dispersion and subsequent contamination along the rail corridor. Very limited public information is available on Broken Hill Rail Corridor contamination compared to other sites, such as the Goulburn Rail Corridor Lead Contamination by Transport for NSW (Transport for NSW, 2024).

An isotopic investigation of lead contamination within the rail corridor demonstrated clear differences between surface and sub-surface soil lead, with surface soils along the rail corridor similar to that of the Broken Hill ore body, suggesting that the source of the lead is emissions from transporting raw ore (Kristensen et al., 2015). Analysis of deposited dusts in households in proximity to the rail corridor further supported this hypothesis (Kristensen et al., 2015).

Direct and indirect methods to reduce emissions from freight trains have been implemented over time. Historically, ore was typically wet loaded onto uncovered rail wagons at Broken Hill, presumably to minimise product losses from the top of the wagons, but it would dry while in the Broken Hill shunting yards and during transportation to Port Pirie (Kristensen et al., 2015; citing Body, 1986). Contamination from rail wagons, however, was not specifically targeted until the NSW EPA required the wagons to be covered in 1996 (in response to the aforementioned Broken Hill rail corridor survey, a decade prior in 1986) (Kristensen et al., 2015). Improvements associated with the design of the wagons, including better sealing, has likely helped reduce contamination from wagons.

Despite these mandated requirements to cover rail wagons, the issue of lead within the rail corridor is not resolved (Kristensen et al., 2015). Resuspension of lead-contaminated material necessitates the rehabilitation of the rail corridor to prevent the dispersion of this legacy source.

Emissions and contamination control measures have been applied on the rail corridor sites, for example, the use of Total Ground Control as dust depression and stormwater runoff management (Information observed by OCSE during site visit).

In 2016-2017, BHELP commissioned a rail corridor lead contamination assessment which included research into previous remediation works and sampling and assessment of lead levels along the rail corridor (BHELP, 2017); however, OCSE does not have the visibility and status of assessment.

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[26] "Free areas wind erosion" is usually defined as areas that will not be disturbed by mining activities but are still a source of emissions due to wind erosion. For Perilya operation at North Mines, wind erosions include Waste Rock Harvesting Area and Tailings Harvesting Area (SLR, 2021).

[27] "Free areas" for Rasp Mines can be from existing free areas and also project-related exposed areas. The characterisation of existing '"free area" emissions can be found in Table 25 of the *Air Quality Assessment for Rasp Mine* (Environ Australia, 2010).

1.5.3 Recirculating contamination within the community

BHELS Phase II (2020-2024), which commenced in March 2020, aimed to measure ambient lead concentrations according to the AAQ NEPM and compare the data against both the benchmarked AAQ NEPM standard of 0.5 µg/m^3, as well as with comparable locations in other jurisdictions (NSW DCCEEW, 2025). Phase II also aimed to provide justification for continued monitoring, per the criteria in the NEPM Technical Paper No. 9 (NEPC Peer Review Committee, 2001).[28]

The Phase II study found that for all four HVAS sites (shown in Figure 7),[29] annual lead concentrations were consistently below the AAQ NEPM standard, ranging from 0.029 – 0.128 µg/m^3 (6%-26% of the standard). However, levels were frequently above the level of precision threshold of 0.05 µg/m^3. In addition to the variability in lead levels, this led the study to conclude that ongoing monitoring was justified under the NEPM criteria. It is also reported that the lead in dust levels ranged from 0.00034 – 0.0059 g/m^2/month across all seven DDG sites for the reporting period (NSW DCCEEW, 2025).

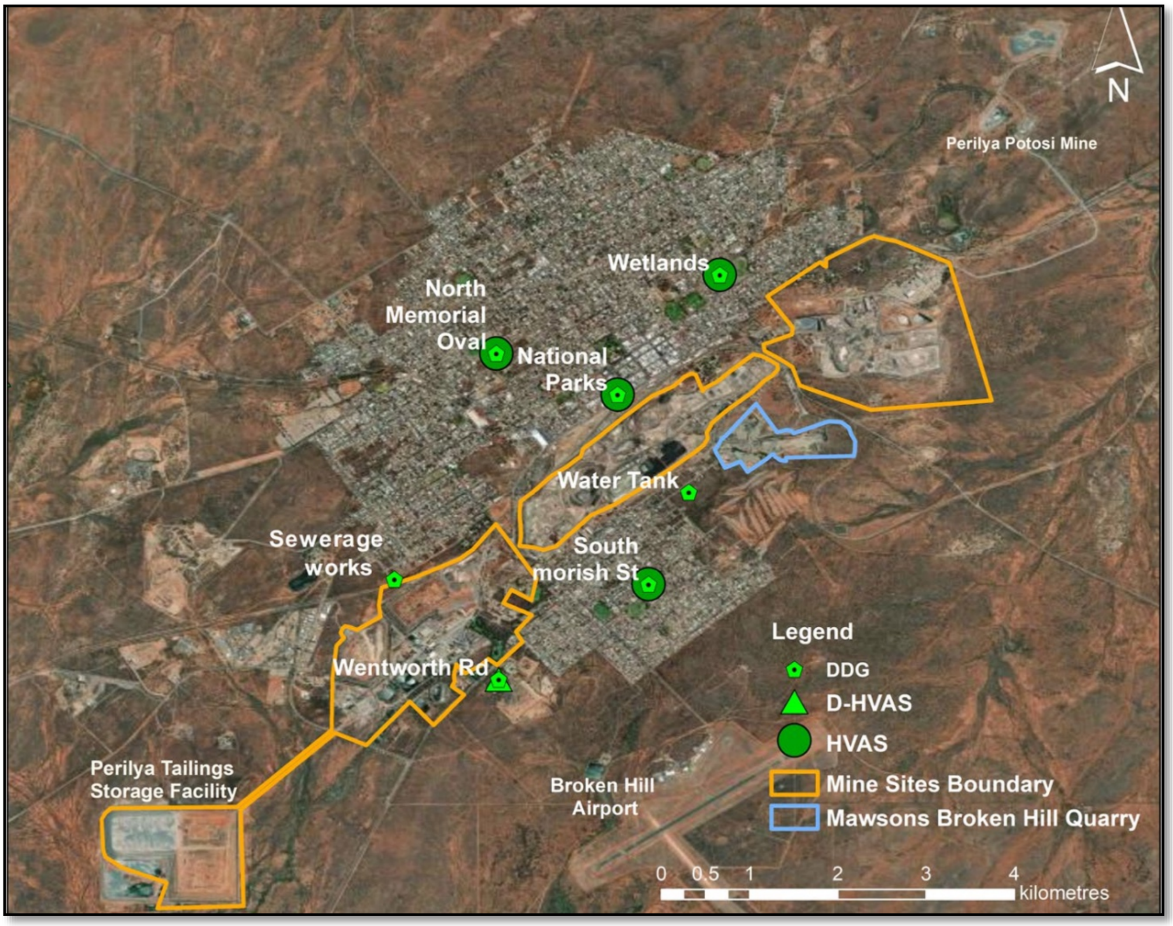

Figure 7: Broken Hill air quality monitoring site locations (green symbols), with sampling type indicated as: DDG – dust deposition gauge; DHVAS – directional high-volume air sampler; HVAS – high-volume air sampler (NSW DCCEEW, 2025).

Measurements from the monitoring network could be used to monitor progress in reducing mining and non-mining emissions (i.e. for evaluation purposes) (NSW EPA, 2020). Additionally, with climate change potentially resulting in a higher frequency of dust storms, it has been suggested that the monitoring network could potentially incorporate data for local air quality/dust indices into community warnings for

[28] The NEPM Measure Technical Paper No. 9 (May 2001) notes that "monitoring of 24-hour lead levels will no longer be required once measurements at peak sites are consistently at or below the level of precision threshold" (which for lead is 0.05 µg/m^3, or about 10% of the NEPM standard of 0.5 µg/m^3).

[29] HVAS sites for Phase II study are National Parks, Wetlands, North Memorial Oval and South Morish Street.

impending high-dust conditions e.g. when there are high levels of pollutants in the air, such as in the event of bushfires (NSW EPA, 2020).

2. Recommendations for Broken Hill

Addressing the problem of lead contamination in Broken Hill should be viewed primarily through a public health lens. Given the widespread presence of lead in the Broken Hill environment, exposure of Broken Hill residents to lead at some level is inevitable, although the degree of exposure and impacts on individuals and specific groups will differ greatly. As such, any strategy to minimise lead exposure should prioritise those most impacted by lead (i.e. children aged less than 5 years old) and support those at high risk of exposure.

Broken Hill will likely remain a viable and active mining community for many years to come. Hence, targeted remediation and emissions control measures – to minimise dispersion and further environmental contamination, respectively – should be implemented alongside public health initiatives to support community members to minimise their exposure. Addressing environmental contamination or implementing public health initiatives in isolation is unlikely to deliver long-term effective outcomes. Desired outcomes and targets should be defined in consultation with an Expert Panel.

A coordinated, adaptive response is required, with clear targets based on desired outcomes (not just tracking activities). This response should follow a clear program logic, and evidence-based decision-making to strengthen community trust. Embedding a Monitoring, Evaluation, Reporting and Improvement (MERI) framework will support adaptive management and ensure that programs can be adjusted to continue to achieve the desired short-, medium-, and long-term outcomes.

A summary diagram of the recommendations is shown in Figure 8. This section draws on findings from the previous chapter and examples of national and international approaches to managing lead contamination, taking into consideration applicability of approaches to Broken Hill's unique climate, geology, economy and social factors.

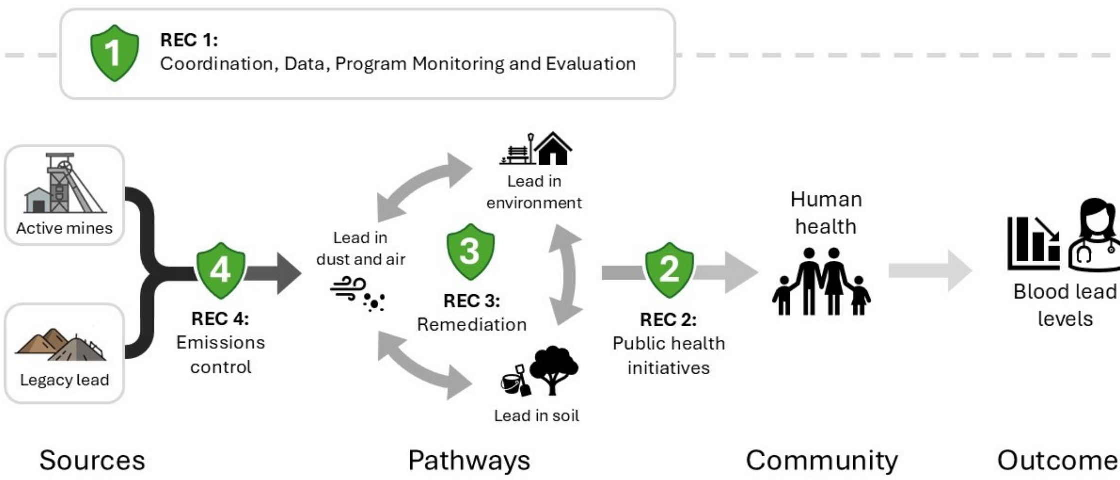

Figure 8: Expected interaction of report recommendations on reducing lead contamination risks across the exposure pathway in Broken Hill to improve human health outcomes.

2.1 Coordinated and collective response

A whole-of-community response to the complex issue of lead contamination and exposure in Broken Hill is necessary, with the NSW Government working alongside key partners and stakeholders in local and Commonwealth governments, industry, and community groups to achieve long-term outcomes that cannot be achieved by a single agency. A long-term commitment to a coordinated response at Broken Hill is critical in enabling design and implementation of actions that will achieve a durable, multigenerational reduction in lead exposure. Continuity of the program will underpin long-term reduction and maintenance of childhood BLL in Broken Hill for as long as mining activities continue. Recommendations in this report should be approached holistically rather than in isolation. Actions that deliver immediate impact should be prioritised and progressed alongside recommendations that require further data and information.

This coordinated response will ensure a consistent approach across partners, sharing knowledge and experience to develop the overarching Program Logic and MERI framework, and facilitate the monitoring of progress and improvement across the Broken Hill community. Central to this concept is the need for a single data depository to allow transparent, evidence-based decision-making and program development, measure effectiveness, and guide adaptive management.

Recommendation 1: Coordination, data and program evaluation

The NSW Government, alongside key partners and stakeholders should implement these recommendations as the future lead program to address lead contamination and exposure in Broken Hill. This should include establishing a centralised resource in Broken Hill to act as the responsible entity for coordinating activities and communication to enable timely, transparent and evidence-based decision making.

Recommendation 1a:

Ensure individual recommendations are not considered in isolation; progress those that can be advanced immediately, while gathering further information to inform others.

There is little publicly available information about BHELRG, including its functions, membership and remit. To build community trust and support clear communication between stakeholders and the community, a centralised resource should be established in Broken Hill, with a dedicated individual or team to coordinate ongoing activities or programs.

Further, this co-ordinated approach should be supported by ongoing Expert Panel guidance. The Panel should consist of professionals with relevant expertise, be independent of any ongoing programs and BHELRG, and operate in an advisory capacity to ensure that evidence-based guidance informs decision-making on a continuous basis. A model example is the Advisory Committee on Tunnel Air Quality (ACTAQ). ACTAQ consists of a range of experts/officers across government and academia undertaking work to better understand air quality issues associated with road tunnels in Sydney (OCSE, n.d.). ACTAQ undertakes regular studies and produces technical reports as part of ongoing advice to government on issues that arise from the assessment and operation of road tunnels. ACTAQ also provides advice to the appropriate Department on air quality aspects of relevant Environmental Impact Statements, which is then published on the Department's Major Projects Assessment portal. Transparency and/or oversight of this decision-making is important for ensuring that stakeholders have confidence that decisions have been made using robust scientific evidence.

Recommendation 1b:

The centralised resource should be supported by ongoing Expert Panel guidance, independent of the BHELRG and the future lead program, to provide evidence-based guidance that informs decision-making on a continuous basis.

Recommendation 1c:

Establish an integrated, transparent and whole-of-system approach to data and information collection storage and analysis to support timely, evidence-based decision-making and strengthen community trust.

2.1.1 Better decisions require better data

Monitoring and evaluation of the overall success of the programs must be supported through effective data management, reporting and transparency of process. This in turn dictates a data management regime that adopts an integrated approach to data collection, analysis and management to strengthen predictive capabilities, adaptive learning and decision-making. The regime should include a default position of open data for decision-maker use, e.g. data should be FAIR (Findable, Accessible, Interoperable and Reusable).[30] This means data that is high quality, readily accessible, in usable formats and transparent in its assumptions and applications.

A careful balance will need to be struck between transparency and compliance with privacy legislation, including both general and health-specific requirements under NSW law. While protecting individual health information is paramount, sharing and analysing aggregated data can provide evidence of success and aid in an adaptive management approach. To achieve maximum value of data while still considering confidentiality, it is essential to consider the legal frameworks governing privacy, establish clear protocols for what data can be shared, and define guidelines that safeguard confidentiality while maximising the value of data for community health outcomes.

Assumptions and biases underpinning collected data will also need to be clearly defined prior to using data for decision-making. For example, most emissions data come from mine areas due to emissions monitoring programs at mining sites. This should be clearly stated to avoid the assumption that all emissions are coming from mining areas – rather, the data is just predominantly collected at mining areas. Similarly, soil lead concentration data is usually collected where there is a high BLL occurrence, not collected proactively across all sites, so it may not provide an overall picture of Broken Hill soil lead concentration outside of areas with observed high BLL. Transparency about how and why data is collected and used is paramount to making good lead management decisions.

Data collection, evaluation and all information compiled through current and any future lead programs should also be a consideration from initial program design stages onwards. Data collected should align to the outcomes stated in the Program Logic and will also serve to identify knowledge gaps that can be filled by intentionally designed programs. By setting key evaluation questions and identifying what relevant monitoring information (e.g. data) is needed to answer these questions, it is possible to assess both the efficacy of actions taken and progress towards short-, medium- and long-term outcomes. This would be most effectively achieved through a centralised data repository, providing access to monitoring data for all agencies involved in lead programs, and promoting better coordination between agencies and evaluation/monitoring efforts.

Legislative requirements may need to be considered when establishing a single data depository and engagement with people experienced in data management is essential to ensure these legislative requirements are being adhered to while allowing the group to access as much information as possible to support the program and its effectiveness.

Recommendation 1d:

Develop a Program Logic for the future lead program that includes clear outcomes and targets to reduce lead in the environment.

2.1.2 Program Logic

A well-defined and agreed Program Logic will provide all stakeholders with a shared understanding of objectives, which in turn helps coordinate activities and increases the likelihood of successful outcomes. To support actions through program planning, a preliminary Program Logic was developed by the OCSE (Figure 9). This outline communicates how program components will contribute to the short-, medium- and long-term outcomes needed to reach the overarching intent aligning BLL in the Broken Hill population with that of the broader NSW population. Broadly, a Program Logic can be used to support program monitoring through determining what data to collect, identifying key measures and indicators to track progress, and providing a program performance narrative. This Program Logic should be further developed through working with a range of stakeholders and government agencies to draw on their understanding of the program and its outcomes to clearly delineate understanding of roles and responsibilities, lines of

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[30] FAIR Principles and resources can be found at https://ardc.edu.au/resource-hub/making-data-fair/, accessed 17 December 2025.

communication and triggers or thresholds for action by stakeholders if activities are not progressing towards intended outcomes.

A Program Logic contributes to an effective monitoring and evaluation approach through determining what to evaluate, identifying key evaluation questions and identifying what information is needed to answer evaluation questions and when. It can provide a mechanism for ensuring acceptability of an approach with stakeholders, by clarifying how specific issues relate to an overall program goal. An example of matrix mapping activities against outcomes is shown in Table 1. With further development, the monitoring and evaluation principles suggested here could be used to develop MERI framework actions to evaluate program performance against outcomes in a structured, standardised format. The evaluation approach is further discussed in Section 2.1.3.

Recommendation 1e:

Design and implement a robust, effective and transparent MERI framework that facilitates adaptive management of the future lead program, reflects the Program Logic and measures progress towards outcomes.

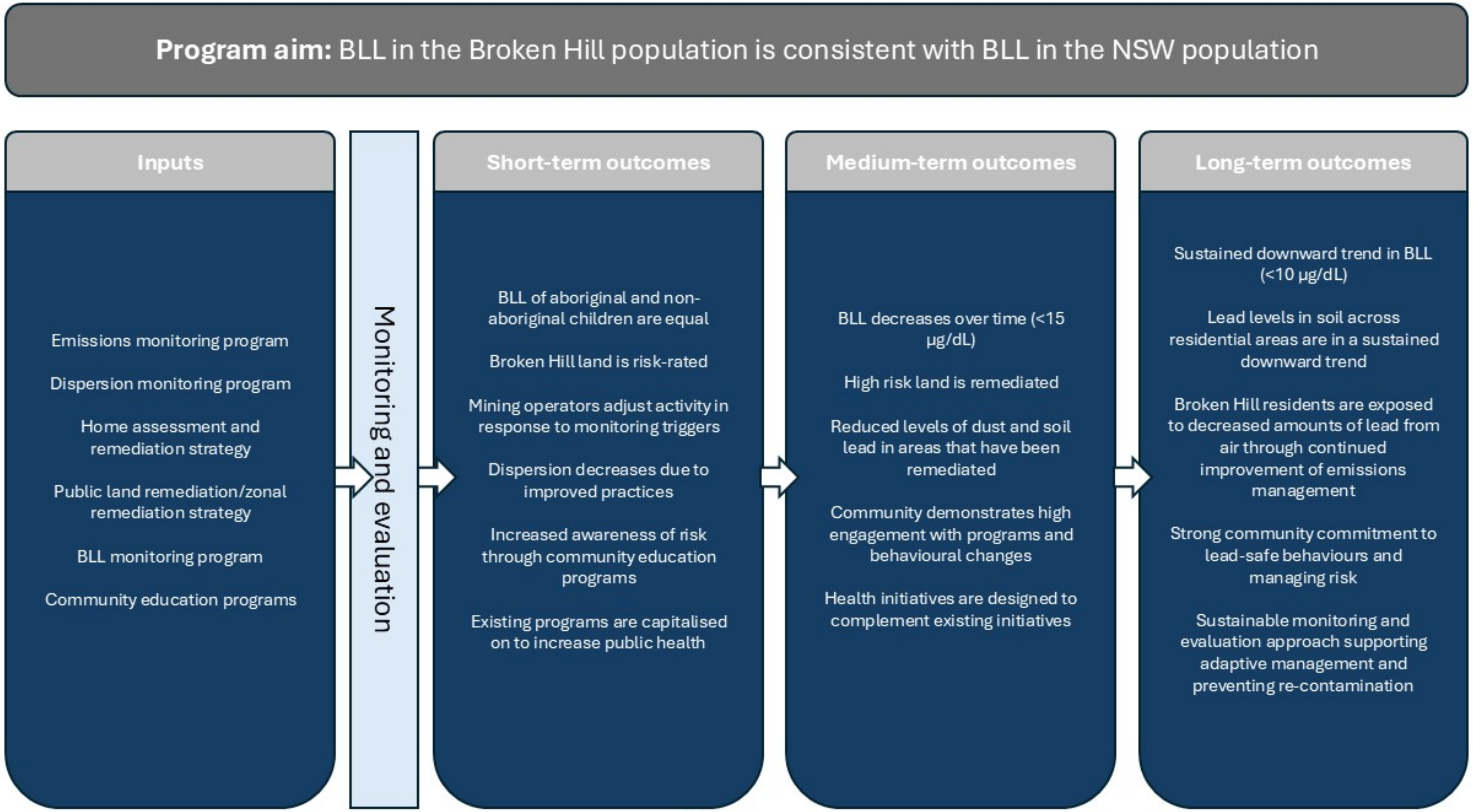

Figure 9: Preliminary Program Logic.

Table 1: Framework linking actions to measurable outcomes for Iterative Assessment

Term	Outcome	Emissions monitoring program	Dispersion monitoring program	Home assessment and remediation strategy	Public land remediation/ zonal remediation strategy	BLL monitoring program	Community education programs
Short	BLL of aboriginal and non-aboriginal children are equal					X	
Short	Broken Hill land is risk-rated	X	X		X		
Short	Mine operators adjust activity in response to monitoring triggers	X					
Short	Dispersion decreases due to improved practices		X				
Short	Increased awareness of risk through community education programs					X	X
Short	Existing programs are capitalised on to increase public health					X	X
Medium	BLL decreases over time (<15 µg/dL)					X	
Medium	High risk land is remediated				X		
Medium	Reduced lead concentration in deposited dust and soil in areas that have been remediated			X	X		
Medium	Community demonstrates high engagement with programs and behavioural changes						X
Medium	Health initiatives are designed to complement existing initiatives					X	X
Long	Sustained downward trend in BLL (<10 µg/dL)					X	
Long	Lead concentration in soil across residential areas in a sustained downward trend			X			
Long	Broken Hill residents are exposed to decreased amounts of lead from air through continued improvement of emissions management	X	X				
Long	Strong community commitment to lead safe behaviours and managing risk						X
Long	Sustainable monitoring and evaluation framework supporting adaptive management and preventing re-contamination	X	X	X	X	X	X

2.1.3 MERI framework

An effective monitoring and evaluation approach can be used to form a Monitoring, Evaluation, Review and Improvement (MERI) framework. This framework will support all-of-program implementation, evaluation and progress towards goals. For this report, we suggest potential metrics for monitoring activities that can be used to guide evaluation of the activity's progress towards the short-, medium- and long-term outcomes outlined in the Program Logic (Table 2). This is a preliminary framework based on the initial findings outlined in this report and should be developed further by the BHELRG/relevant bodies into a comprehensive MERI. Further development should include reporting and improvement actions.

The MERI framework is intended to support adaptive management in response to progressive monitoring and evaluation. It is designed as a continuous cycle of evaluation, rather than a discrete evaluation event ensuring suitable evaluation metrics are chosen and that data are readily available. The framework should consider all lead management efforts in Broken Hill as an ecosystem, accounting for their impacts in relation to each other to maximise efficiency.

For example, zonal remediation needs to be designed alongside a monitoring approach and adaptive management plan. Without monitoring, remediation efforts may be counterproductive. For example, lead-rich dust from mining operations and railway corridors continues to be deposited on remediated areas. Long-term durability (e.g. erosion, maintenance needs) of remediation efforts is not well documented. The approach of 'cap and cover' has only been found to be effective for a limited period, which may lead to reduced caution from community members if they believe that remediation efforts have completely removed lead from yards and public areas (Cattle & Wimborne, 2016). Once a baseline level of lead concentration in soil and deposited dust at a site pre- and post-remediation is established, remediated sites should be monitored regularly to ensure that remediation is not becoming less effective. If remediation is becoming less effective, there need to be trigger values that indicate this and a plan in place to increase efficacy.

Additionally, the efficacy of public health initiatives (including community programs such as education and nutrition initiatives) should be assessed on a regular basis using a standardised set of metrics. Currently, there is no standardised evaluation framework or data repository for all programs under the BHELRG. Evaluation metrics are not consistent year-to-year and are often descriptive data pertaining to program delivery (e.g. number of homes remediated, number of tests delivered) versus quantitative data on program efficacy.

Adaptive management should be supported by ongoing Expert Panel input to ensure scientifically robust triggers, timely incorporation of new data, and continuous review of the overall lead management approach in Broken Hill.

Recommendation 1f:

Use technology to better understand lead contamination across Broken Hill. Mapping of lead across Broken Hill to assist in targeted remediation works and using sensors and associated technologies to provide real-time monitoring of lead in air and dust levels would support timely, informed decision-making.

Table 2: Draft MERI framework

Theme	Activity	Monitoring	Evaluation
Lead source management	Emissions monitoring program	Airborne lead-in-air concentrations (μg/m^3, lead in TSP); number of exceedances of trigger values or standards over a period of time; magnitude of such exceedance; meteorological data (wind speed, direction, weather events); emissions volumes from major sources (monitoring at mines)	1. Are lead levels higher in source areas or non-source areas? 2. Are lead levels below AAQ NEPM standards? 3. Are lead sources depositing lead dust to remediated and non-remediated areas at levels that will keep children at risk?
	Dispersion monitoring program	Lead in deposited dust (g/m^2/month) using DDG; surface and sub-surface soil lead levels; D-HVAS/TSP analysis; meteorological data (wind speed, direction, weather events)	1. Is dispersion decreasing due to lead management activities? 2. Are there areas where dispersion is greater than others? 3. How are environmental factors (wind, storms etc.) influencing dispersion patterns?
Management of lead in land	Home assessment and remediation strategy	Number of homes assessed/remediated; remediation actions taken; pre- and post-remediation soil/dust lead levels; condition of capping materials after certain period of time	1. Are remediation activities effectively reducing lead levels in homes and resident lead exposure? 2. Are remediation activities effective over time? 3. Is the current home assessment process accurately identifying homes that are at higher risk? 4. Which remediation methods are the most effective? 5. Are participation rates and remediation actions equitable and accessible to all community members?
	Public land remediation/zonal remediation strategy	Soil lead levels (mg/kg) pre- and post-abatement; condition of capping materials after a certain period of time; identification of risk areas based on a risk matrix for prioritisation	1. Are set trigger values, alongside other risk assessment measures, effective for identification risk areas? 2. Are abatement measures effective over time at source sites? 3. Are abatement and remediation efforts remaining effective over time, or is replenishment/dispersion changing lead levels?
Community health initiatives	BLL monitoring program	Mean BLL disaggregated by age group, area, risk level, etc.; participation rate by demographic; % of children < 5 ug/dL	1. Are community members consistently participating in the BLL monitoring program? 2. Are BLL declining and if so, is this consistent across demographic groups? 3. Are BLL reductions aligned with other program areas (e.g. home remediation efforts)?
	Community education programs	Engagement metrics (regular surveys – e.g. % of households receiving lead safety education, % of parents reporting safe cleaning practices); participation rates/attendances at community events; number of events; website/dashboard traffic	1. How is the community engaging with behavioural and educational initiatives? 2. Are behavioural and educational initiatives translating into safer management practices (e.g. handwashing, nutrition)?

2.2 A public health-centred approach to lead exposure

Addressing lead exposure in Broken Hill requires a two-pronged approach to manage environmental contamination while also supporting the public to minimise their exposure. Involving the community in health and safety programs supports community members to be the catalysts and agents of change. A community-based approach to health and safety requires the key elements of community focus, community member participation, intersectoral collaboration, substantial resource requirements, a long-term program view, multifaceted interventions and a population outcome (Nilsen, 2006). A community-based approach is predominantly aimed at achieving population- or community-wide health and safety outcomes, rather than directly targeting high-risk individuals including pregnant women and children from low socioeconomic backgrounds.

One potential risk of a community-based approach is that community heterogeneity can reduce engagement and participation. Ensuring that initiative design considers accessibility to the different groups within the Broken Hill community (e.g. ethnicity, income, educational and work experience) can reduce this risk. Community empowerment – through changing both the availability of health resources and programs and the messaging around these programs – is also critical. Making program participation the standard across all groups at Broken Hill can support the 'bottom-up' ideal of a community-based approach.

Additionally, community mobilisation to solve a shared issue, i.e. lead exposure in children, is more likely to occur if the issue is regarded as a 'whole of community' public health issue. Some researchers have proposed that between 6,000 and 20,000 people is the ideal catchment size for community-based program success (Hancock et al., 1997). As the population of Broken Hill is small (~17,000) and the issue of lead is shared among all residents, there is reason to believe that a community-based approach can be successful.

Programs such as the Trail Area Health & Environment Program (THEP)[31] rely on this community-based approach, where community leadership and participation are fundamental to the program's success. Community members actively participate in updating the THEP's strategic direction, and public meetings are held five times per year. Regular surveys are conducted with members of the public to better understand the impact of THEPs (THEP, 2024b).

Recommendation 2: Public health initiatives

Strengthen the public health response to lead exposure through a more comprehensive education and access program, supported by an approach that considers all relevant risks

2.2.1 BLL screening program

The current BLL screening program commenced in 2015 and over time there have been attempts to assess the program to improve its reach and ability to capture those at greatest risk.

The *Health Check* report, which aimed to assess the effectiveness of the BHELP, highlighted an opportunity to gain further insight into the BLL screening data through deeper statistical analysis and independent or scientific review of the data. Examples include reporting the proportion of age groups exceeding the guideline level, stratified year-to-year age group comparison, regular spatiotemporal mapping of data or comparison of case management and home assessment numbers over the years etc. (NSW EPA, 2020). Some of these recommendations are already reflected in the latest lead health report (WNSWLHD Public Health Unit, 2025) and recently published journal articles, for example using the BLL data in machine learning to identify influencing factors (Liu et al., 2021) or using longitudinal BLL data to inform high-risk areas and remediation strategies in Broken Hill (Lyle et al., 2022). Through consultations, the Broken Hill community have expressed concerns that BLL screening participation rates may drop if there is not a clear link between identifying high BLL and offering practical solutions.

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[31] More information about THEP is available at https://thep.ca/, accessed 17 December 2025.

Using geometric mean to present BLL (as currently presented in the annual reports) may not be the best statistical approach for representing and analysing long-term health data. Geometric mean has the potential to down-weigh extremely high values as it aims to better represent 'typical' exposures. Misrepresenting 'very high' BLL may mask individuals or subgroups with very elevated exposures and has the potential to make a population risk appear lower than it actually is - or at least presents challenges with communicating risk. This therefore misrepresents vulnerable groups such as Aboriginal children, even though health risk assessments and intervention strategies should be driven by these groups of children. An expert statistician should be engaged to advise on analysis of BLL data, with deeper insights likely being useful in guiding ongoing public health and remediation activities.

Evaluation of historical BLL screening data has also been performed to inform ongoing BLL screening program activities. For example, FWLHD and BHUDRH investigations of historical BLL in 2017 found that the increase in BLL in the first 2 years of life can already be observed at the age of 12 months (BHELP, 2017). Hence, BLL screening for children starting at 6 months was reintroduced in 2018, aligning with the immunisation schedule, as an early detection and prevention measure (BHELP, 2018; WNSWLHD Public Health Unit, 2019). However, in 2024 BLL screening data showed the average number of children in the 6-month-old cohort with BLL greater than 10 µg/dL was less than one, meaning almost all the children in this cohort would not be eligible for home remediation. Combined with the limited remediation pathway, the age of first screening was moved back to 12 months by the MMAHC and families are provided with education and resources.

However, lead screening is still offered for children under 12 months through FWLHD CFH at general health checks and immunisation appointments, which includes the 6-month check. Families can also request lead screening on an ad hoc basis or at intervals that suit them. This may take a risk-based screening approach, such as having older siblings with high BLL, residing in homes with known high lead risk, and/or upon parents'/guardians'/carers' request (WNSWLHD Public Health Unit, 2025). FWLHD noted that retaining the screening at 6 months was important because if the BLL is already starting to increase before the child is starting to properly engage in their environment, then their risk is most likely higher. In this case, regular monitoring or a home assessment to identify the source, and/or education, can be targeted and is an appropriate measure. For annual reports, OCSE is aware that the 6-month screening data is no longer included as it is not a complete data set but can still be accessed by relevant health agencies upon approval.

A targeted approach for additional BLL screening of at-risk children could be implemented using data collected from zonal remediation to identify areas where additional screening may be necessary. Data could also be used to identify others at high risk of lead exposure (e.g. newborns in affected homes) and develop a standardised set of criteria for screening of children outside of the standard screening age group. These criteria should be based on individual lead risk exposure factors and additional screening should accompany existing population-based BLL screening.

Additional screening data of at-risk children, identified using zonal remediation data and/or environmental data collected as part of a risk-based approach to remediation, should not be included in statistical analysis of the BLL screening program as it will not be consistently collected and there are likely to be outliers.

Recommendation 2a:

Continue the current blood testing program, ensuring that there is consistent screening of age groups, consistent data collection, and a standardised/structured statistical analysis approach that seeks to understand trends in BLL data and potential links to causal environmental factors.

Recommendation 2b:

Link zonal remediation data and a risk-based approach to remediation to inform and enhance a targeted approach for additional BLL screening of at-risk children. Data can be used to identify others at high risk of lead exposure, for example siblings of children with high BLL or newborns in affected homes and develop consistent 'trigger criteria' for screening of children outside of the standard screening age group.

2.2.2 Community programs

The current BHELP program has had some success as a community-based approach to managing lead risk in Broken Hill – through ongoing home remediation, community dust monitoring, education and awareness activities (as discussed in Chapter 1). Improvements in children's BLL have occurred since the BHELP was established in 2015 (NSW EPA, 2020), however geometric mean has plateaued in recent years. (WNSWLHD Public Health Unit, 2025). This long-term, whole-of-community approach to reducing the impacts of environmental lead in Broken Hill should continue in its current capacity, but also be iteratively improved through increased engagement, coordination, and better monitoring and evaluation.

Community consultations highlighted the value of general community messaging from the BHELP. Continuing and expanding the BHELP's consistent, plain-language campaigns, delivered through local media, community events and schools can help to normalise lead-safe behaviour across the community. Examples include continued messaging around increased handwashing, general cleanliness and increased use of Lead Ted as interactive messaging for children. Families going through relevant life changes, such as young couples looking to have a child, should have additional support and messaging from the BHELP on changes they can make to lower their own exposure and that of their newborn.

Increasing community engagement overall will require changing not only the availability of health resources, but also the norms and messaging around lead prevention initiatives so that protective behaviours become universally accepted and self-sustaining. This can be achieved through fostering a culture where actions such as regular BLL testing for all children, safe home maintenance and dust management are seen as routine and responsible. By normalising community member participation through consistent and positive messaging, supported by multifaceted interventions, the BHELP can encourage unofficial 'policy shifts' at the community level that reinforce positive health habits in the long term as a community responsibility.

Recommendation 2c:

Strengthen the community reach program and revamp initial BHELP programs that identified lead exposure as a public health concern, such as hand washing and Lead Ted.

2.2.3 Nutrition

There is a growing body of evidence suggesting that education and accessibility to nutritional interventions should be considered alongside a primary prevention approach to mitigate lead exposure in children. Evidence linking nutrition and lead exposure in children primarily centres on the relationship between elevated BLL and iron deficiency (Kordas, 2017). The biological mechanism linking diets high in iron, calcium and vitamin C with lower absorption of lead in children appears to be competition for lead absorption across cell membranes in the gut with other divalent metals (Kordas, 2017, 2017).

Iron deficiency has been associated with pica in children, and the consumption of non-food substances (such as dirt) may increase lead exposure through the increased ingestion of lead-laden soil. The complex interplay between iron deficiency, pica and co-morbidities highlights the need to consider iron deficiency as a potential risk factor for remediation programs and other interventions to reduce lead exposure in children (Shah & Hauptman, 2025).

Food fortification and supplementation of specific nutrients such as iron, calcium and zinc have previously been considered as potential interventions to reduce lead uptake; however the evidence is equivocal (Kordas, 2017; Zimmermann, M.B et al., 2006). In children without deficiencies, evidence for nutritional interventions remains anecdotal, indicating a need for further research. Nutritional approaches may therefore be best framed around preventing iron deficiency rather than mitigating BLL in children with normal iron status.

Improving the nutritional intake of children in Broken Hill, with a focus on increasing access to sources of iron, vitamin C and calcium, provides a key opportunity to improve diet quality in general. This is particularly significant for children from socioeconomically disadvantaged backgrounds, where improved nutrition can have lasting positive impacts on both individual and community health (Kordas, 2017).

Anecdotally, OCSE heard that some lead mines take a similar approach to help protect their workforce, providing one meal a week high in iron and vitamin C (to aid in iron absorption). The LeadSmart program recommends the consumption of iron-rich wholefoods (e.g. meats, poultry, wholegrain breads), vitamin C to aid in the absorption of iron (e.g. citrus fruits and vegetables), and calcium (e.g. dairy).

Improved accessibility to iron-rich wholefoods in conjunction with foods high in vitamin C may reduce lead uptake and assist with addressing the high BLL in children in Broken Hill and should be further considered. It may be possible to leverage existing public health nutrition initiatives available through State and Commonwealth programs (e.g. Nutrition NSW, Healthy School Canteens for Healthy Kids, and Munch and Move). For Broken Hill, building the community knowledge base could involve improving nutrition literacy through cooking demonstrations and lessons, advice for pregnant mothers, and targeted cooking classes utilising community cooking facilities.

Recommendation 2d:

Promote nutritional knowledge on lead and diet across the community and improve access to health foods by continuing to incorporate nutrition messages in the LeadSmart program and establish community programs to assist access.

2.3 Remediation

As discussed in Section 1.2.2, responsive home assessments and remediation are being performed at homes of children with elevated BLL, along with some preventative remediation across private and public properties. As lead contamination is a multifaceted problem with various sources and pathways of exposure, a zonal remediation approach based on both environmental and health risk factors is needed to ensure overall reduction of lead exposure to the whole of community, while reducing BLL in the most at-risk community members (i.e. children aged 0-5 years old).

It is important to reiterate that zonal remediation in isolation will not be effective without mining emissions monitoring and control, which will be further discussed in Section 2.4.

2.3.1 A zonal remediation approach

Zonal remediation is a targeted approach that aims to reduce exposure to lead from existing legacy contamination and decrease the possibility of lead dispersion from known sources to other areas within the community. The remediation activities may include and are not limited to residential properties, childcare centres, schools, public parks, railways, and legacy and current mining areas.

Targeted zonal remediation can be an effective strategy for reducing BLL in children. For example, Lyle et al. (2022) found that children (born 2009-2015) living in the highest-risk zone closest to the Line of Lode were 2.6 times more likely to develop very high BLL than children living the furthest away from the Line of Lode. However, since the majority of children with very high BLL (69%) lived elsewhere in the community, a zonal remediation strategy would have to be extended beyond just the highest-risk zones. The key goal should be to eliminate risk by removing contamination in the wider environment (as well as in individual homes) (Dong et al., 2020).

This approach would progressively expand to include low exposure risk areas of the city and capture secondary residences (and other places) where children with elevated BLL may be exposed to lead (NSW EPA, 2020). Of children up to 3 years of age (from 65 families interviewed), eighty-eight per cent were found to spend time at other locations outside of the family home, with 68% most commonly visiting private residences and 15% visiting childcare facilities (Lyle et al., 2021). This research highlights the importance of remediation beyond primary residences.

A zonal approach to remediation for either public land or private housing is not currently in place, although it has been proposed. The *Health Check* report on BHELP recommended that the BHELP explore the cost-effectiveness of zonal remediation (NSW EPA, 2020). Since then, the EPA has informally outlined an approach for developing an evidence-based zonal remediation strategy for non-mining areas to minimise childhood impacts of lead exposure, noting that no comprehensive testing of remediated public lands has occurred since 2017.[32]

In the near term, a zonal remediation approach should consider:

- identifying high risk zones (i.e. lead contamination hotspots) for targeted measures based on current criteria of BLL and lead in soil (Section 2.3.2-2.3.3)
- prioritising remediation where community members have been identified to be at greater risk based on other risk factors (Section 2.3.4)
- monitoring and evaluation of remediated sites over time (Section 2.3.5).
- incorporating all remediation activity across Broken Hill

Further measures to ensure the effectiveness of zonal remediation in the medium to long term include:

- Addressing redispersion from known sources (e.g. legacy mining area, railway corridor) and the potential contribution of stormwater in redispersion (Section 2.3.6) (medium term).
- Engaging experts to determine lead-in-soil target values (i.e. lead-in-soil concentration after remediation) to meet human health outcomes in the long term (Section 2.3.7).

2.3.2 High-resolution geospatial mapping

In reviewing the available documents, including the Conceptual Site Model (Ramboll, 2024), OCSE has identified data and evidence that can inform identification of high-risk areas for targeted zonal remediation (summarised in Appendix 2). Key findings include:

- Significant evidence highlighting areas proximate to the Line of Lode (0.4 km north and 0.8 south of ore body) that have higher concentrations of lead in soil, household dust and dust deposition (Dong et al., 2019, 2020; Gillings et al., 2022; Taylor, Isley, Lyle, et al., 2019, updated 2022).
- D-HVAS results also show that wind blowing from the Line of Lode has higher lead in air and dust, compared to wind blowing into the Line of Lode (NSW DPIE, 2021a, 2021b; OEH, 2018, 2019). A National Parks site AAQ NEPM compliance reading shows consistently higher lead-in-air concentration than other AAQ NEPM sites due to its location being north of the Line of Lode with prevailing southerly winds (NSW DCCEEW, 2025).
- Dust deposition gauges at Silver City Highway and National Park sites confirm high lead levels observed from D-HVAS (NSW DPIE, 2021a, 2021b; OEH, 2018, 2019).
- Geospatial distribution of children with high BLL trajectory based on longitudinal data shows clustering of residences adjacent to and mostly south of the Line of Lode and one north locality. This is associated with high-risk soil lead concentrations (Lyle et al., 2022).

Examples of key mapping are presented in Figure 10. There are limitations and gaps within the existing geospatial data on concentration of lead in soil. For example, the dataset includes historical readings, and it is not clear if these values are updated after remediation. Further, lead in soil data collection might be skewed towards most properties referred during home remediation programs following identification of elevated BLL. Therefore, further work is needed to comprehensively map lead in soil across Broken Hill to guide identification of high-risk areas for zonal remediation. Recent developments in remote sensing and other technology (e.g. drones, LiDAR, etc.) should be considered to expedite this effort.

[32] NSW EPA, pers. comm., 2025

Recommendation 3: Remediation

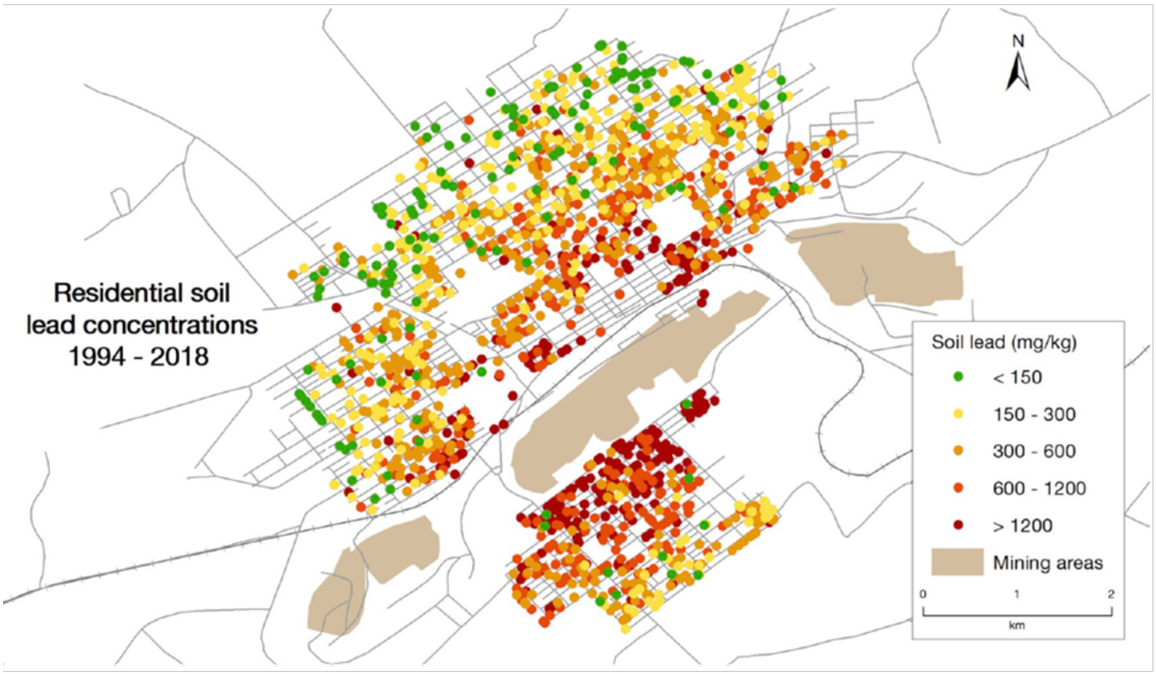
Continue to manage lead in soil through the development of a co-ordinated and strategic remediation program.

Recommendation 3a:

Pivot to a zonal remediation program that utilises the best available information on lead exposure sites across Broken Hill. This should include:

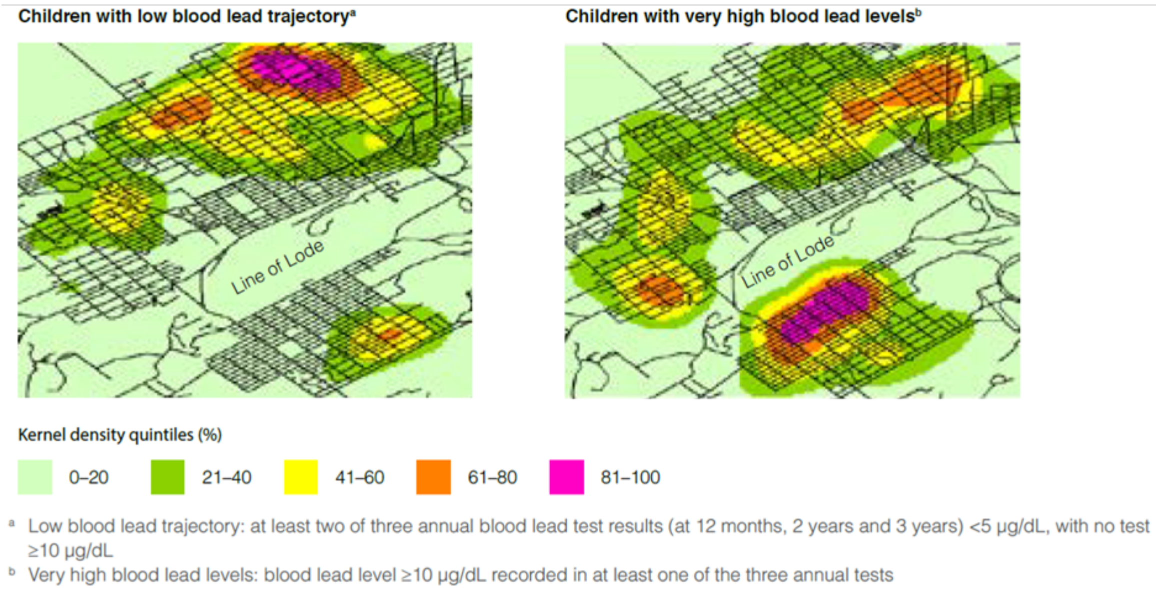
- developing a high-resolution geospatial map of lead exposure across Broken Hill based on existing data including BLL and lead in soil.

A) Residential soil lead concentrations 1994 - 2018



(Dong et al., 2020)

B) Geospatial maps of BLL trajectory



(Lyle et al., 2022)

Figure 10: A) Spatial distribution of soil lead (mg/kg) data from the period 1994 -2018, with majority of soil samples (n=10,160) were collected between 1995-2015 with additional data from 62 homes (mean values) collected in 2018. Reproduced from (Dong et al., 2020). B) Geospatial maps of Broken Hill showing where children with a low BLL trajectory or very high BLL were clustered, based on longitudinal data from children born 2009-2013 (Lyle et al., 2022).

2.3.3 Managing high-risk areas

Lead contamination in soil is currently managed through the National Environmental Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM), which outlines health-based investigation levels (HILs). The ASC NEPM HILs for lead contaminants in soil are shown in Table 3.

Table 3: Health-based investigation levels (HILs) for lead contaminants in soil (mg/kg). Source: Schedule B1 – Guideline on Investigation Levels for Soil and Groundwater, Table 1A (1), (NEPC, 2013a).

Land use	Lead in soil HILs (mg/kg)	Land use description
Residential (A)	300	Residential with garden/accessible soil (home-grown produce <10% fruit and vegetable intake (no poultry)), also includes childcare centres, preschools and primary schools.
Residential (B)	1,200	Residential with minimal opportunities for soil access; includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments.
Recreational (C)	600	Public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. This does not include undeveloped public open space where the potential for exposure is lower and where a site-specific assessment may be more appropriate.
Commercial/ industrial (D)	1,500	Commercial/industrial, includes premises such as shops, offices, factories and industrial sites.

The ASC NEPM HILs for lead in soil predate the latest NHMRC BLL guidelines. They were derived using blood lead models (specifically, the Integrated Exposure Uptake Biokinetic (IEUBK) model) based on an Australian population BLL goal of ≤10 µg/dL, accounting for all routes and all sources of exposure including soil concentration, and intake from other sources such as air, diet and drinking water. The National Environmental Protection Council (NEPC) also noted a sufficiently conservative value of 50% oral bioavailability (absolute bioavailability) has been considered in deriving the HILs (NEPC, 2013a, 2013b). This value is equivalent to 100% relative lead bioavailability, and is higher than the 21% mean relative bioavailability (n=10) found in Broken Hill South soil samples (Juhasz, 2018). NEPC also notes that site-specific bioavailability may be important and should be considered when appropriate (NEPC, 2013a, 2013b). Derivation of lower health-based lead in soil concentration will be further discussed in Section 2.3.7.

In-situ analysis of front yard surface soils across Broken Hill returned a median bulk lead concentration of 382 mg/kg (n=62) (Gillings et al., 2022), which indicates that most soil samples are above the ASC NEPM HIL value. Until further information is available to inform the preventive remediation strategy, the existing investigation criteria of 300 mg/kg soil lead concentration (i.e. trigger for further investigation and action) is appropriate. This should be used alongside other risk assessments (e.g. ground cover condition, presence of a nearby storm sprout, presence of children with pica condition) and the current reactive remediation parameters such as the presence of children with elevated BLL of > 5 µg/dL).

Recommendation 3a:

- Identifying high-risk areas where BLL exceed 5 µg/dL and with soil values above 300 mg/kg. Values are based on current criteria and should be revised by an Expert Panel.

An example of preventative lead home assessment and remediation that uses existing ASC NEPM HILs, taking other risk factors into consideration, is discussed in the case study below.

Case study 1 (Broken Hill, NSW): Inclusion of preventative lead assessment and lead exposure reduction measures during scheduled property maintenance as a proactive initiative.

In 2024/2025, as a part of overarching Aboriginal Housing maintenance works across the Murdi Paaki region, the Aboriginal Housing Office (AHO) collaborated with the BHELP team and MMHAC to assess lead contamination levels in 45 Broken Hill properties which were scheduled for maintenance works. The collection of over 800 environmental samples was proactive – it was not triggered by elevated BLL or previous contamination. Out of 45 properties, it was found that 53% were at high risk level requiring remediation, and another 11% were at marginal risk. Regardless of testing results, both preventative and responsive measures were applied to all properties to reduce all tenants' exposure to lead (NSW EPA, 2025a).

The comprehensive remediation strategy recommendations in the AHO report (NSW EPA, 2025a) take into consideration:

- the location of the property and its distance from the Line of Lode
- clearly defined risk indicators based on type of lead source, visual assessment and lead concentration in samples taken compared to existing ASC NEPM HILs
- other exposure risk factors (e.g. the thickness of ground cover, whether the child living in the property has pica/eats soil), and/or
- case-by-case management (e.g. for elevated lead in soil, exemptions from water restrictions may be requested for the family to maintain grass cover, or restricted access to areas where remediation cannot be done).

The work by AHO and BHELP highlights a potential prioritisation and proactive risk-based remediation strategy, that could be applied to Broken Hill city-wide. Anecdotally, OCSE was informed that a similar initiative was being undertaken for the 150 mining workers' homes that are owned by Perilya.[33]

2.3.4 Prioritising high-risk places and exposure risk factors

The BLL and lead-in-soil datasets should be used with other assessments as multiple lines of evidence to inform prioritisation of remediation work. For example, topsoil lead concentration and visual assessment of vegetation cover percentage were previously used in a risk assessment matrix to prioritise sites for public remediation work (Green et al. (2016). Similarly, the proactive remediation work described above by AHO takes into account other exposure risk factors like the thickness of ground cover or the presence of a child with pica (NSW EPA, 2025a).

The inclusion of other risk factors to be considered may include (in no particular order):

- properties that are primary or secondary residences for children with high BLL
- properties that are primary or secondary residences for children ages 0-5 years old
- preventative home assessments for identified high-risk groups (e.g. families expecting newborns, Aboriginal families)
- high lead exposure risk homes and properties that are aged[34] and poorly maintained
- areas with poor ground cover or vegetation
- areas with high frequency of use (Green, et al., 2016) and access to the area (e.g. parks and playgrounds) which may indicate higher risk of exposure and risk of wear and tear
- areas that are at high risk of recontamination (e.g. within the vicinity of known lead sources such as near the Line of Lode or railway corridor).

These additional risk factors can be informed through consistent collection of environmental and health data.

Recommendation 3a:

- within high-risk areas, prioritising places and premises where children aged 5 or less are likely to be present, as well as other high-risk groups (e.g. families expecting newborns or Aboriginal families).
- developing and implementing a zonal remediation program (based on previous remediation programs) focused on mitigating lead in high-risk areas, places and premises.

[33] Perilya, pers. comm., 2025.

[34] It is highlighted in Taylor, Isley, Lyle, et al. (2019, updated 2022) that aged housing poses an increased lead exposure risk and addressing this was a part of the report's recommendation.

The case study of Trail, Canada demonstrates how a zonal remediation approach with prioritisation can be applied.

Case study 2 (Trail, Canada): Establishment of environmental management area and prioritisation framework for risk-based remedial strategy.

In Trail, Canada, the Environmental management area (EM Area) associated with Teck Trail Operations was established or delineated based on metallurgical concentration limits (including lead) attributable to historical emissions. Trail Area Health & Environment Programs (THEPs) were delivered in Areas 1, 2 and 3 based on the proximity to Teck Trail Operations (AtkinsRéalis, 2025).

To assist in implementing risk-based remedial strategies in these areas, a comprehensive prioritisation framework was used in the Trail Area Soil Management Program (SMP) (AtkinsRéalis, 2025; SNC Lavalin, 2019). This framework, which was adapted from the US Department of Housing and Urban Development, is intended as a 'scientifically defensible' approach to identifying and prioritising properties for which remediation is most important, determined through three primary key attributes of a given property:

- presence of children in target age groups of <6 years old (i.e. younger children) and 6 to <12 years old (i.e. older children)
- quality of ground cover (e.g. grass, gravel or mulch); and
- soil lead concentration.

Sites that represent the highest risk were categorised as Priority 1 (out of 3) and received the most immediate attention for risk-management activities. On top of this primary prioritisation, a more detailed secondary prioritisation was applied to further rank properties within their priority groups, using screening quotients that assess the exposure terms (number of days per week children spent at the properties) and soil lead concentrations relative to the ages of children. Any property within the EM Area request soil assessment whether a child is present or not, as any property can become child occupied, but undergoes a similar prioritisation framework for remediation. Detailed frameworks and assessments are available in their latest report (AtkinsRéalis, 2025).

Note that the highest priority group (Priority 1) refers to properties with poor ground cover and either soil concentrations >400 ppm (mg/kg) with children of ages <6 years old or soil concentrations >8,400 ppm (mg/kg) with children ages 6 to <12 years old. In both cases, the soil criteria are higher than the ASC NEPM HILs. Further detail on the derivation of Trail site-specific investigation criteria is in Section 2.3.7.

Acknowledging the potential influence of neighbourhood soil lead concentrations on children's BLL, a Pilot Block Initiative (PBI; a neighbourhood block remediation) was done for a group of properties that were joined by a common laneway or boundary. It follows the same framework as above and considers the number of children within the blocks (AtkinsRéalis, 2025).

2.3.5 Monitoring and evaluation of remediation activities

Short to medium-term reduction in environmental lead

Evaluations of prior remediation efforts (Cattle & Wimborne, 2016) and consultations indicate that long-term effectiveness of remediation can be undermined through re-contamination by natural processes (e.g. erosion), or by other activities or contracted work (e.g. soils dug out for phone lines) disturbing the clean soil or capping materials. Over a longer timeframe, the impact of climate change on the frequency of extreme weather events such as flooding or extended dry periods may further redisperse lead in soil or dusts and re-contaminate remediated areas.

There does not appear to be any particular remediation strategy that is more effective than others (Cattle & Wimborne, 2016). While there are many studies to guide setting potential soil investigation criteria based on the impact to BLL, there is a limited understanding of how different remediation strategies (e.g. capping) can further reduce exposure to contaminated soil or if they are sufficient for highly elevated lead concentration in soil. Taylor, Isley, Lyle, et al. (2019, updated 2022) suggested a pilot testing of phosphate to reduce bioavailability of lead in soil. The feasibility of this measure should be investigated.

Hence, there is an opportunity to systematically study the effectiveness of any remediation strategy by ensuring measurements before (i.e. baseline) and after remediation are taken. Sites should also be evaluated over defined time periods as a part of a monitoring and evaluation framework to guide potential adaptation of approaches. Monitoring physical lead concentration in the environment is a more responsive indicator of remediation than BLL and may help to avoid elevated BLL by mitigating exposure through ingestion.

Long-term reduction in BLL

A number of studies that have evaluated the effectiveness of home remediation activities in Broken Hill (Boreland & Lyle, 2006; Boreland et al., 2009; Cattle & Wimborne, 2016). While immediate changes in environmental lead have been observed after remediation (e.g. reduction in indoor lead dusts (Boreland & Lyle, 2006)), Boreland et al (2009) suggests that “remediation did not significantly change the rate of decline in BLL (P=0.609)” and that “there was no evidence of association between change in children’s BLL and changes in lead loading in their homes”. In a community where lead is widely dispersed, it is difficult to directly link home remediation to any specific effect on BLL, especially without an effective program logic and MERI framework in place.

Monitoring of children’s BLL following home remediation shows BLL decline by an average of 4.4 µg/dL 10-14 months after remediation (BHELP, 2020). However, it is difficult to attribute any observed reduction of an individual’s BLL to a particular intervention activity due to the presence of a complex set of potential confounding factors (including nutrition, behaviour change and current mining activity etc). This highlights a need for the best available data to support home remediation.

Nonetheless, a zonal remediation approach presents an opportunity to track children’s BLL within the identified area to better understand remediation effectiveness outside of individual home remediation over the longer term (see case study below). A more comprehensive discussion on program evaluations can be found in Section 2.1.3.

Recommendation 3b:

Develop evaluation measures and timeframes for remediation activities to assess effectiveness. This should include both health and environmental monitoring and should be coordinated across the different groups in Broken Hill.

Case study 3 (Trail, Canada): Data collection for monitoring and evaluation.

THEPs have annual work plans which include collection of post-remediation soil concentration and excavated depth data, and reassessment of previously remediated sites. THEPs not only focus on soil remediation and management but also air, health and building environment with community connections at the heart of the programs. Children’s BLL data can be categorised by area to understand BLL trends and potential relationships between BLL and remediation efforts in each environmental area (Figure 11) (THEP, 2024a).

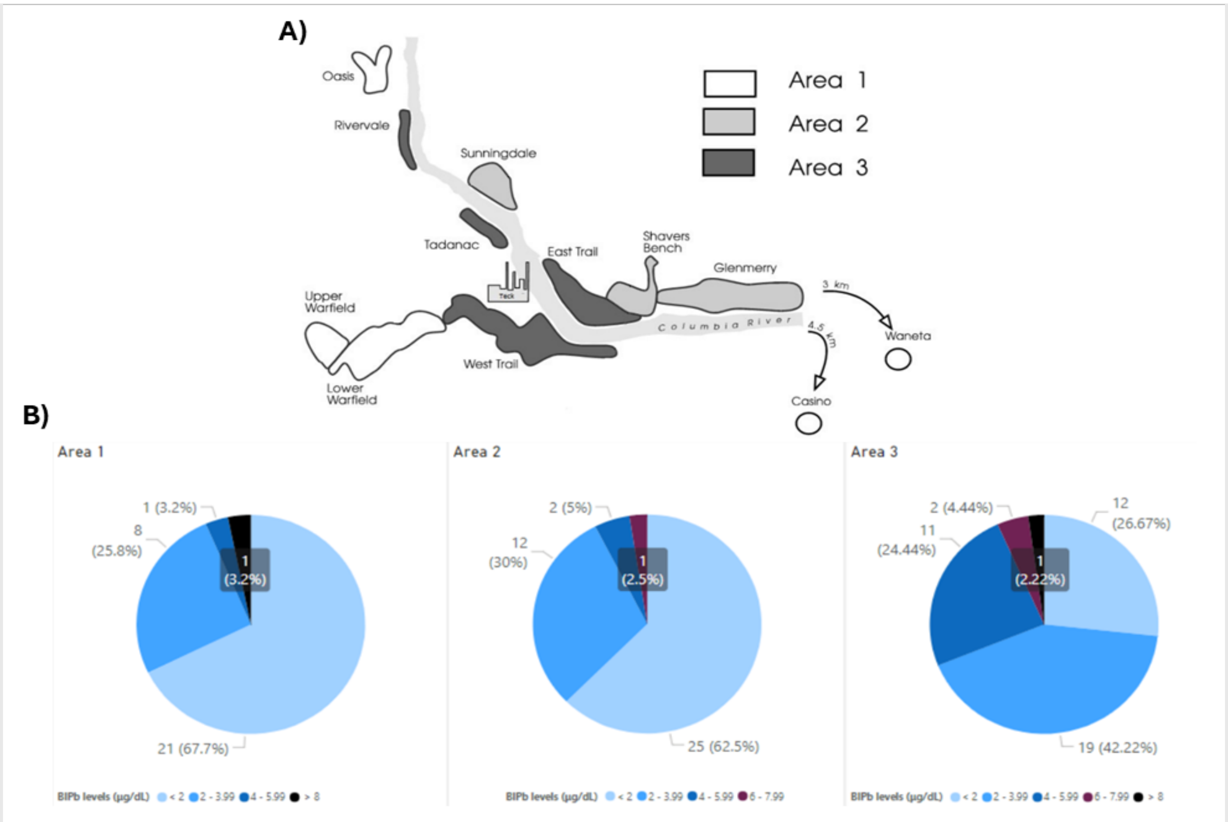


Figure 11. A) Environmental management area boundaries (Area 1, Area 2 and Area 3) surrounding the Teck Trail Operations; B) The proportion of children stratified by BLL for the three areas in 2024 (THEP, 2024a).

2.3.6 Additional factors to zonal remediation

Mining lease area and railway corridor

As discussed in Sections 1.4 and 1.5, it is likely that lead in dust from legacy lead contamination at the Line of Lode and areas in close proximity to it (including mining lease areas and railway corridor) contributes to redispersion of lead in dust in the community. While some ‘free areas’ are controlled using water and chemical suppressants,[35] the frequency, extent and efficiency of these controls is unclear. Some past rehabilitated and revegetated area were shown to deteriorate over time (RWC, 2023). OCSE notes that rehabilitation works have been trialled (e.g. use of growth medium, direct seedings and hydromulch), and research programs are ongoing for the Potosi Mine, North Mine and Southern Operations.[36] Insights from the rehabilitation research and trials should be shared with the BHCC, rail corridor owners and other mining companies.

Stormwater management

The effect of stormwater and creek flows on the migration or redispersion of lead in soil, and subsequent exposure impact on human health was highlighted as a data gap requiring future work in Section 1.2.3. While mine stormwater is managed using the mine site drainage system (Ramboll, 2024), there is limited stormwater drainage infrastructure in Broken Hill (BHCC, 2025).

The BHCC recently commissioned a comprehensive Broken Hill Flood Study,[37] which includes mapping the area topography and stormwater drainage infrastructure, and modelling water flow during weather events. The flooding simulation takes into consideration various parameters including the impact of climate change

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[35] Chemical dust suppressants are designed to bind dust particles together, with an aim to prevent them from becoming airborne.

[36] Refer to Section 9 of *Rehabilitation Research and Trials of the Rehabilitation Management* of the *Rehabilitation Management Plan of the Broken Hill North Mine* (RWC, 2023).

[37] The draft report of *Broken Hill Flood Study* was temporarily available for public exhibition.

on rainfall intensity and probability. Due to limited drainage infrastructure, typical short-duration flash flooding mechanisms are mostly governed by overland flow in high-density urban areas, with stormwater conveyed by large roadway corridors. In the rarer case of major floods, there is the potential for increased property inundation. The results of the flooding simulation identify several key flood locations in Broken Hill (BHCC, 2025).[38]

OCSE notes from discussions with stakeholders that there is a potential link between stormwater flow/flooding and the soil lead level. However, more comprehensive analysis of this requires further investigation and better data. To better inform potential exposure and appropriate management, the following work should be considered:

- Lead-in-sediment assessment across public waterways and discharge points (Ramboll, 2024).
- Lead-in-water assessment across surface water and water bodies, and various weather events (e.g. flooding) (Ramboll, 2024).
- Using additional assessment above, understand community use of surface water that is potentially contaminated with lead (Ramboll, 2024).
- Using additional assessment above, understand how weather events such as flooding may temporarily increase local topsoil lead concentration.

As flooding will remain an issue, stormwater management may need to be considered as another aspect to fortify and prolong the effectiveness of zonal remediation. The recent report on Aboriginal housing assessments also includes recommendations regarding improvements in property stormwater management to prevent recontamination of yards from stormwater runoff (NSW EPA, 2025a).

Recommendation 3c:

Undertake further work to better understand dispersion of lead across Broken Hill including investigation into potential stormwater pathways and strategies to minimise runoff and dispersion of lead from key areas (e.g. the railway corridor).

Housing

Due to the proximity to known lead sources in the Line of Lode, properties in some residential areas with highly elevated lead levels may not necessarily benefit from home remediation due to high potential for recontamination. It may be necessary to consider restricting access to these areas, raising the prospect of relocating vulnerable households. A more comprehensive environmental lead strategic initiative in relation to housing was discussed in the *Housing and Environmental Health Plan* (MPS, 2022). The strategy includes coordination between agencies, and a systematic and risk-based approach to remediate or relocate households to low-risk areas (MPS, 2022).[39]

Poor quality housing stock remains a systemic issue across Broken Hill, especially for Aboriginal people. Increasing appropriate housing stock is essential to ensuring Aboriginal families have secure living environments that protect them from the risks of lead contamination. While housing is not the focus of this report, it is an important issue to address alongside remediation activities. The OCSE has not made specific recommendations on underlying housing issues affecting Aboriginal people in Broken Hill, as the Premier's Department indicated that this matter is being progressed separately.

Programs from adjacent sectors offer learnings to improve housing in Broken Hill. Lead assessment and remediation through scheduled home maintenance by AHO and BHELP is a great example of an initiative that addresses the social housing sector and has a positive impact on reducing lead exposure to the community. Another example that could be considered is the NSW and Commonwealth Governments' Social Housing Energy Performance Initiative (SHEPI) for the social housing sector. SHEPI offers energy

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[38] Refer to Figure 7-2: Peak Probable Maximum Flood (PMF) and Inundation Extent in the *draft report of Broken Hill Flood Study*.

[39] See Section 9.5 of *Broken Hill Community Working Party – Housing and Environmental Health Plan* (MPS, 2022).

efficiency upgrades that could include reverse-cycle air conditioners, insulation and drought proofing measures, which might indirectly reduce lead exposure to residents (NSW Government, 2025).

> **Recommendation 1g:**
>
> Align to other government funding and leverage existing strategic initiatives to efficiently advance the objectives of the future lead program.

Heritage status

As the entirety of Broken Hill is listed in the National Heritage List (Place ID, 10581) and has over 380 individual items of state and local significance,[40] heritage value and regulation need to be assessed alongside health risk context. Requested action on a heritage item may require further assessment of the referred action. This is outlined in the *Matters of National Environmental Significance* (Cth Department of the Environment, 2013), which considers significant impact to heritage items and what other concurrent actions are being done to reduce risk with minimal impact to heritage. Note that deeming a referral as a controlled action does not necessarily mean that an action cannot be taken, rather that further assessment of the referred action is needed, and this may take several months (Cth DCCEEW, 2024). It is possible to apply for an exemption under the EPBC Act s 158, however, there is not yet a case where an exemption has been applied for health-related considerations (Cth DCCEEW, 2025a).[41]

To the best of OCSE's knowledge, mining companies in Broken Hill have engaged with consultants, the BHCC and Heritage NSW to identify, assess and manage heritage items within the mining lease sites during and after completion of mining operations. These are documented in a specific heritage management plan or embedded within an existing environmental, conservation or rehabilitation management plan:

- Operational Historic Heritage Management Plan for Broken Hill North Mine (RWC, 2022b)
- Conservation Management Plan for Rasp Mine (EMM Consulting, 2024).

Any insights gained from this process by mining companies should be shared with the heritage group and BHCC to forward a more coordinated strategy for heritage management that involves future remediation actions, not only on the mining sites on the Line of Lode, but also across Broken Hill more widely.

> **Recommendation 3d:**
>
> Develop a strategy that considers heritage value while meeting human health outcomes.

2.3.7 Lead-in-soil target values

A study by Yang and Cattle (2015) shows that the IEUBK model data using Broken Hill specific parameters was closely validated by BLL screening data, indicating that the IEUBK model is a promising tool to develop management strategies for remediation in Broken Hill. For example, the IEUBK model (using a default value of 30% absolute bioavailability) suggests that achieving a BLL of ≤5 µg/dL for 80% of the children aged 1-4 years old in Broken Hill, would require a mean topsoil lead concentration of 150 mg/kg across Broken Hill to be met (Yang & Cattle, 2015). This is below the ASC NEPM HIL (A) for residential areas (300 mg/kg) and was recommended by Taylor, Isley, Lyle, et al. (2019, updated 2022) in their review.

Further analysis of 10 soil samples in Broken Hill South shows that the mean relative lead bioavailability was 21.5%, which is lower than the 100% relative bioavailability (equal to 50% absolute bioavailability) used in ASC NEPM HIL calculations (Juhasz, 2018). Due to variations of soil lead concentration and soil lead bioavailability across Broken Hill, different soil investigation criteria may be derived for different risk-zones to achieve the same child BLL outcomes (Yang & Cattle, 2015).

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[40] The Australian Heritage Database are available at https://www.environment.gov.au/cgi-bin/ahdb/search.pl, accessed on 17 December 2025.

[41] Register of published exemption notices are available at https://epbcpublicportal.environment.gov.au/all-referrals/, accessed on 17 December 2025.

Therefore, OCSE recommends that an Expert Panel should evaluate the available evidence for developing site specific investigation criteria in Broken Hill, preferably in different zones, noting that one mean topsoil value may not be applicable to all of Broken Hill when there is considerable heterogeneity in soil lead levels. Below are some international examples for consideration, with more detailed international standards and criteria for soil, household dust and paint listed in Table 10, Table 11 and Table 12 in Appendix 3.

Case study 4 (US and Trail, Canada): Other considerations for developing site-specific investigation criteria.

While international standards or examples may not be directly applicable to the unique environment of Broken Hill, they form a solid basis for guiding limits or standards that could be applied. For example:

- The US EPA can apply a more stringent limit when it is known that soil is not the only lead-contaminated medium during evaluation on residential sites. It was recommended that the regional screening level (RSL)[42] is 200 mg/kg but this is lowered to 100 mg/kg if other sources are identified (e.g. lead-in-water line, lead-based paint and when lead in air exceeds the US National Ambient Air Quality Standard (NAAQS)). This considers the aggregate lead exposure and increased risk of children living in communities with multiple exposures. The recommended RSLs of 200 and 100 mg/kg are based on the IEUBK modelling which results in BLL geometric means of 2.3 µg/dL and 1.7 µg/dL respectively, noting the target BLL is 3.5 µg/dL (95th percentile of US population). However, US EPA notes that the RSLs are not remediation goals (i.e. soil lead concentrations after clean up), acknowledging the possibility of the natural or anthropogenic lead background level in soil unique to the site (US EPA, 2024b).
- Medical Health Officer of Canada Interior Health (IH) recommends a wide-area risk-based standard for lead, with remediation goals of ≤ 400 mg/kg specific to the Teck Trail site to enable easier application of the ~250 km^2 Wide Area Remediation Plan (WARP). The standard was based on a local BLL model, with 400 mg/kg of lead in soil to contribute approximately 0.4 µg/dL to BLL (IH, 2024).

Previous work indicates that the median 'background level' of lead in soil at Broken Hill is 100 mg/kg (n=29, σ=560) represented by concentrations of soil samples at depths below 30 cm (Kristensen & Taylor, 2016). This level is similar to the concentration of 'clean replacement soil' in Bunker Hill remediated properties, which generally contain lead less than 100 mg/kg, not exceeding 150 mg/kg (Brown et al., 2023).[43]

As such, the 150 mg/kg lead level in topsoil suggested by Yang and Cattle (2015) could be an appropriate target criteria for a remediation goal (i.e. new clean fill soil lead concentration after clean-up), rather than as an investigation criteria (i.e. trigger for further investigation). Currently, there is limited data on the vertical distribution (i.e. depth) of lead concentration in soil (Ramboll, 2024) and post-remediation topsoil lead concentrations or lead dust on the capping materials. If these data are collected, it could inform future options and evaluation of remediation work. Sourcing of sustainable and quality local topsoils will also need to be explored.

Recommendation 3e:

Engage experts to explore site-specific investigation criteria and remediation strategies for Broken Hill. Experts should consider whether targeting a lead-in-soil concentration after remediation of <150 mg/kg can meet health outcomes.

[42] The RSL is a screening tool to identify and define areas for further evaluation.

[43] Bunker Hill, Idaho, US, is one of the lead contaminated sites due to historical and current mining and historical smelter operations. It is being managed by US EPA as the Coeur d'Alene Basin Cleanup.

2.4 Emissions and dispersion

Addressing elevated BLL in Broken Hill requires considering all potential sources of lead exposure. These include emissions from both current mining operations and past mining areas, including mining areas where remediation strategies have been implemented. Redispersion of lead contamination from other private and public sites around Broken Hill should also be considered, including railway corridors, parks, yards, verge, disturbances from public works, and non-mining occupational exposure. Stakeholder consultation suggests that these are potentially significant avenues of lead exposure in Broken Hill that are not necessarily well understood and deserve further attention.

2.4.1 Implementing a continuous improvement approach

Lead in both air emissions and dust deposition from current mining operations is monitored and managed using standards and licence requirements. However, there is potential for applying a continuous improvement approach to both lead in air and lead in deposited dust for mining sites in Broken Hill, utilising data from monitoring to trigger responses and inform further actions (described in case studies 5 and 6 below). Further investigation and expert input are required to determine Broken Hill-specific criteria. If new targets are to be introduced, it is necessary to identify and address major contributors and explore technologies or process that can assist in meeting those targets.

Case study 5 (Port Pirie, SA): Achieving three levels of lead-in-air performance (i.e. limit, target and goal) through an adaptive management approach.

In 2023, SA EPA applied a progressive lead-in-air (LiA) limit and stepwise target reduction as a requirement for the Nyrstar licence renewal through the *Environmental Protection (Air Quality) Policy 2016* (SA) and *Port Pirie Smelting Facility (Lead-In-Air Concentrations) Act 2013* (SA), from 0.38 µg/m^3 in Dec 2023 to 0.32 µg/m^3 in Dec 2026 (0.02 µg/m^3 reductions yearly) (SA EPA, 2023, 2025). In a separate linear regression analysis, for Port Pirie's children below 5 years of age to remain below 5 µg/dL, the lead in air must not exceed 0.11 µg/m^3 (geometric mean) at either the Oliver St or Pirie West Primary monitoring site. This value is 80% lower than the AAQ NEPM of 0.5 µg/m^3 (Taylor, Isley, & Glover, 2019)**.**

In deriving LiA limits and targets, the SA EPA considered international best practices and the latest advice in health (SA EPA, 2025). The LiA limit and target vary based on the distance from the facility and whether it is a 'high exposure risk' area (such as a school) (see Figure 12). For example, at the Pirie West Primary School location and Oliver Street location, the 2024 LiA is 0.36 µg/m^3 (annual limit) and 0.45 µg/m^3 (3-month target) (SA EPA, 2025). Note that these are lower than the AAQ NEPM limit. Exceeding limits would result in a regulatory response, but target exceedance is intended as an opportunity to improve operations through implementation of an appropriate response (SA EPA, 2023).

The LiA goal is a long-term expectation and commitment to be achieved during the licence period, in this case a 12-month rolling average of 0.25 µg/m^3 TSP in lead through actions and milestones specified in the Environmental Improvement Plans (EIPs) within a timeframe (SA EPA, 2023). SA EPA also includes an adaptive management approach to continuously assess LiA results against the LiA goal, focus on key EIP actions in reducing dust and lead emissions, and in the case where goals are not met, for Nyrstar to review or amend the EIP (SA EPA, 2023). A total of 37 actions are to be completed within fixed timeframes (SA EPA, 2025).

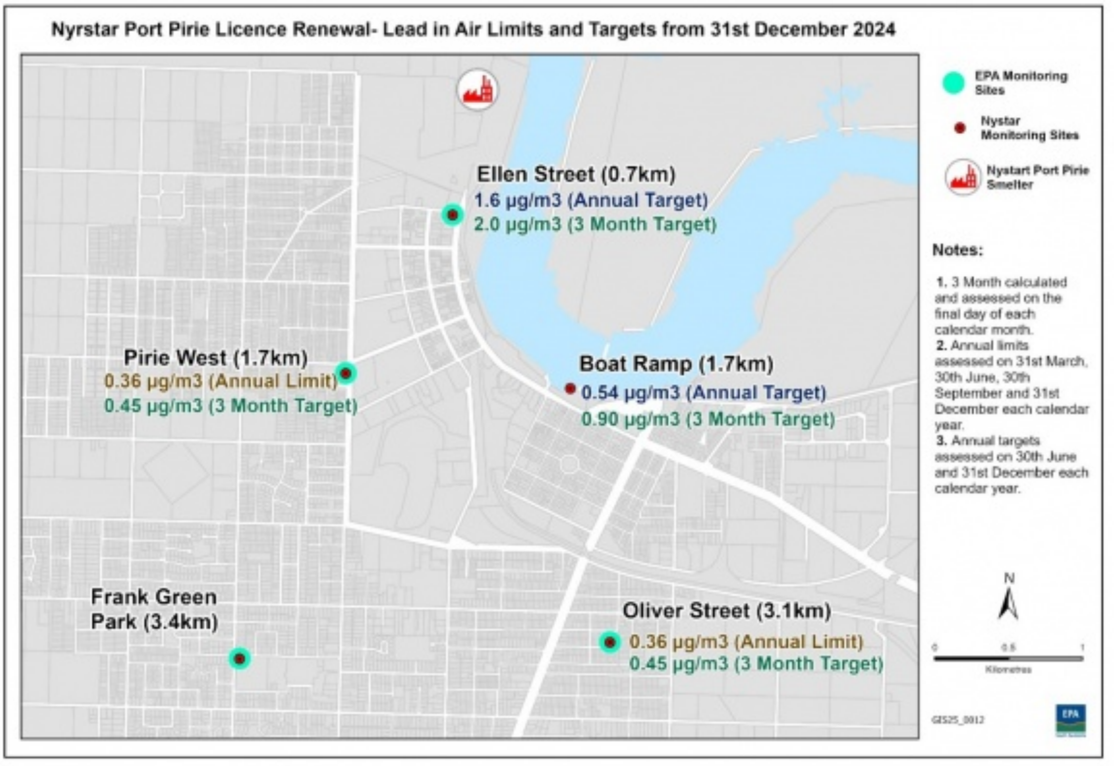

Figure 12. Nyrstar Port Pirie Licence Renewal – Lead in Air Limits and Targets from 31st December 2024 (SA EPA, 2025).

Case study 6 (Mount Isa, QLD): Predictive and reactive use of AQC system and real-time lead concentration monitoring to manage emissions and dust.

Mount Isa Mines use air-quality control (AQC) systems for mining, processing and smelting of copper, zinc and lead. Based on real-time air quality data or weather forecasting, the AQC controllers can shut down the smelters and curtail dusty operations when necessary. The system incorporates 5 passive monitoring stations, 9 high volume samplers and 10 dust deposition gauges (Mount Isa Mines, 2024; Noller et al., 2017). As part of the AQC system, two continuous metal monitors were installed in the community in addition to the Queensland Government's monitor (Mount Isa Mines, 2024).

The Queensland Government uses an XACT ambient metals monitoring instrument by drawing samples on a filter tape and using XRF technology to analyse metal content, at an interval of 1 hour (Queensland Government, 2023). The XACT is located at The Gap station (residential area, since 2010), and the data is available online.[44] For the last five years, the maximum lead concentrations have not exceeded 40% of the AAQ NEPM in Mount Isa (QLD DETSI, 2025c). The metal monitoring using the XACT instrument could fill in data gaps between every sixth day sampling and analysis using the AAQ NEPM method. OCSE understands that NSW EPA is currently trialling a continuous lead-in-air monitoring system with the mining companies in Broken Hill.

Mount Isa Mines has also developed a smartphone app for more information on the air quality in suburbs and releases notifications on the likelihood of sulphur dioxide emissions (Mount Isa Mines, 2024).

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[44] The Gap station's metal in air monitoring results is available online at: https://apps.des.qld.gov.au/air-quality/stations/?station=oai, accessed on 12 October 2025.

Recommendation 4: Emissions control

Continue efforts to reduce emissions (lead in air and lead in deposited dust) from mining operations and at the community level.

Recommendation 4a:

Continue efforts to reduce lead and dust emissions from mining operations by implementing a continuous improvement approach informed by monitoring data and trigger levels for response. If new targets are introduced, identify and address major contributors, and explore technologies or processes that can assist in meeting these targets. Further investigation, guided by an Expert Panel, is needed to determine specific criteria appropriate to the unique conditions in Broken Hill.

2.4.2 Managing lead in air and deposited dust in the community

Lead in air emission and lead in deposited dust are being monitored at the community level in Broken Hill through BHELS Phase II (see Section 1.5.3). The BHELS Phase II report highlights that the continuation of lead-in-air monitoring at the community level is necessary when considering public health risk, spatial variability, wind driven exposure, exceedance risk and adhering to AAQ NEPM guidelines (NSW DCCEEW, 2025).

There is an opportunity to use the existing air monitoring network data as a baseline to inform both the monitoring and evaluation framework, and potential site-specific triggers for further investigation in the longer term. Currently, the annual average lead in air concentration during the data collection period at Broken Hill sites ranges from 0.029 $\mu g/m^3$ to 0.128 $\mu g/m^3$ (NSW DCCEEW, 2025). Measurements exceeding these baseline values, even though below the AAQ NEPM standard, could be a trigger for further investigation.

While current lead-in-air emissions measured in the Broken Hill community are below the AAQ NEPM standard, the lead-in-dust deposition values are not negligible. Across seven DDGs, the lead-in-dust deposition ranged from 0.00034 to 0.0059 g/m^2/month (NSW DCCEEW, 2025). Although there is no NEPM standard for dust deposition rate, some sites' annual averages exceed the proposed limit by Taylor, Isley, Lyle, et al. (2019, updated 2022).

If this monitoring system is paired with predictive meteorological data or other continuous monitoring systems (e.g. lead-in-air concentrations or PM monitors), Broken Hill may benefit from a proactive weather warning system to further reduce exposure to lead in dust. As a part of a larger program monitoring and evaluation framework, the data might also be used as an indirect indicator of the effectiveness of remediation work to reduce dust redispersion.

Redispersion of lead dust in the community

As dust redispersion is a likely source of lead exposure in the community, actions are needed to manage it in parallel with zonal remediation and education efforts. Some areas of action that could be addressed in the short-term to reduce dust redispersion in the community were identified during engagement with stakeholders, including street sweeping, revegetation, WHS efforts to minimise non-mining occupational exposure.

For example, the BHCC owns a street sweeper which operates 3-4 times a week to reduce dust on roads in an attempt to minimise dust redispersion. Increased sweeping capacity, especially after dust storms may improve the suppression of dust on roads in Broken Hill.[45] One evaluation of the effectiveness of municipal street sweeping indicates that regenerative-air street sweepers can efficiently remove 35 – 65% of metal(loid)s from roads (Das & Wiseman, 2024).[46] In Port Pirie, the city council partnered with the Targeted Lead Abatement Program (TLAP) for footpath sealing upgrades to enable an increased frequency of street

[45] BHCC, pers. comm., 2025.

[46] In the study, lead is a trace element, and the street sweeper shows 38% removal efficiency.

sweeping (Port Pirie Regional Council, 2023b). Street sweepers also act as a visual cue that lead remains a community risk, supporting continued public health messaging.

Revegetation of public areas such as verges with appropriate shrubs or plants has potential as a strategy to help stabilise loose soils and minimising dust dispersion. OCSE observed an example of this approach in the revegetation of rail ballast on land adjacent to the railway corridor - where native seeds sprouted, forming unplanned green space. Other areas with high levels of dirt/dust could be considered by BHCC and NSW Government agencies (e.g. Public Works, NSW National Parks and Wildlife Service or Crown Lands) for revegetation with appropriate plants – or through providing appropriate substrates for natural seeding. Site selection would need to consider water availability, foot traffic, vehicular access, etc. For long-term resilience to climate change and dry weather, maintenance and re-grassing activities should be considered, along with the feasibility of using other alternatives such as synthetic turf[47] or geotextile covers. Insights gained from different approaches to revegetation and maintenance should be shared across agencies.

Case study 7 (Port Pirie, SA): Native plants and water program support improved greening in Port Pirie.

Greening Port Pirie is a four-year project funded by the SA Government, in partnership with Port Pirie Regional Council and the TLAP to reduce the amount of airborne lead dust and improve health outcomes in Port Pirie (Port Pirie Regional Council, 2023a). This initiative is supported by:

- *Port Pirie Native Plan Giveaway*: Native plants that are climate resilient, drought tolerant and locally adaptable were offered for the local community, businesses and organisations (Port Pirie Regional Council, 2025)
- *Water Sensitive Urban Design:* Urban water management planning and solutions enable more efficient stormwater use in supporting plant growth and sub-surface irrigation (Aurecon, n.d.).
- *Greening Port Pirie Railway Yards*: The railway yards which were prone to wind erosion and considered a high dust risk area were seeded and planted with over 33 species of native vegetation. Ongoing maintenance includes weed management and watering to support growth of native vegetation (SA Water, 2024).

Improving the lead safety knowledge of non-mining employees (e.g. tradespeople) for minimising occupational exposure and further dust dispersion from work activities is required. This would include both workers based at Broken Hill and transient workers involved in building renovations and construction, road/street works, utilities (e.g. electricity and telecommunications) and contractors associated with the mines. OCSE understands that SafeWork NSW was previously developing a lead safety module for non-mine workers, and this agency should be re-engaged to revisit the development and implement the module to improve lead safety among non-mine workers in Broken Hill. Lead awareness in the overall community was discussed in Section 2.2.

Recommendation 4b:

Assess how monitoring results can inform remediation programs, including evaluation. For all air and dust monitoring, ensure there is a clear understanding of the method utilised, its limitations and interpretation.

Recommendation 4c:

Incorporate dust dispersion management strategies, such as revegetation and street sweepers into remediation and dust mitigation activities for places and premises.

[47] While synthetic turf may require less maintenance (i.e. no watering), it may have some limitations such as high temperature and are still susceptible to recontamination.

2.4.3 Understanding exposure

The annual average of lead-in-air concentrations in Broken Hill is consistently below the AAQ NEPM limit and may appear to be consistent with protection of human health. However, current AAQ NEPM standards and monitoring techniques for measuring lead in air (i.e. TSP-Pb) have a number of limitations (also discussed in Section 1.3.2):

- Annual averaging of TSP-Pb may not be adequate to capture exposure risk from potential short-term elevated emissions (Taylor & Isley, 2014).
- The 1-in-6-day sampling period means that potentially heavy emission days are not captured
- Due to the inherent sampling inefficiency of HVAS, up to 40-60% of the TSP-Pb is potentially not being captured
- The limit is based on a 10 µg/dL BLL target and was developed in 1998 focusing on inhalation pathway of lead sourced from petrol

These limitations must be considered when interpreting the risk of lead exposure from monitoring data. As such, analysis of other complementary data such as lead in deposited dust, particulates matter and meteorological data is necessary to inform potential actions.

Lead in deposited dust measurement using DDG, for example, is another line of evidence that could fill the gap in understanding exposure through ingestion pathways. However, according to AS 3580.10.1-2016, DDG is measured monthly (30 ±2 days) to ensure a sufficient and measurable quantity of dust is collected in the gauge for analysis. The monthly sampling period, along with the time required for laboratory analysis, makes it difficult to apply any proposed daily dust deposition limit or timely action if this value is exceeded.

Meteorological data such as wind direction and speed, and proximity to known sources of lead, is currently used to some extent to help determine the source of lead in dust in the case of an exceedance. For example, a high spike of lead in deposited dust in one of CBH's DDGs in June 2022 was attributed to both non-mining and mining sources based on the predominant wind directions at that time.[48]

Continuous PM monitors similar to those already used in part of the mines monitoring network and dust management plan may be used as a direct indicator of air quality within the community. However, care needs to be taken in using PM monitors as high dust levels do not necessarily correlate with high lead levels (e.g., events of dust storm). Correlation of the levels of lead in air to lead in dust may provide better understanding of how much airborne contaminants accumulate as deposited dust and in topsoil over time. This in turn would indicate whether or not the continuous monitoring of lead in air can predict the risk of exposure to lead in deposited dust.

Recommendation 4d:

Understand the limitations of current AAQ NEPM standards and monitoring techniques to ensure risk of lead exposure is interpreted appropriately and informs further action. Inclusion of other complementary data (e.g. lead in deposited dust, particulate matter and meteorological data) may assist responses to minimise lead exposure.

[48] See page 13, CBH (2022) *Rasp Mine Monthly Environmental Monitoring Report June 2022.*

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Appendices

Appendix 1 – Stakeholders consulted

Appendix 2 – Data and information relevant to the Review

Appendix 3 – National and International lead levels

Appendix 1: Stakeholders consulted

Site visits

The review team went out to Broken Hill to meet with local stakeholders and visit various locations of interest. The site visit itinerary is set out in the table below:

Table 4: Broken Hill site visit itinerary

Date	Location	Action
15 September 2025	Broken Hill office	Visit sites of interest
	Broken Hill	
16 September 2025	Broken Hill	Visit sites of interest
	Broken Hill offices	Stakeholder consultations: Broken Hill City Council; Public Works; Maari Ma Health Aboriginal Corporation
	ARTC Broken Hill Railyard	Transport for NSW consultation; site visit (near Rasp Mine)
17 September 2025	Broken Hill	Visit sites of interest
	Community Health Centre	Department of Rural Health consultation
	Broken Hill Mine	Site visit
	Perilya	Site visit
18 September 2025	Broken Hill	Far West Local Health District consultation
		Aboriginal Affairs consultation

Stakeholder consultations

The review team consulted with representatives from the following organisations, groups or individuals:

Organisations, groups or individuals
Aboriginal Affairs
ARTC
BHELRG
Broken Hill City Council
Broken Hill Mines
Department of Rural Health
NSW Environment Protection Authority
Far West Local Health District
Maari Ma Health Aboriginal Corporation
Perilya
NSW Ministry of Health
NSW Premier's Department
NSW Public Works

NSW Resources Regulator
Transport for NSW
NSW DCCEEW Science and Insights Division
Cth DCCEEW Heritage Division
EPA Tasmania
Professor Mark Taylor

Appendix 2: Data and information

This section contains a summary of non-exhaustive data and information that informs this report. The purpose of this section is to systematically collate information from various sources as a quick reference.

Lead related data and findings in Broken Hill

Table 5: Summary of available lead related data and its findings

Data type	Summary of data available and findings
Blood lead level	Annual reports are publicly available from WNSWLHD Public Health Unit at LeadSmart website https://leadsmart.nsw.gov.au/resources/. 2022 – Geospatial maps of children with low BLL trajectory and very high BLL trajectory based on longitudinal data (Lyle et al., 2022, Figure 1) 2019 – Geospatial maps of children's BLL in Broken Hill from 2011 to 2015, data source from BHELP (Taylor, Isley, Lyle, et al., 2019, Figure 18, updated 2022)
Air – lead emission (active mining)	Monthly environmental reports are available from: • BHM website: https://brokenhillmines.com/projects/approvals-and-reporting • Perilya website: https://perilya.com.au/sustainability/environment/ The report contains all environmental monitoring including lead in deposited dust, lead in TSP, particulate matters and meteorological monitoring.
Air – estimates of total lead emissions into air (kg)	NPI is a publicly accessible online database presenting information on lead point source and fugitive emissions estimates rather than measurements. For Broken Hill sites, the estimates of total lead emissions into air (kg) are available for Perilya, CBH and other facilities such as TASCO and Mineral distributors and wholesalers (Cth DCCEEW, 2025b)
Air – ambient lead air data (community exposure)	2025 – BHELS Phase II report found that for all four HVAS sites, annual lead concentrations were consistently below the AAQ NEPM standard, ranging from 0.029 – 0.128 µg/m^3 (6%-26% of the standard). It is also reported that the lead in dust levels ranged from 0.00034 – 0.0059 g/m^2/month across all seven DDG sites for the reporting period (NSW DCCEEW, 2025) 2022 – Dust deposition gauges within 1.5 km of Line of Lode return lead deposition rates exceeding intervention value used in Mount Isa (Dong et al., 2020)
Air – directional source of lead	2018-2020 – BHELS Phase I report 1-3 and summary report examined how contemporary mining activity contributes to environmental lead contamination. Two D-HVAS were installed at five sites representative of community exposure to lead in Broken Hill. The study found that lead TSP and lead content of TSP were both higher when the prevailing wind is blowing downwind of legacy and current mining areas (NSW DPIE, 2021a, 2021b; OEH, 2018, 2019) 2019 – Dong et al. (2019) analysed children's BLL *via* generalised linear regression models including covariates of household soil lead, city dust lead concentrations, demographic factors, and lead ore production, including two natural experiments involving wind direction and the 2009 dust storm. They found that children living downwind and proximate to

Data type	Summary of data available and findings
	the mine had substantially higher BLL outcomes than children who lived similarly distant but upwind.
Soil - topsoil lead concentration (mg/kg)	2025 – Topsoil lead concentration of 45 Aboriginal housing in Broken Hill shows 24 properties (53%) above the NEPM HILs, with 10 of the 24 properties exhibiting very high risk (NSW EPA, 2025a) 2024 – Heat-map of soil based lead concentration in Broken Hill (Ramboll, 2024) 2022 – Mapping of front-yard soil lead concentration from 62 houses in Broken Hill and distance to Line of Lodes. In-situ analysis of front yard surface soils across Broken Hill returned a median bulk lead concentration of 382 mg/kg (Gillings et al., 2022). Elevated lead concentrations are detected in the topsoil and subsoil within approximately 0.4 km north and 0.8 km south of the Line of Lode. 2020 – Mapping of residential soil lead concentrations from data collected between 1994-2018 (Dong et al., 2020) 2017-2018 – The high lead concentrations detected in the topsoil and subsoil within approximately 0.4 km north and 0.8 km south of the Line of Lode (Yang & Cattle, 2017, 2018) 2017 - pXRF mapping of topsoil concentration in four sites (Green, et al., 2016) and 10 public parks (Cattle & Wimborne, 2017); along with distances to Line of Load 2015 – Soil immediately adjacent to train lines has elevated lead concentrations of 695 mg/kg with decreasing concentrations away from the train line. Isotopic compositions shows up to 97% apportioned to Broken Hil ore body (Kristensen et al., 2015).
Soil – vertical distribution of lead in soil (depth of soil) (cm vs mg/kg)	2015 – Vertical profile lead averages in North, South and Central Broken Hill and Historical sites indicates lead concentration of 100 mg/kg below 30 cm of topsoil (Kristensen & Taylor, 2016)
Ground cover percentage (%)	2025 – High-level mapping of cleared/maintained areas and vegetated areas (BHCC, 2025) 2017 – Generally, soil lead concentration is low around the area where ground cover is intact. Conversely, areas where the ground cover is patchy, topsoil concentrations are generally higher (Cattle & Wimborne, 2017) 2016 – Percentage of vegetation cover of four public sites, along with soil lead concentrations are used as a risk matrix to assist with remediation prioritisation (Green, et al., 2016)
Ground cover surface lead concentrations (mg/kg)	2017 – With exception of two mulch sample and artificial turfs samples, all non-soil surface lead concentrations (e.g. woodchips, grass, mulch etc.) in 10 public parks returns lead concentration below HILs (Cattle & Wimborne, 2017)
Household indoor lead dust (μg/m^2/day)	2022 – Household dust lead loadings from 62 houses in Broken Hill and their distance to Line of Lode. The indoor lead dust concentrations increase as the distance from Line of Lode decreases. The household indoor dust correlates with front yard soil concentrations. (Gillings et al., 2022).

Data type	Summary of data available and findings
Lead in paint (mg/cm^2)	2024 – Modelled heat map based on pXRF data collated from BHELP (Ramboll, 2024)

Other environmental data

Table 6. Other environmental data

Other data	Description
Lead bioavailability	2018 – Analysis of 10 soil samples in Broken Hill South shows that the mean relative lead bioavailability was 21.5% which is lower than the 100% relative bioavailability (equal to 50% absolute bioavailability) used in ASC NEPM HIL calculations (Juhasz, 2018).
Stormwater flow	2025 – Mapping of drainage flow path, flood infrastructure, land use, topographical and historical flood (BHCC, 2025)
Metrology data	Real-time data available from Broken Hill Airport station – rainfall, wind rose (speed and direction), temperature etc. from https://www.bom.gov.au/products/IDN60801/IDN60801.94691.shtml Some mining sites such as North Mine have their own meteorological station. Locations of 12 community rainfall gauges around Broken Hill (BHCC, 2025)
Climate change projection data by NARCliM 2.0	Climate projections indicate that climate change is impacting the Far West region through increasing temperature, rainfall patterns will change, and droughts will be more severe. By 2050, average temperature is projected to rise by around 1.2 °C under a low emissions scenario and around 2.1°C under a high emissions scenario. The annual average rainfall is projected to decrease by approximately 15.3% (low emission scenario) and by 20% (high emissions scenario) by 2050 (NSW DCCEEW, 2024).

Lead level correlation studies

Table 7. List of lead level correlation studies in Broken Hill.

Parameters	Correlation studies
Lead in soil and BLL	Geometric mean of BLL of children (0-4 years of age) against geometric mean of lead in soil at their residential address, data from 1994-2015 (Taylor, Isley, Lyle, et al., 2019, Figure 11, updated 2022; citing Dong et al., 2020) If a target blood lead goal of ≤5 µg/dL for 80% of the children aged 1-4 years-old is set in Broken Hill, the IEUBK model suggests that a mean topsoil lead concentration of 150 mg/kg (a default value of 30% absolute bioavailability was used) across all Broken Hill is required (Yang & Cattle, 2015).
Lead in air and BLL	No publicly available correlation for lead in air and BLL in Broken Hill
Lead in deposited dust and BLL	Updated annual geometric mean of BLL against concentration of lead in deposited dust in Broken Hill, data from 2017-2024 (this report, Figure 3) Annual geometric mean of BLL against concentration of lead in deposited dust in Broken Hill, data from 1992-1996 and 2012-2017. It shows that if lead in deposited dust exceeds 90 µg/m^2/day, the annual geometric

	mean of children's BLL is likely to exceed 5 µg/dL (Taylor, Isley, Lyle, et al., 2019, Figure 12, updated 2022)
Lead ore production and BLL	Annual arithmetic mean of child BLL and production of lead ore between 1991-2015 (Dong et al., 2019, Figure 4)

Data gaps

Table 8. List of potential data gaps for future work

Data type	Data gaps and purpose
Lead in sediments	Lead in sediments in public waterways and bodies, and lead in surface water/water bodies to understand community use of surface water that is potentially contaminated (Ramboll, 2024)
Child occupancy	88% of children up to 3 years of age (from 65 families interviewed) were found to spend time at other locations outside of the family home, with 68% most commonly visiting private residences and 15% visiting childcare facilities (Lyle et al., 2021) The Trail Area Soil Management workplan highlights determining child occupancy or premises and places as data gaps for prioritisation of remediation work (AtkinsRéalis, 2025)
Dispersion modelling	Lead in air *vs* lead in dust or lead in air / dust correlation to particulate matter to understand lead dispersion within the community

Appendix 3: National and International Environmental Lead Levels

Table 9: Ambient air quality standards (i.e. lead in air)

Jurisdiction	Lead limit	Measurement	Notes	Ref.
Australia	0.5 µg/m^3 (arithmetic mean averaged over calendar year; National Environment Protection (Ambient Air Quality) Measure)	Lead sampling must be carried out for a period of 24 hours at least every sixth day, and must be carried out on Total Suspended Particles (TSP) or its equivalent determined by: Determination of Particulate Lead-High Volume Sampler Gravimetric Collection-Flame Atomic Absorption Spectrometric Method (AS2800-1985) Determination of Total Suspended Particulates (TSP) - High Volume Sampler Gravimetric Method (AS2724.3-1984)	This was subject to a 2001 Technical Paper by the Peer Review Committee to the National Environment Protection Council (NEPC Peer Review Committee, 2001). No maximum exceedances per year is prescribed. (NEPC, 2012) AAQ review report in 2011 recommended the standard should be revised as it is currently based on BLL not exceeding 10 µg/dL (NEPC, 2011)	*National Environment Protection (Ambient Air Quality) Measure 2011* (Cth), sch 2
US	0.15 µg/m^3 (3-months average, TSP; National Ambient Air Quality Standards (NAAQS))	The current Federal Reference Method (FRM) for lead sampling and analysis is based on the use of a high-volume TSP FRM sampler to collect the particulate matter sample and the use of atomic absorption (AA) spectrometry for the analysis of lead in a nitric acid extract of the filter sample	US EPA's 2016 review of the air quality criteria and the NAAQS for lead retained the current standards without revision (US EPA, 2016, n.d.)	*National Primary and Secondary Ambient Air Quality Standards for Lead*, 40 CFR § 50.16 (2024)
Canada	No national CAAQS standard; however, 0.1 µg/m^3 (limit value, 1 year) in Quebec	The concentration of a contaminant in the atmosphere for a single source must be calculated either: a simple model, called a level 1 model, for a single source, or	The initial concentrations of contaminants in the atmosphere, without the contribution of the source or sources considered for the modelling, must be added to the concentrations calculated.	*Clean Air Regulation*, OC 501-2011, 18 May 2011, GOQ 2011.II.1253, sch G, K.

		a multi-source complex model, called a level 2 model, simulating a single source or if several emission sources are present.		
EU	0.5 µg/m³ (annual mean, calendar year) 1.0 µg/m³ (notified industrial sources)	The reference method for the measurement of lead is that described in EN 14902:2005 'Standard method for measurement of Pb/Cd/As/Ni in the PM10 fraction of suspended particulate matter'. Assessment thresholds: Upper – 70% of limit value (0.35 µg/m³) Lower – 50% of limit value (0.25 µg/m³) Number of sampling points for fixed measurement of lead in ambient air is based on the above thresholds and the population of the agglomeration/zone	N/A	*Directive 2008/50/EC of the European Parliament and the of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe* [2008] OJ L 152/1 (EEA, 2012)

Table 10: Lead in deposited dust

Jurisdiction	Lead limit	Measurement	Notes	Ref.
Mount Isa (Queensland)	100 µg/m²/day	Arithmetic mean of the daily deposition rate for individual samples expressed to a 30-day month as per AS/NZS 3580.10.1:2016 (or more recent edition) over the calendar year	Environmental licensing requirement for mining and smelting at Mount Isa, QLD. Limit type is a trigger value, where investigations must be conducted for any exceedance.	Schedule B – Table 4 – (Ambient Air Quality – Dust Deposition Limits and Trigger Values) (QLD DETSI, 2025b)
Germany	100 µg/m²/day	One year averaging period	German air quality guidelines	Table 6 (TA Luft, 2002)

Table 11: Soil lead level

Jurisdiction	Use type	Soil lead limit (mg/kg or ppm)	Notes	Ref.
Australia	Residential (A)	300	Residential with garden/accessible soil (home-grown produce <10% fruit and vegetable intake (no poultry)), also includes childcare centres, preschools and primary schools.	*National Environment Protection (Assessment of Site Contamination) Measure 1999* (Cth), sch B1 table 1A(1)
	Residential (B)	1,200	Residential with minimal opportunities for soil access; includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments.	
	Recreational (C)	600	Public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. This does not include undeveloped public open space where the potential for exposure is lower and where a site-specific assessment may be more appropriate.	
	Commercial (D)	1,500	Commercial/industrial, includes premises such as shops, offices, factories and industrial sites.	
Canada	Agricultural and residential $PSoQG_{HH}$ 0.5 IQ pt	61	Canadian Council of Ministers of the Environment (CCME)'s Provisional Soil Quality Guideline ($PSoQG_{HH}$) for Human Health. The CCME recommends: • $PSoQG_{HH}$ for 0.5 IQ pt additional source present / soil is not the only contaminated media, or • $PSoQG_{HH}$ for 1 IQ pt decrement when soil is the only contaminated media	(CCME, 2025b, 2025a)
	Agricultural and residential $PSoQG_{HH}$ 1 IQ pt	113		
	Commercial, $PSoQG_{HH}$ 0.5 IQ pt	82		
	Commercial, $PSoQG_{HH}$ 1 IQ pt	154		
	Industrial, $PSoQG_{HH}$ 0.5 IQ pt	743		

Jurisdiction	Use type	Soil lead limit (mg/kg or ppm)	Notes	Ref.
	Industrial, PSoQG$_{HH}$ 1 IQ pt	1477		
Canada (British Columbia)	Residential	120	Soil lead limit for protection of human health. The IH note that the current standard for lead in soil in BC is based on ‘background’ concentration and not necessarily reflect health risk (IH, 2024).	*Contaminated Sites Regulation*, BC Reg 375/96
	Commercial	150		
	Industrial	4,000		
US	Residential – RSL	200	Regional screening level (RSL) – screening tools to identify areas that need further evaluation. This is based on Office of Land and Emergency Management (OLEM) recommendations.	(US EPA, 2024b)
	Residential – RSL – if other source identified	100	RSL if other source identified including exceedance of US NAAQS	
	Residential – RML	200	Removal management level (RML) – to help prioritise and define areas that pose threat to human health. RML and RSLs are not remediation goals. The recommended RSLs of 200 and 100 ppm are based on the IEUBK (Integrated Exposure Uptake Biokinetic Model for Lead) to results in geometric mean BLL of 2.3 µg/dL and 1.7 µg/dL respectively.	
France	Soil level	300	France screening trigger level – the environmental contamination value of the media that should lead to screening for childhood lead poisoning (expected BLL > 5 µg/dL in about 5% of children).	(HCSP, 2014)

Table 12: Household deposited dust level

Jurisdiction	Type of household dust	Lead limit (µg/m^2)	Notes	Ref.

US	Floor	54	The limits are dust-lead action levels (DLAL), in which: • if measured value is more than DLAL, remediation is required • if measured value less than DLAL, manage dust with vacuum but no remediation. Limit also applies to childcare facilities. US EPA considers any reportable level by US EPA laboratory as dust-lead reportable levels (DLAR).	*Lead-Based Paint Poisoning Prevention in Certain Residential Structures*, 40 CFR § 745.65 (2024)
	Windowsills	430		
	Window trough	1,076		
France	Household dust	70	France screening trigger level – the environmental contamination value of the media that should lead to screening for childhood lead poisoning (expected BLL > 5 µg/dL in about 5% of children).	(HCSP, 2014)