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Australia
Create Change

Literature review of the levels of lead and other heavy metals in soil and roof dust in Wollongong and measures to manage any associated health risks

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Abbreviation List

ABA	Absolute bioavailability
ABC	Ambient background concentration
ACL	Added contaminant limit
ANZECC	Australian and New Zealand Environment and Conservation Council
As	Arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
BC	British Columbia
BCR	Community Bureau of Reference
BHSS	Bunker Hill Superfund Site
BLL	Blood lead level
BMD	Benchmark Dose
Cd	Cadmium
CEC	Cation-exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLM	Contaminated Land Management
Cu	Copper
DCP	Development Control Plan
DECCW	Department of Environment, Climate Change and Water
DP&E	Department of Planning and Environment
EC	Electrical conductivity
EDS	Energy Dispersive Spectroscopy
EIL	Ecological Investigation Level
EIS	Environmental Impact Statement
EMP	Environmental Management Plan
EP&A	Environmental Planning and Assessment
EPA	Environmental Protection Agency (QLD and USEPA)
EPA	Environment Protection Authority (NSW)
EPP (Air)P	Environmental Protection (Air) Policy (Queensland)
ERA	Environmental Risk Assessment
FSANZ	Food Standards Australia New Zealand
GMR	Greater Metropolitan Region
HIL	Health Investigation Level
HNELHD	Hunter New England Local Health District

ICBLS	Illawarra Child Blood Lead Study
ICP	Institutional Control Program
IEUBK	Integrated Exposure Uptake Biokinetic
ILMP	Illawarra Lead Management Plan
IPHU	Illawarra Public Health Unit
IRATE	Illawarra Residents Against Toxic Emissions
IRIS	Integrated Risk Information System
ISO	International Organisation for Standardisation
LAS	Lead Abatement Strategy
LEP	Local Environment Plant
LGA	Local Government area
LMAP	Lead Management Plan
LOEC	Lowest observed effect concentrations
LRC	Lead Reference Centre
MAQS	Metropolitan Air Quality Study
MIL	Monitoring investigation level
ML	Maximum level
MOE	Margin of exposure
MPC	Maximum permissible concentration
NATA	National Association of Testing Authorities
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health & Medical Research Council
NLM	North Lake Macquarie
NRCNA	National Research Council of the National Academies
NSW	New South Wales
OC	Organic carbon
Pb	Lead
PBET	Physiologically based extraction test
PHD	Panhandle Health District
PM	Particulate matter
PRP	Pollution reduction program
PTMI	Provisional Tolerable Monthly Intake
PTWI	Provisional Tolerable Weekly Intake
QA/QC	Quality Assurance/Quality Control

S	Sulfur
SA	South Australia
SEM	Scanning electron microscopy
SEPP	State Environmental Planning Policy
SFCDR	South fork of the Coeur d'Alene River
SPCC	State Pollution Control Commission
TA LUFT	Technische Anleitung zur Reinhaltung der Luft
TAHEC	Trail Area Health and Environment Committee
TAHEP	Trail Area Health and Environment Program
TSP	Total suspended particulate
TSP	Total suspended particulates
UBM	Unified BARGE Method
UoW	University of Wollongong
WHO	World Health Organisation
XANES	X-ray absorption near edge spectroscopy
XAS	X-ray absorption spectroscopy
XRD	X-ray diffraction
XRF	X-ray fluorescence
Zn	Zinc

1. Summary

The NSW Environment Protection Authority (EPA) has sought the services of a consultant to undertake a literature review and prepare a report on the key legacy contamination issues in the Port Kembla area from lead, other heavy metals (cadmium, copper and zinc), and arsenic in soil and associated human exposure.

Information has been generated from the Working Group but no meeting has yet been held with the Port Kembla Pollution Meeting, Port Kembla Harbour Environment Group and other relevant stakeholders due to the unprecedented COVID-19 related events. All reports, papers and internet listed in Schedule A were examined as were several papers and reports from past and recent literature.

The comprehensive independent review and analysis of information was undertaken in relation to the Wollongong LGA on levels and distribution of heavy metals and arsenic in soils and roof dust, lead in air, blood lead levels (BLLs) and associated strategies/measures to manage human exposure and prevent/minimise human health risks.

The review has considered the available information and data for the Port Kembla area. The data is compared against relevant, contemporary national Australia and international guidelines. These include the National Health & Medical Research Council and National Environment Protection Council guidelines that are listed in the NSW Contaminated Land Management Act 1997 (CLM Act) (listed in Appendix C of this report), together with aspects of sampling and reporting for site contamination and managing contaminated land.

The rationale for the guidelines used to interpret information has been achieved by following the current NEPM practices for soil and air, the NHMRC, the enHealth Human Risk assessment methodology, ANZECC/ARMCANZ (2000)/ANZG (2018) for water and sediment and making reference to FSANZ food guidelines. Some application of overseas guidelines was appropriate in the absence of suitable Australian guidelines, including the USEPA house clearance standards (2001) and the German air pollution control regulation TA LUFT (TA LUFT, 1990, 1999) and New Zealand guidelines (2001). Best practice is achieved if the health risk assessment approach of enHealth (2012) is followed with guidance of NEPM (NEPC 2013) and the NHMRC (2016) by using their standardised procedures, including those of Standards Australia. In the absence of Australian guidelines or standards, those from overseas are used.

This independent review report makes the following conclusions:

Soil

- The highest arsenic copper and zinc total concentrations do not exceed HIL A when plotted vs. distance from the copper smelter.
- Total lead concentration exceeds HIL A when <1km from the smelter but testing with a proper bioaccessibility (gastro-intestinal) assay is likely to confirm the finding that 0.1M Hydrochloric acid extractable lead concentration could show no exceedances of HIL A for all samples excluding the highest slag sample S58.
- Based on some of 22 samples total cadmium concentration above detection limit exceeding HIL A, further investigation of cadmium in soil, as collected by Jafari (2009) is warranted and should include both total and bioaccessible cadmium to enable a complete health rísk assessment to be undertaken.

House dust

- House dust samples collected from houses between 1992 and 1997 as accumulated roof dust, ceiling, wall vent and crack dust, floor and carpet dust, shelves and window sills showed highest concentrations of lead and arsenic in house dusts between 0.3 and 1.0km from the copper smelter (Willison, 1993). Although lead in house dust is recognised as one of the best predictors of childhood exposure to lead poisoning, it remains least understood as no data set exists from Port Kembla.

There is no data available measured via a health risk based guideline to identify if dust in houses within 1km of the former copper smelter at Port Kembla is a potential health risk, or from lead paint.

- The houses within 1km of the former copper smelter need to be screened by using of floor wipe concentrations together with soil and house dust for total and bioaccessible lead concentrations that can be inputted to the IEUBK model to predict blood lead of children.

Lead in air

- Monitoring of lead in air particulates is of limited importance for health risk assessment as the fraction collected as PM_{10} (10 µm diameter) that enter the bronchial tubes only constitutes 5% of exposure dose. The apparent importance of monitoring airborne PM_{10} for lead is outweighed by the need to have data which explains contribution to dose from the ingestion exposure pathways.

Blood lead levels

- Since the copper smelter operations have ceased it is unlikely that fall-out dust deposition is likely to reach significant levels as occurred during the operational phase at Port Kembla. However, reconstitution and remobilisation of historical dust deposition in soil through undertaking earthworks or renovation of older houses may occur.
- Since 1994, there has been no community BLL survey at Port Kembla. Since 2016, the NHMRC recommended that if BLL is greater than 5µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman. Investigating the source of exposure where BLLs are greater than 5µg/dL will reduce the risk to individuals, particularly children (NHMRC, 2016).
- The US EPA IEUBK model is considered suitable at Tier 2 for assessing risks from lead and can be applied for predicting blood lead on children who are exposed to lead from soil and house dust (Section 3.6.4; NEPC 2013, Schedule B4).

Any associated strategies/measures to manage human exposure and prevent/minimise human health risks

Key details of relevance to the Port Kembla case were identified as follows:

- Reduction of lead in air and BLL is a basis for closure on site. A lead budget gives an estimate of total lead in the environment to map the fate.
  - Remediation is based on removal of lead and/or prevent its dispersion and re-entrainment in air.
  - Assessing effects on people require guidelines that are based on human health risk assessment.
  - There is a common observation that highest surface soil within 2km of smelter and accompanies highest child BLL.
- Utilisation of appropriate techniques at houses including indoor lead flux and passive wipe methods in houses and measurement of bioaccessibility in soil and dust for hazard assessment including dose response, and BLL for exposure assessment, enables effective application of health risk assessment.
- Lack of capability to identify sources of lead is dependent on insufficient range of analytical techniques being used.
- House study for health risk assessment together with IEUBK model to predict BLL of children requires site specific soil and dust levels using.

The extent and limitations of the data and information available

Appropriateness of guidelines and lack thereof

- House dust assessment lacks an appropriate health risk based method that can be applied routinely at locations like Port Kembla. In the absence of validated guidelines, estimates based on exposure are required to identify if the surface wipe criteria are valid to assess the health risk from dust in houses.

Analytical methods

- House dust health risk assessment stands out as an area requiring further development of methodology, particularly for arsenic and cadmium.

Limited data collection and routine monitoring

- The data limitation for the environmental and health studies conducted at the Wollongong LGA in the 1990s or earlier reflects the importance of maintaining a level of monitoring that will enable health risk assessment to be performed.

Insufficient selectivity of analytical techniques

- Synchrotron X-ray absorption (XAS) analysis, in contrast to lead isotope ratios, shows resolution of lead source at Mt Isa based on compound composition differences in environmental samples. This approach will assist in undertaking more accurate human health risk assessment.

Recommendations

The following recommendations from this independent review report are made:

1. Undertake measurement of both total and bioaccessible (gastro-intestinal- sieved at < 250μm) assay concentration of cadmium in soils <1km from the former smelter location to establish site specific data for more accurate comparison with the HIL A criteria.
2. Develop a methodology that will enable performing a health risk assessment on houses within 1km of the former copper smelter by screening using of floor wipe concentrations together with soil and house dust for total and bioaccessible (gastro-intestinal-sieved at < 250μm) assay for arsenic, cadmium and lead concentrations that can be inputted to the IEUBK model to predict blood lead of children and dose calculations for arsenic and cadmium.

2. Scope of Works

2.1 Terms of Reference

The NSW EPA has sought the services of a consultant to undertake a literature review and prepare a report on the presence of lead and other heavy metals in air, soil and roof dust in the Wollongong LGA and any associated measures to manage human health risks.

The review will include the following:

1. Seek information from the Port Kembla Pollution Meeting, Port Kembla Harbour Environment Group and other relevant stakeholders that may be available that should be considered under (2) below and has not already been identified in Schedule A.
2. Undertake a comprehensive independent review and analysis of information in relation to the Wollongong LGA and:
    - the levels and distribution of heavy metals in soils and roof dust;
    - lead in air;
    - blood lead levels; and
    - any associated strategies/measures to manage human exposure and prevent/minimise human health risks.

This review is to include a detailed commentary and analysis of:

- the information against relevant, contemporary national and international Australia guidelines. Australian guidelines include the NHMRC and NEPC;
- the rationale for the guidelines used to interpret information; and
- the extent and limitations of the data and information available.

Appendix A contains the complete Scope of Works.

The Independent Review Report is to include the information listed in Schedule A and the stakeholders identified in (1) above. The Independent Review Report will also provide recommendations concerning the abovementioned tasks.

2.2 Purpose

The literature review is being prepared to inform the Lead & Other Heavy Metal Contamination Working Group (the 'Working Group') comprising representatives from the EPA, Wollongong City Council and NSW Health. The purpose of this group is to understand what has been done in the past and to determine what (if any) future actions are required to further address heavy metal contamination in the Wollongong LGA, particularly where human health risks are identified. The proposed literature review will be one of the matters considered by the Working Group in developing strategies to address contamination issues, should the need be identified.

2.3 Background Information

Reports provided by NSW EPA (Appendix A) and others for this literature review comprise the following types of documents:

- Scientific papers published in peer reviewed journals (predominantly on soil, dust and blood lead levels, as well as mapping locally and measurement methods globally and review of the Working Group).

- Thesis studies from UoW.
- Presentations from community meetings.
- Standards and regulatory guidance documents (including Fact Sheets) for NSW, the Australian government and overseas.
- Company technical reports on environmental studies on the Port Kembla sites to meet regulatory requirements.
- Government initiated technical studies/reports on the local area and specific materials.
- Lead & Other Heavy Metal Contamination documents.

All supplied and available reports were read to give familiarity with the contents and enable key details of soil contamination data to be compiled, summarised and interpreted in the context of assessing soil metal contamination against the Australian National Environment Protection Measure (NEPM) for soil contamination (NEPC, 2013). Selected other data sources and literature comprising published papers and reports accessible from the internet were also reviewed. Particular attention has been paid to locating literature and report details of studies that have been undertaken to assess the contamination from lead and other heavy metals at sites in Port Kembla and adjacent Lake Illawarra, against current guidelines. This approach enables the first steps of health and environmental risk assessments to be performed for the historically contaminated sites.

The literature relevant to this review provided by NSW EPA focusses on the legacy contamination issues in the Port Kembla area. Other information across the LGA and other areas of NSW (Broken Hill and Lake Macquarie) and Australia (Port Pirie, South Australia and Mount Isa, Queensland) is also reviewed where relevant. Literature known by the Working Group on air quality, soils, roof dust, blood lead studies and measures to manage human exposure and prevent/minimise human health risks are listed in Schedule A (Appendix A) and considered in this review.

Information has been generated from the Working Group but no meeting has yet been held with the Port Kembla Pollution Meeting, Port Kembla Harbour Environment Group and other relevant stakeholders due to the unprecedented COVID-19 related events.

3. Regulatory Requirements and Health Risk Assessment Frameworks

3.1 Regulatory Requirements in NSW

Land management of the former copper smelter and related sites in the Wollongong LGA fall under the jurisdiction of NSW state and local government agencies. In NSW, the EPA, the Department of Planning and Environment, and planning consent authorities (usually local councils) share the management of contaminated land. Sites such as Port Kembla are typically clustered in areas formerly used for heavy industry or intensive agriculture or exist as individual sites that have been used for chemical storage, such as service stations and dry cleaning sites.

In very broad terms, the management framework for contaminated land in NSW consists of two tiers[1]:

1. The EPA, which uses its powers under the CLM Act 1997 to deal with site contamination that is significant enough to warrant regulation under the Act, given the current or approved use of the site.
2. Local councils who deal with other contamination under the planning and development framework, including SEPP No. 55 - Remediation of Land and the Managing Land Contamination - Planning Guidelines, on sites which, though contaminated, do not pose an unacceptable risk under their current or approved use. In these cases, the planning and development process determines what remediation is needed to make the land suitable for a different use.

The NSW EPA can make or approve guidelines under Section 105 of the CLM Act 1997 for the purposes connected with the objects of the Act.

Statutory guidelines must be considered by:

- the EPA;
- accredited site auditors;
- contaminated land consultants; and
- those responsible for land contamination with a duty to notify[2] the EPA.

Note also that the EPA's contaminated sites guidelines refer to:

- The Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC, October 2000), are replaced as of 29 August 2018 by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality[3] (ANZG, August 2018), subject to the same terms with the exception of the Water quality for primary industries component[4] which still refer to the ANZECC 2000/ANZG 2018 guidelines; and
- The National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC 1999) are replaced as of 16 May 2013 by the National Environment Protection (Assessment of Site Contamination) Measure 1999 (April 2013), subject to the same terms.

[1] See the *Contaminated Land Management Act 1997* (CLM Act) to deal with site contamination under the Act and the following sites for managing contaminated land: https://www.epa.nsw.gov.au/your-environment/contaminated-land/managing-contaminated-land; https://www.epa.nsw.gov.au/your-environment/contaminated-land/statutory-guidelines
[2] https://www.epa.nsw.gov.au/your-environment/contaminated-land/managing-contaminated-land/duty-report-contaminated-land
[3] http://www.waterquality.gov.au/anz-guidelines
[4] http://www.waterquality.gov.au/anz-guidelines/Documents/ANZECC-ARMCANZ-2000-guidelines-vol3.pdf

Wollongong City Council is required to ensure that the requirements of the CLM Act, SEPP No. 55 and the associated Managing Land Contamination: Planning Guidelines 1998 are complied with. This ensure that the use of contaminated land, or suspected contaminated land, occurs by minimising risk to the community and the environment.

The management of contaminated land is a shared responsibility between the NSW EPA, NSW Department of Planning and Environment (DP&E), and Wollongong City Council.

Under the CLM Act, the NSW EPA regulates contaminated sites that are significant enough to warrant regulation (see Part 3 Division 2 of the CLM Act). The NSW EPA:

- regulates the appropriate investigation and clean-up of significantly contaminated land;
- administers the NSW site auditor scheme under Part 4 of the CLM Act;
- makes or approves guidelines for use in the assessment and remediation of contaminated sites; and
- administers the public record of regulated sites under the CLM Act.

Contaminated or potentially contaminated sites that are not regulated by the NSW EPA are managed by Wollongong City Council through land use planning processes i.e., SEPP55 and related guidelines, LEP (2009), DCP (2009), and any other relevant council policies and procedures.

Wollongong City Council has developed a framework to manage those sites, which are contaminated or potentially contaminated, that do not pose an unacceptable risk to human health or the environment under its current or approved use. The planning and development process will determine what remediation or abatement is required to ensure the land is suitable for a different use. This policy is a land-based policy only. Part 7A of the Environmental Planning and Assessment Act 1979 (EP&A Act) provides that planning authorities who act substantially in accordance with SEPP55 and related guidelines, are taken to have acted in good faith when carrying out planning functions.

Wollongong City Council can also determine if the land is affected by a policy that restricts the development of the land because of a contamination risk. Notifying restrictions on land use and any other additional information is also applied by using ‘Notations’ as a component of Section 149(2) Planning Certificates at Question 7(e) (Council and other public authority policies on hazard risk restrictions) in the following cases: “Notation 1. Contaminated or potentially contaminated land; Notation 2. Contaminated or potentially contaminated land that has undergone some form of remediation or abatement; Notation 3. Land that has undergone some form of testing and found to be under the threshold level for further investigation; and Notation 4. No clear site history”.

The following information should be provided (if available in the Council’s database) on all Section 149(5) Planning Certificates, or provided during any other enquiries made to Wollongong City Council about land:

- Any activities listed in Council’s DCP 2009, or SEPP55 shown by Council’s records as having occurred on the land.
- The results of any site investigations held by the Council.
- The results of any site abatement.
- Any notifications of remediation.
- Copies of any site audit statements if held by the Council.

All information recorded and actions taken, such as remediation or abatement, will be held in Wollongong City Council’s database in perpetuity as facts about the land and available to all enquirers.

Other information that may be relevant to an enquirer under Section 149(5) or other enquiries made to Council about land in the CPCL Database should include any of the types of information that may be held by Council as listed in Attachment 1 of this policy.

3.2 Lead Management Action Plan

Lead exposure re-emerged as a public health concern throughout NSW and Australia in 1993 (NSW GOVERNMENT, 1993). This concern was expressed by, and directed to, communities near industrial point sources of lead pollution or communities that were potentially exposed from non-industrial sources such as leaded petrol and lead-based paints, particularly in urban areas. In the Illawarra region, environmental lead contamination had been an issue with people living near the Port Kembla industrial complex for many years.

In March 1993, the NSW Government released the Lead Issues Paper, developed by the NSW EPA and the Health Department, which reviewed the extent and severity of community lead exposure in NSW. The paper recommended that an Inter-departmental Lead Taskforce be established to develop a coordinated strategy for NSW (NSW Government, 1993).

The re-emergence of this public health concern in 1993 was largely because BLLs, which were once thought to be safe, were now considered to represent a risk for young children. This followed the recognition in North America and Europe that as low as 10µg/dL among young children may have detrimental effects on intellectual development and behaviour (Alperstein and Vimpani, 1994; Wigg, 2001). In June 1993, the NHMRC set a national goal for all Australians to have a BLL of less than 10µg/dL, with a particular urgency in achieving this goal for children aged 1-4 years old (Alperstein et al., 1994).

In 1993 an Inter-departmental Lead Taskforce was convened to oversee and coordinate the development of a LMAP for NSW. The LMAP was released in late 1994 and included recommendations of specific actions for the point source communities of Broken Hill, North Lake Macquarie and Port Kembla (NSW EPA, 1994).

The Taskforce was established in April 1993, and eight Working Groups were formed to investigate eight specific issues and recommend strategies to reduce lead exposure in each case. These specific issues included: lead in (1) air, (2) soil and dust, (3) water and wastewater, (4) food, (5) paint, (6) petrol, (7) children's blood and (8) Broken Hill. In November 1993, a ninth Working Group was established to focus on lead education given that all other Working Groups had identified early on that education was crucial to reducing lead exposure in NSW (Inter-departmental Lead Taskforce, 1994).

The key elements of the final report (released December 1994) of the Taskforce were (Inter-departmental Lead Taskforce, 1994):

- Establishment of a Lead Reference Centre to (1) coordinate the implementation of effective strategies by organisations identified in the Plan, and (2) develop and implement lead education strategies contained in the Plan.
- If deemed necessary after preliminary investigations, establishment of Environmental Lead Centres in point source communities, e.g. Port Kembla.
- Additional actions on specific issues, including education on: lead in air, paint, petrol, soil and dust, water and wastewater, food, and lead in children's blood.
- Investigation and planning: implementation of the Port Kembla Interim Action Plan as recommended by the Inter-departmental Lead Taskforce; preparation and implementation of a lead management plan similar to the lead management plan for North Lake Macquarie, in conjunction with a determination of the extent of environmental contamination of air, soil, water and sediments.
- Southern Copper license: community participation in formulation of license conditions; incorporation of standard of 1.0µg/m^3 for lead in air; incorporation of conditions for continual annual reductions of fugitive and stack emissions, and direct lead discharge in effluent.

- Air quality monitoring: daily monitoring at existing monitoring stations at existing sites; regular cross checks on industry monitoring; more ambient monitors if smelting recommences; ambient air monitors in school grounds close to smelter.
- Technology impact: re-evaluation of Southern Copper upgrade or proposal to re-commence smelting, to examine whether technology can meet standard of 1.0µg/m^3 for lead in air and recommended annual reductions in emissions.
- Buffer zone: investigation of question of buffer zone.
- Transport: development and implementation of a standardised cleaning protocol to prevent lead from escaping from lead processing sites as a result of transportation.
- Site remediation: remediation of site during care and maintenance phase with particular attention to fugitive emissions.

Of specific relevance to Port Kembla, the Taskforce report (Inter-departmental Lead Taskforce, 1994) noted that no comprehensive, integrated, environmental study of lead had been undertaken in the vicinity of the smelter. Only limited health studies had been undertaken in the area and the reliability of the data, and non-standard methods used in the studies, had limited the significance of the results. There were no reliable figures available on the rate of emission of lead (both point source and fugitive) from the smelter, but the estimates indicated that emission rates may be higher than the emission rates from the lead smelter in North Lake Macquarie. A comprehensive action plan could not be developed and implemented until the extent of the lead problem had been investigated.

The proposed Port Kembla Interim Action Plan had two objectives:

1. To determine the magnitude and effects of lead contamination on public health and the environment in the vicinity of Port Kembla, and develop a comprehensive management strategy where appropriate. Recommended strategies were:
   - Development and implementation of an investigation program to determine the status of environmental contamination and the consequent effect on public health in the vicinity of the Port Kembla smelter. *Strategy implementation: a multidisciplinary team incorporating NSW Health, EPA, industry, local government*; and
   - Development of an Action Plan for the management of lead contamination issues which is based on the findings of the investigation program, and could incorporate the establishment of an Environmental Lead Centre (if appropriate) and the development of an education strategy. *Strategy implementation: a multidisciplinary team incorporating NSW Health, EPA, industry, local government*.
2. To determine the impact of the smelter on surrounding areas by accurately determining the rate of emissions from the plant. The recommended strategy was:
   - Establish emission rates for fugitive and point source emissions from the smelter by undertaking a comprehensive audit of the plant. *Strategy implementation: fugitive and point source emission rates from the smelter should be established by the smelter and the EPA should be responsible for ensuring this action is undertaken*.

The development of this Action Plan for the management of lead contamination issues was recommended, following the findings of the investigation program (NSW EPA, 1994).

In 1996, the NSW Lead Reference Centre (LRC) was established to coordinate the NSW Government's response to environmental lead hazards and implement the recommendations of the LMAP. The EPA, Roads and Traffic Authority, Department of Public Works and Services, Department of Housing, WorkCover Authority and NSW Health Department funded the LRC, which was part of the NSW EPA.

Part of the recommended investigation program was the Illawarra Child Blood Lead Study (ICBLS) and was commissioned by the NSW Health Department in 1994. Among the group of children aged 1-4 years old living in Port Kembla/Kemblawarra, 11% had BLLs above 10µg/dL, as compared to 9% in Warrawong and 7% in Cringila (Kreis et al., 1994). Average BLLs were slightly higher among children living in Port Kembla/Kemblawarra, being suburbs closest to the smelter; however elevated BLLs were not confined to these children.

In Port Kembla/Kemblawarra, 5% of children aged 1-4 years old had BLLs above 15µg/dL. The NHMRC guidelines suggested that when more than 5% of children aged 1-4 years old have BLLs above 15µg/dL, the community should be considered 'at risk' of lead exposure, and action should be taken accordingly.

Of those children with high BLLs, almost all of them were in the range of 10-20µg/dL, which is only considered moderately elevated. Consistent with other studies, the follow-up of these children indicated that the usual cause of moderate blood lead elevation was 'multifactorial', i.e. likely to have resulted from multiple small exposures to lead from a number of sources. In addition to emissions from the copper smelter, the other main sources of lead exposure in the Port Kembla area are typical of urban areas, i.e. lead based paint and leaded petrol. This also suggests that action needs to be taken beyond the community living in close proximity to the industrial point source at Port Kembla, at least in terms of community and professional education.

3.3 Illawarra Lead Management Plan

3.3.1 Background

In early 1995, an Illawarra Lead Taskforce was convened by the Illawarra Public Health Unit (IPHU) to develop a LMAP to quantify the lead issue in the Illawarra, and develop a plan for lead management. The Taskforce includes representatives from State Government agencies (Illawarra Area Health Service, NSW Health Department, NSW EPA and the Department of Housing), Local Government (Wollongong Council), UoW (Illawarra Environmental Health Unit), industry (Southern Copper, previously Port Kembla Copper) and the Port Kembla community.

The aims of the Taskforce were to:

- review available information related to the magnitude, distribution and determinants of the lead problem in the Port Kembla area;
- critically review action taken to date; and
- develop an 'Illawarra LMAP', which:
  - focuses on the Port Kembla community, recognising that strategies developed may be useful in other parts of the Illawarra;
  - addresses the needs for: appropriate education of health and other professionals and the community; relevant environmental and health monitoring; and control strategies; and
  - identifies responsible organisations, tasks, timeline and resources required for implementation.

An Illawarra Lead Management Plan (ILMP) was developed in 1998. The Plan included the following aims:

- Monitor, investigate and regularly feedback information to the community about BLLs and environmental lead levels in the Illawarra, focussing on Port Kembla.
- Increase the awareness, knowledge and skills of people in the community, in particular parents of young children, and people working in local health services, childcare/education, local government and relevant trades, so as to minimise lead exposure and environmental lead contamination in the Illawarra, focussing on Port Kembla.

- Minimise the potential for exposure to historical lead contamination and further reduce the environmental lead contamination, focussing on the Port Kembla area.

In late 1994, a Select Committee Upon Lead Pollution (Senate, 1994) was formed, just prior to the release of the NSW LMAP (Inter-departmental Lead Taskforce, 1994) to:

- examine the extent of lead pollution past and present in NSW;
- examine the impact of lead pollution on the health of people in the community, particularly communities in close proximity to industrial point sources, namely Port Kembla, Boolaroo and Broken Hill; and
- recommend appropriate strategies and action including remediation, health monitoring, timetable for lowering air quality and blood lead goals and standards, and financial responsibility of the polluting industries for the costs of remediation and monitoring.

Specific recommendations relating to Port Kembla were:

- Investigation and planning: implementation of the Port Kembla Interim Action Plan as recommended by the Inter-departmental Lead Taskforce; preparation and implementation of a lead management plan similar to the lead management plan for North Lake Macquarie, in conjunction with a determination of the extent of environmental contamination of air, soil, water and sediments.
- Southern Copper license: community participation in formulation of license conditions; incorporation of standard of 1.0µg/m^3 for lead in air; incorporation of conditions for continual annual reductions of fugitive and stack emissions, and direct lead discharge in effluent.
- Air quality monitoring: daily monitoring at existing monitoring stations at existing sites; regular cross checks on industry monitoring; more ambient monitors if smelting recommences; ambient air monitors in school grounds close to smelter.
- Technology impact: re-evaluation of Southern Copper upgrade or proposal to re-commence smelting, to examine whether technology can meet standard of 1.0µg/m^3 for lead in air and recommended annual reductions in emissions.
- Buffer zone: investigation of question of buffer zone.
- Transport: development and implementation of a standardised cleaning protocol to prevent lead from escaping from lead processing sites as a result of transportation.
- Site remediation: remediation of site during care and maintenance phase with particular attention to fugitive emissions.

3.3.2 Progress of the ILMP

In 1998, a strategic plan for 1998-2001 was drawn up by the Illawarra Lead Taskforce (ILT) which was aimed at minimising lead exposure in the Illawarra. The following comprise the review of progress of the ILT Meeting held 13 December 1999 (ILMP, 1999).

3.3.2.1 Health risk

The 1994 Illawarra Child Blood Lead Study (ICBLS) found that 11% of 1-4 year old children in Port Kembla/ Kemblawarra had BLLs (PbB) above the national goal of 10µg/dL (ILMP, 1999). This was higher than:

- in suburbs further from the point source (Warrawong 9.1%, Cringila.7.3%);
- the national average (7.3% among 1-4 year olds in 1995); and
- in suburbs more than 10km from Sydney CBD (9% among 9 months-5 year olds in 1992-94).

It was lower than:

- in suburbs within 10km of the Sydney CBD (25% among 9 months-5 year olds in I992- 94); and
- in other point source communities (e.g. 66% in Broken Hill in 1993; 59% in North Lake Macquarie in 1994).

Similarly, in 1994 average PbB among 1-4 year old Port Kembla children were 6.7µg/dL, as compared to 6.1µg/dL in Warrawong, 6.0µg/dL in Cringila, 5.8µg/dL as a national average, 6.3µg/dL in outer Sydney suburbs, and 8,0µg/dL in inner Sydney suburbs.

The vast majority of children with elevated PbB in the Port Kembla area had PbB in the range 10-20µg/dL, i.e. 'moderately elevated'.

3.3.2.2 Environmental exposure sources and pathways

Health risk depends on exposure to a hazardous substance or situation - if there is no or minimal exposure to the lead hazard(s), there is no or minimal health risk (ILMP, 1999).

Consistent with other studies of children with moderately elevated PbB, the follow-up of Port Kembla children from the ICBLS indicated that the usual cause of elevated PbB was 'multifactorial', i.e. likely to have resulted from multiple small exposures to lead from a number of sources. The main pathway for lead exposure among children is ingestion.

The probable main sources/ pathways contributing to elevated PbB in Port Kembla were:

- lead-based paint in pre-1970 houses with deteriorating paint and/ or following unsafe renovations;
- soil lead: from paint and airborne lead (from industrial emissions and petrol); and
- household dust from lead-based paint, soil lead and air-borne lead (with a negligible contribution from roof dust where ceiling spaces are sealed and undisturbed).

PbB levels among Port Kembla children have been shown to be:

- significantly correlated with paint and soil lead levels, the correlation being slightly higher for paint than soil; and
- not significantly correlated with household lead dust levels (although it is possible that this lack of association was at least partly due to the study methods used).

Important potential additional risks to individual children concern exposures to lead from:

- paint and ceiling dust during unsafe renovations; and
- parent's work clothes and hobbies (e.g. fishing sinkers).

That is, while relatively high concentrations of lead may be present in paint, fishing sinkers, and to a lesser extent ceiling dust and work clothes, risk only arises if and when there is exposure to the hazard.

The ILMP (1999) stated that more than 90% of soil samples taken following 1993 in the Port Kembla area had soil lead levels of less than 1,000mg/kg, with the vast majority being below 300mg/kg which is still the current guideline for Level A Residential with garden (Table 1). As a general guideline, no action was required at that time where typical soil lead levels were below 300mg/kg, and grass cover was recommended where soil levels were 300-1,500mg/kg. Soil samples taken periodically from 'high contact' areas for young children, e.g. play pits in pre-schools and child care centres, had lead concentrations below 300mg/kg. Soil lead levels were on average higher closer to the smelter. Household lead dust loadings (µg lead/m^2 of lead-bearing surface) were thought to be more important than lead dust concentrations. The limited household lead dust loading measures which were undertaken in the Port Kembla area had shown low levels of lead dust loads, but may now exceed international guidelines.

Lead in air levels in past years near the copper smelter frequently exceeded the national goal of 1.5ug/m^3 as a 90 day average (ILMP, 1999). The new development consent and licence conditions for the copper smelter in Port Kembla state that lead in air concentrations cannot exceed 1.0µg/m^3 as a running 90 day average.

3.4 Recognised Frameworks

The success of programs to control human exposure to lead is assessed against available data for soil total lead concentration and local population BLLs against appropriate guidelines using recognised frameworks. Best practice involves following the risk assessment approach following enHealth (2012) with guidance of NEPM (NEPC, 2013) and the NHMRC (2016).

3.4.1 Guidelines made by the EPA

The CLM Act (Section 3.2) lists a number of guidelines to deal with particular kinds of contaminated sites and aspects of sampling and reporting site contamination. These guidelines are listed in Appendix C. The NSW EPA's contaminated sites guidelines approve the use of a number of Australian guidelines that appear in the following sections.

3.4.2 Health risk assessment

Risk assessment is a process that enables management and communication tools to be developed to aid controlling any adverse effects of chemical applications (Ricci, 2006). It comprises the discrete steps of identification of source and hazard, dose response, exposure and calculation of risk (ISO, 2009). Acceptable risk management concepts may be applied for public health and environmental management of contaminated land if exposed to hazardous substances. The recognised framework for health risk assessment in Australia is Environmental Health Risk Assessment Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth, 2012), and is shown in Figure 1.

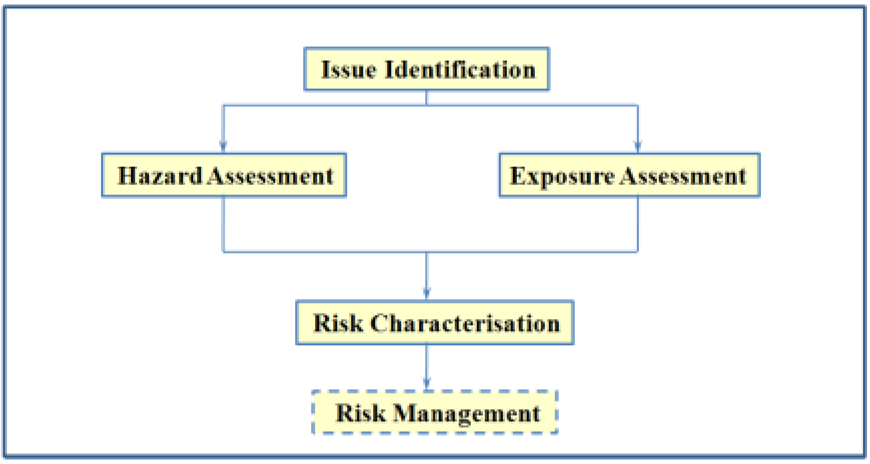


Figure 1 *Accepted risk assessment used as a framework in this study (enHealth, 2012).*

The risk assessment procedure for considering the impact of lead and other heavy metals, which is generally adopted (enHealth, 2012), considers the following steps:

1. hazard identification;
2. dose response assessment; and
3. exposure assessment.

Risk characterisation then enables the estimation of any adverse effect and provides a means of devising risk management, if appropriate. Risk management can then be applied on the basis of the assessments given below.

The enHealth (2012) guidelines present a general environmental health risk assessment methodology which has been adopted nationally to evaluate risks and establish standards for the protection of human health and the environment. The evaluation of specific components of the environment is dealt with by the NEPMs and consist of a policy framework for the assessment of contamination in particular categories.

3.4.3 Soil contamination guidelines

The NEPM has developed a policy framework for the assessment of site contamination for soil: Schedule A (Recommended General Process for the Assessment of Site Contamination) and Schedule B (Guidelines).

Health Investigation Levels (HILs) for soil

The NEPM guidelines for soil contamination (Table 1) are the current guidelines in Australia for metals and metalloids (NEPC, 2013). A framework is provided for use of various levels in Schedule B1 (NEPC, 2013). The extent of contamination of soil is evaluated by comparing total concentration against the NEPM HILs (Table 1) criteria for contaminated soil (NEPC, 2013). A site may be assessed based on investigation levels, or a site specific assessment can be undertaken.

***Table 1** NEPM Soil Investigation Levels (NEPC 2013).*

Metal or Metalloid	Residential with garden	Residential no access	Recreational	Commercial
(mg/kg)	(HIL Level A)	(HIL Level B)	(HIL Level C)	(HIL Level D)
Antimony (Sb)	NA	NA	NA	NA
Arsenic (As)	100	500	300	3000
Cadmium (Cd)	20	150	90	900
Cobalt (Co)	100	600	300	4000
Copper (Cu)	6,000	30,000	17,000	240,000
Lead (Pb)	300	1200	600	1,500
Manganese (Mn)	3,800	14,000	19,000	60,000
Nickel (Ni)	400	1,200	1200	6,000
Zinc (Zn)	7,400	60,000	30,000	400,000

Note:

Level A – Residential with garden/accessible soil (homegrown produce <10% fruit and vegetable intake, no poultry), also includes children's day care centres, preschools and primary schools.

Level B – Residential with minimal opportunities for soil access includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments.

Level C – 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.

Level D – Commercial/industrial includes premises such as shops, offices, factories and industrial sites.

Soil metal and metalloid concentrations may be compared against the NEPM criteria (NEPC, 2013). The Australian Standard (AS) 4482.1 “Guide to the investigation and sampling of sites with potentially contaminated soil, Part 1: non-volatile and semi-volatile compounds” (Standards Australia, 2005) and NSW EPA soil sampling guidelines (DEC NSW, 2006) provide guidance for collecting sufficient and reliable information for the assessment of a site potentially contaminated by metals and metalloids.

In cases of minor exceedance of investigation levels or exceedance related to contaminants that have low human toxicity and limited mobility, a qualitative risk assessment may be sufficient. The risk assessment process (enHealth, 2012) may lead to the development of site-specific response levels generated by risk assessment and agreed in consultation between the professionals assessing the site and the regulatory authorities (Ng et al., 2015). The Tier 2 risk assessment process described by NEPC (2013) allows for toxicity (bioavailability) assessment when HILs for the designated category or land use is exceeded. The current NEPMs assume that the bioavailability of contaminated soil is 100% and allow for bioaccessibility adjustment of total concentrations for arsenic and lead ((NEPC, 2013; Schedule B4). However, bioavailability of lead in mine wastes is usually <100% (Diacomanolis et al., 2007).

Therefore, a risk assessment conducted on a metal and metalloid survey of surface soils at Wollongong may employ as tools:

(i) in-vivo bioavailability measurement of selected composite wastes using animal uptake with rats (this testing, although expensive and time consuming, gives standardisation of the following in-vitro measurement); and

(ii) in-vitro bioaccessibility methods such as the physiologically based extraction test (PBET) of bioaccessibility of metals and metalloids in individual soil samples (Ruby et al., 1996; Bruce et al., 2008) provide a practical measurement that predicts the bioavailability and can be calibrated against HILs (Diacomanolis et al., 2007; see Section 3.6).

The NEPM Ecological Investigation Levels (EILs) have been expanded and cover a range of soil types and constituents that apply for fresh and aged contamination in soil (NEPC, 2013). The former Interim Urban EILs (NEPC, 1996) were intended to give an indication of potential phytotoxicity at urban locations only. Thus, the current NEPM requires that both the potential effects to human health and the environment (ecology) of metals and metalloids associated with the Eastern Precinct be fully evaluated. (Appendix D).

The NEPM (2013) now defines the EIL as the concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values will be required. The EILs are calculated using EC30 or lowest observed effect concentrations (LOEC) toxicity data. EILs are the sum of the added contaminant limit (ACL) and the ambient background concentration (ABC) and the limit is expressed in terms of total concentration. EILs depend on specific soil physicochemical properties and land use scenarios, and generally apply to the top two metres of soil.

3.4.4 Air particulates

Nature of air particulates

The measurement of ambient 24-hr average air concentrations of air particulates may cover the following categories:

- total suspended particulates (TSP, i.e. less than 50 μm in diameter);
- PM_{10} suspended particulates (i.e. less than 10 μm in diameter);
- $PM_{2.5}$ suspended particulates (i.e. less than 2.5 μm in diameter, “respirable”); and
- particle identification in the TSP fraction of the dust.

The PM_{10} and $PM_{2.5}$ air quality standards that apply in NSW are summarised in Table 2. The numerical value of the air quality guidelines adopted by the World Health Organisation (WHO) for PM_{10} are based on studies of the health effects associated with $PM_{2.5}$ exposures in cities located in developed and undeveloped countries throughout the world. A ratio of $PM_{2.5}$ to PM_{10} of 0.5 is assumed, which is at the bottom end of the range of values in developed country urban areas (WHO, 2005).

In general, particles that are emitted from an emission source consists of a range of particle sizes that is dependent on the source characteristics. Particles that are generated using mechanical means generally consist of larger-sized particles (i.e. greater than $PM_{2.5}$) when compared with particulate matter (PM) generated during combustion (high temperature) processes which contains a higher percentage of particles in the range of $PM_{2.5}$ to ultrafine particles. Particles generated from spraying activities can also be fine to ultrafine. Fine particles remain suspended in the atmosphere until they undergo deposition under the force of gravity. Any particles that fall out of suspension and are collected using a dust deposition gauge, are described as 'deposited matter'.

The NEPM (Air) standard for PM_{10} and the NEPM (Air) Advisory Reporting Standards for $PM_{2.5}$ (NEPC, 2016) have been derived from health in urban areas where the majority of the PM_{10} and $PM_{2.5}$ are due to motor vehicles. The accepted Australian framework for human health risk assessment (Figure 1) of air particulates and dust is described by enHealth (2012).

***Table 2** PM_{10} and $PM_{2.5}$ air quality standards.*

Pollutant	Averaging period	Maximum ambient concentration	Goal/maximum allowable exceedance	References
Particles as PM_{10}	annual mean	20µg/m³		(NEPC, 2016)
	1 day mean	50µg/m³		(NEPC, 2016)
Particles as $PM_{2.5}$	annual mean	10µg/m³		(NEPC, 2016)
	1 day mean	25µg/m³		(NEPC, 2016)
Total suspended particles	1 year	90 µg/m³		(NEPC, 2016, EPP (Air)P, 2019)
Lead in total suspended particles ('TSP')	1 year	0.5 µg/m³	None	(NEPC, 20162) (EPP (Air)P, 2019)
As in PM_{10}	1 year	6 ng/m³		(EPP (Air)P, 2019)
Cd in PM_{10}	1 year	5 ng/m³		EPP (Air)P (2019)
Mn in PM_{10}	1 year	0.16 µg/m³		EPP (Air)P (2019)
Ni in PM_{10}	1 year	22 ng/m³		EPP (Air)P (2019)
V in PM_{10}	24 hr	1.1µg/m³		EPP (Air)P (2019)

Note: [1] Indicates using ISO DIS-4222.2 method (ISO, 1979). ** indicates using AS 3580.9.6-1990 method (Standards Australia, 2003).

Air–particulate sampling

AS 3580 titled '*Methods for sampling and analysis of ambient air'* specifies a gravimetric method for determining suspended PM in ambient air as total suspended PM (<50 µm) or PM_{10} (<10 µm). Sampling is normally undertaken over a 24-hour period to average out daily variations in particle levels and to allow a sufficient mass of PM to be collected. Ambient air quality measurement of particulate levels for air NEPM standards are measured using AS 3580 (Standards Australia, 2003).

National Environment Protection Measure (Air)

National Environment Protection (Ambient Air Quality) Measure ('Air NEPM') standards (NEPC, 2016) are uniform standards for ambient air quality in Australia (Table 2) and provide guidelines relevant to airborne particles as particulate matter 10µm (PM_{10}) for a one-day averaging period and lead for a one-year averaging period. Since 2003, the additional parameter of advisory reporting standards for 2.5 µm fine particles have been added. The Air NEPM does not include indoor air criteria. These NEPM criteria are useful in the absence of site-specific criteria.

NSW Air Policy

The NSW EPA relies on the full complement of air quality indicators of the current Air NEPM (NEPC, 2016) and are listed in Table 2 with some other air quality standards, including lead and the goal/maximum allowable exceedance. The Queensland Environmental Protection (Air) Policy (EPP (Air)P, 2019) air standards for arsenic and other metals (arsenic, cadmium, manganese, nickel and vanadium) apart from lead. $PM_{2.5}$, PM_{10}, and total suspended particles (TSP) are different classes of air particulates and are listed together with maximum allowable exceedances (Table 2). The air-PM_{10} being finer material .is a subset of the TSP level which is <50 µm.

Fall-out dust

'Dust' is a generic term for describing fine particles that are suspended in the atmosphere. Any dust that falls out of suspension, and is collected using a dust deposition gauge, is referred as 'deposited matter'. Fall-out may be material that can be ingested (<250µm – larger particles do not adhere as readily to the hands) (Ng et al., 2015) once deposited to the ground. The most simple and cost-effective method for undertaking dust monitoring is to monitor deposition rates using a dust deposition gauge. The dust sampling method in this study followed the description in AS 3580 (Standards Australia, 2003).

The Queensland recommended guideline for fall-out dust is 120µg/m^2/day for nuisance soiling of property and is adopted from the NSW guideline (Table 2).

There is no health-based guideline for fall-out dust. The New Zealand ISO DIS-4222.2 method (ISO, 1979) 130 (mg/m^2/day) above background concentration has also been used for rail dust evaluation (NZMFE, 2001).

Fall-out dust guidelines in Australian and New Zealand are limited to nuisance soiling of property. The German regulation for air pollution control 'Technische Anleitung zur Reinhaltung der Luft' (TA LUFT) (1990, 1999) provides metal deposition guidelines that are useful for assessing environmental deposition from spraying and that are lower than house clearance levels for contaminated situations.

The TA LUFT regulation (1990) which is employed to review applications for permits to build and operate industrial facilities within Germany describes metal deposition guidelines. The TA LUFT guidelines for metal deposition constitute trigger values under this regulation. Industries that contribute to an overall deposition rate of metals below these values are approved subject to further regulations. Deposition rates beyond these guideline values require 'special-case examination' to determine whether adverse soil 'alterations' can occur, and to what extent. (TA LUFT, 1990 and Annex 2, 1999).

Table 3 presents the trigger deposition guidelines specified for arsenic and other metals including lead under the TA LUFT regulation and give an indication of how conservative the TA LUFT guidelines are for lead in fall-out compared with the US EPA clearance standards.

Table 3 *Dust and Metal/metalloid Deposition Guidelines (TA LUFT, 1990, 1999).*

Dust or metal/metalloid deposition (Queensland Environmental Authority)	Standard (µg/m²/day)	Averaging Period
	120 (mg/m^2/day)	1 month
Dust deposition (NZMFE, 2001)	130[1] (mg/m^2/day) above > background	1 month
Arsenic	4	1-year
Cadmium	2	1-year
Lead **Protection of human health** **Protection of crop land integrity** **Protection of grassland integrity**	 100 (1990) 185 (1999) 1900 (1999)	1-year
Nickel	15	1-year
Mercury	1	1-year
Thallium	2	1-year

House dust and clearance standards

The AS 4874 titled *'Guide to the investigation of potentially contaminated soil and deposited dust as a source of lead available to humans'* (Standards Australia, 2000) sets out procedures for collecting deposited dust and soil samples to determine whether lead or other metals and arsenic present is able to cause toxicity in humans. Special emphasis is placed on infants and the collection of samples from areas this population group would come into contact with surface dust. A detailed description of dust sampling approaches for soil and dust in houses is provided. The AS 4874 guide does not give guidelines for contaminated houses, but it does identify appropriate international criteria, such as those from the United States (US) EPA (US EPA, 2001).

The AS 4482.1 titled '*Guide to the investigation and sampling of sites with potentially contaminated soil. Part 1: non-volatile and semi-volatile compounds*' (Standards Australia, 2005) provides guidance for collecting sufficient and reliable information for the assessment of a site potentially contaminated by lead and other metals and metalloids, apart from other non-volatile and semi-volatile compounds. This standard does not establish regulatory limits but supports those of the NEPM document (NEPC, 1999).

The US EPA has developed 'lead clearance standards' for house floors, window sills and window troughs, but not carpet dust. These standards determine whether it is considered safe to live in the house after lead-removal activities have been completed. Comparison of results for surface wipes is made against the standards given in the US EPA regulation, *Lead — Identification of Dangerous Levels of Lead, Final Rule, Federal Register Friday January 5 2001, Part III Environmental Protection Agency "Clearance Standards for Dust"* (US EPA, 2001). The US clearance lead standards for houses are:

- 430µg/m^2 for dust on the floor;
- 2691µg/m^2 for dust on interior window sills; and
- 4306µg/m^2 for dust in window troughs.

Although the US EPA clearance standards were developed for lead in house floors, window sills and window troughs, there are no equivalent clearance standards for arsenic and other metals. However, Brookhaven National Laboratory (2014) has developed the surface wipe sampling criteria (Table 4). Based on comparison of the US EPA lead clearance standard used (US EPA, 2001), the Brookhaven National

Laboratory surface levels (µg/m^2) correspond to window sill contamination. Chromium-VI is much more toxic than Chromium-III. In the absence of validated guidelines, estimates based on exposure will be required to identify if the surface wipe criteria are valid.

The NSW EPA has recommended to use of lead dust standards to determine the safety of the premises for re-occupancy after renovation and clean-up are completed (CLP Tool Kit, 2010).

The clearance standards recommended by NSWEPA for lead dust in premises are as follows:

- bare and carpeted floors: 1 mg/m^2;
- interior window sills: 5 mg/m^2; and
- exterior surfaces: 8 mg/m^2.

The lead dust loadings for various surfaces are from AS 4361.2-1998 '*Guide to lead paint management Part 2: Residential and Commercial Buildings*' (Standards Australia, 1998) and were originally based on the 1995 US guidance for investigation of lead exposure, subsequently reduced to 0.4 mg/m^2 in 2001 (USEPA, 2001). However, the Australian standard is yet to change to this more rigorous clearance level.

A revised AS/NZS 4361.2-2017 '*Guide to lead paint management Part 2: Lead paint in residential, public and commercial buildings*' (Standards Australia, 2017) was released that now recommends to have a waste management plan in place prior to any lead paint management work being undertaken.

Table 4 *Surface wipe criteria for metals and metalloids (Brookhaven National Laboratory 2014).*

Metal or metalloid	Surface Level (µg/100 cm^2)	Surface Level (µg/m^2)	Criteria type
Arsenic	15	1500	Housekeeping – all
Beryllium	3	300	Housekeeping – all
Cadmium	3	300	Housekeeping – all
Chromium-III	750	75,000	Housekeeping – all
Chromium-VI	7.5	750	Housekeeping – all
Cobalt	30	3000	Housekeeping – all
Lead	26.9	2690	Housekeeping – (US EPA, 2001)
Manganese	300	30,000	Housekeeping – all
Nickel	1500	150,000	Housekeeping – all
Silver	15	1500	Housekeeping – all

3.4.5 Blood lead measurement and prediction

The re-emergence of lead as a public health concern in Australia in 1993 was largely because BLLs, which were once thought to be safe, were now considered to represent a risk for young children. This followed the recognition in North America and Europe that BLLs as low as 10µg/dL among young children may have detrimental effects on intellectual development and behaviour (Alperstein and Vimpani, 1994; Wigg, 2001). In June 1993, the NHMRC set a national goal for all Australians to have a BLL of less than 10µg/dL, with a particular urgency in achieving this goal for children aged 1-4 years old (Alperstein et al., 1994).

Exposure of the population to lead is assessed directly by measuring blood lead. In 2015, the NHMRC released an information paper to provide a summary of evidence on the health effects of lead and how these health effects can be minimised (NHMRC, 2015). The NHMRC based its 2015 information paper on an independent review (Armstrong et al., 2014).

Thus, after 22 years to have a BLL of less than 10µg/dL, in 2016 the NHMRC recommended that if a person has a blood lead level greater than 5µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman (NHMRC, 2016). Exposure to lead in Australia has dropped significantly over recent decades as a result of measures restricting the use of lead in paint, petrol and consumer goods (Gulson et al. 2014). As a result, the average BLL in Australia is estimated to be less than 5µg/dL. Investigating the source of exposure where blood lead levels are greater than 5µg/dL will reduce the risk to individuals, particularly children (NHMRC, 2016).

Measurement of blood lead should be considered when symptoms or health effects associated with lead are present and/or a source of lead exposure is suspected but is the gold standard for lead exposure. Specifically, for lead, a risk assessment technique has been developed to assess the uptake of lead into the blood, which effectively applies an a priori uptake factor to an estimated dose to estimate blood lead concentration (NEPC, 2013; Schedule B4). The US EPA integrated exposure uptake biokinetic model (IEUBK) for lead in children is widely known and used in this respect (US EPA, 2004). This approach, with the appropriate justifications, is considered suitable at Tier 2 for assessing risks from lead. The US EPA IEUBK model (USEPA, 1994) is now commonly used to predict blood lead concentration from lead ingestion and is permitted for NEPM assessment of contaminated soil, but it is only applicable to young children (NEPC, 2013; Schedule B4).

3.4.6 Water quality guidelines

Lead in water may be a relevant health risk issue if there is a contamination of drinking water situation. The health risk assessment of metals and metalloids in water follows the Australian Drinking Water Quality Guidelines (ADWG, 2011) that are applied directly by comparison of total concentrations. Table 5 gives the drinking water quality guidelines for arsenic, cadmium, copper, lead, manganese and zinc (ADWG, 2011).

Recreational use of water is assessed using the NHMRC guidelines (NHMRC, 2008). Waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes. Recreational water should have a pH in the range pH 6.5-8.5 and dissolved oxygen content greater than 80% (ANZECC/ARMCANZ, 2000; NHMRC, 2008). According to the NHMRC (2008), the trigger value for lead in recreational water quality assessment is ten times that of the drinking water quality guideline value.

Table 5 *Drinking water quality guidelines for arsenic, cadmium, copper, lead, silver and zinc (ADWG, 2011).*

Metal or metalloid	Drinking water guideline (ADWG, 2011) (mg/L)
Arsenic	0.007
Cadmium	0.002
Copper	2
Lead	0.01
Mercury	0.001
Manganese	0.5
Nickel	0.02
Zinc	3

The concentrations of metals and metalloids in water used for stock may be significant with respect to metal and metalloid accumulation, which also links to human health via the food chain. The stock and irrigation guidelines for water quality for metals and metalloids that are given in Table 6 (ANZECC/ARMCANZ, 2000) generally have higher values compared with drinking water. The potential effects of metals and metalloids from current dust dispersion and transfer to surface waters may need to be assessed with respect to stock water and irrigation.

***Table 6** Stock and irrigation water quality guidelines for arsenic, cadmium, copper, lead and zinc (ANZECC/ARMCANZ, 2000).*

Water quality trigger values for stock watering and irrigation (ANZECC/ARMCANZ 2000) (mg/L)			
Metal or metalloid	Stock watering	Irrigation water Long term trigger value	Irrigation water Short term trigger value
Arsenic	0.5	0.1	2.0
Cadmium	0.01	0.01	0.05
Copper	1.0	0.2	5.0
Lead	0.1	2.0	5.0
Manganese	Not sufficiently toxic	0.2	10
Mercury	0.002	0.002	0.002
Nickel	1.0	0.2	2
Zinc	20	2.0	5.0

The assessment of water quality for protecting the aquatic ecosystem required a combination of analytical methods based on the decision-tree process for assessing metal and metalloid toxicity in water (ANZECC/ARMCANZ, 2000; ANZG, 2018). The initial step in the decision process is to derive site-specific trigger values for metals and metalloids by using a correction for hardness, calculated from the calcium plus magnesium concentrations ($CaCO_3$), to the default ANZECC/ARMCANZ (2000) guideline value. Aquatic toxicity decreases with increasing water hardness as soluble metal is precipitated. The default trigger value (for a hardness of 30mg/L $CaCO_3$) can be adjusted for the actual (measured) water hardness values using the simple algorithms described (ANZECC/ARMCANZ, 2000; ANZG, 2018).

Table 7 gives the water quality trigger values needed to protect the freshwater aquatic ecosystem (ANZECC/ARMCANZ, 2000) (microgram per litre -µg/L). These trigger values (Table 7) can be extremely low and indicate that increased protection is required for more vulnerable aquatic ecosystems. Also, at a lower pH level the effects on aquatic species are more significant.

Table 7 gives the sediment quality values for protection of aquatic species for arsenic, cadmium, copper, lead, silver and zinc (ANZECC/ARMCANZ, 2000; ANZG, 2018).

***Table 7** Water quality values for protection of freshwater aquatic species for arsenic, cadmium, copper, lead, silver and zinc (ANZECC/ARMCANZ, 2000).*

Water quality trigger values for protection of freshwater aquatic species (ANZECC/ARMCANZ, 2000) (µg/L)			
Metal or metalloid	80% protection of species	90% protection of species	95% protection of species
Arsenic III	360	94	24
Arsenic V	140	42	13
Cadmium	0.8	0.4	0.2
Copper	2.5	1.8	1.4
Lead	9.4	5.6	3.4
Manganese	3600	2500	1900
Mercury	5.4	1.9	0.6
Nickel	17	13	11
Zinc	31	15	8

Note:

Arsenic has two different oxidation states III and V. It is arsenic III that is carcinogenic and the greater health risk.
Mercury is inorganic form.

Sediment quality of freshwater creek systems is assessed by comparing metal and metalloid concentrations against the interim sediment quality guidelines of ANZECC/ARMCANZ (2000). Sediment is sampled according to ANZECC/ARMCANZ (2000) to give a <63µm fraction from each whole collected sediment sample and subsequently analysed for metals and metalloids.

The two kinds of trigger levels that are indicated are:

1. ISQG-High, which is defined as the median of effects data from a large sediment toxicity database and represents a concentration above which there is a high probability of biological effects and below which effects are possible.
2. ISQG-Low, which is derived from the lower tenth percentile of toxicity data from a US effects database and represents a concentration below which there is a low probability of effects.

The decision tree for undertaking sediment quality assessment follows that described (ANZECC/ ARMCANZ, 2000; ANZG, 2018) gives a focus on identifying the issues and protection measures necessary to manage them. The ANZECC/ARMCANZ (2000) / ANZG, 2018 Interim Sediment Quality Guidelines (ISQGs) are trigger values (Table 5) that, if exceeded, prompt further action as defined by the decision tree.

Table 8 *Sediment quality values for protection of aquatic species for arsenic, cadmium, copper, lead, silver and zinc (ANZECC/ARMCANZ, 2000).*

Metal or metalloid	Interim sediment quality guideline for protection of freshwater aquatic ecosystem (ANZECC/ARMCANZ, 2000) (mg/kg)	
	ISQG-low	ISQG-high
Arsenic	20	70
Cadmium	1.5	10
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Zinc	0.2	410

As a first step, the total metal and metalloid concentrations are compared with the ISQG-High and ISQG-Low trigger values (Table 8). If the low trigger value is exceeded and the concentration is greater than background levels, then remedial action or further investigation is required. Further investigation considers the contaminant that is bioavailable in the <63µm fraction or can be transformed and mobilised into a bioavailable form, allowing comparison of contaminant concentrations adjusted for bioavailability with the ISQG-Low trigger value. In the case of metals and metalloids, the bioavailable concentration is estimated by extraction with cold 1M hydrochloric acid extraction (ANZECC/ARMCANZ, 2000; ANZG, 2018). This is considered to be a more meaningful measure than the total contaminant concentration where natural mineralisation in sediment is commonly found (Batley and Maher, 2001).

An additional risk from PM in sediment is that acute human toxicity from the consumption of fish or other aquatic species if contaminated with lead or other heavy metal may be possible. The potential risk is assessed by comparing with the maximum levels set by Food Standards of Australia and New Zealand (FSANZ, 2010) for fish consumption by children and adults. In general, the liver of the fish or shellfish have higher heavy metal and metalloid concentrations compared to the muscle. Frequent or regular consumption of fish or shellfish that exceed Maximum Levels (MLs) of heavy metals and metalloids is not recommended.

The ANZECC/ARMCANZ (2000) / ANZG (2018) guidelines together with food guidelines permit the evaluation and assessment of impact from lead in terms of human exposure as well as ecological effects. The Australian New Zealand Food Standards Code (FSANZ, 2010) gives the maximum levels of specified metal and metalloid contaminants in foods, including aquatic foods. For lead, this maximum level is 0.5mg/kg (FSANZ, 2010).

Diet is generally a minor contributor to blood lead in Australia (Gulson et al., 1999; Gulson et al., 1997b) and universal distribution of lead and other heavy metals and arsenic from food in a community is expected. Therefore, food is not usually considered as a distinct source of lead in investigations, except for the contamination of foods within the home during food preparation, and in other studies such as that in Mount Isa (Noller et al., 2017) and Port Pirie (Body et al., 1991).

3.5 Utilisation of Health Risk Assessment Process

3.5.1 Health Effects

During the 1990s, changes were implemented which ultimately resulted in reductions in airborne lead concentrations and in BLLs of children. The most sensitive organs to the toxic effects of lead are the kidneys, the blood and the central nervous system, with the lowest observable effects of lead occurring in the developing nervous systems of young children (NSW Government, 1993). Other heavy metals and arsenic may induce effects on various body systems as well (NSW Government, 1993). Children aged less than five years are at special risk from high BLLs because the developing brain in young children is more vulnerable to a range of biological and environmental insults. Based on the results of a number of prospective studies done overseas and in Australia (Port Pirie see Section 5.1.2), there was consensus that the effect of each 10µg/dL increase in an average lifetime was a 2-3 point decrease in IQ scores in children aged 4-10 years in 1994 (Alperstein et al., 1994). The contribution of lead to variance in IQ is in the region of 1-4% (NSW Government, 1993). These effects are clinically undetectable in individual children. However, at a population level, the effect of a 10µg/dL increase in average lifetime BLLs in the distribution of IQ scores in 1994 would result in a significant decrease in very bright children and a 2-3-fold increase in children requiring special education (Alperstein et al., 1994).

At low concentrations during pregnancy, lead was considered harmful to the foetus, affecting performance on standardised developmental tests during infancy. Lead exposure during pregnancy was also associated with slightly higher risks of miscarriage and pre-term delivery (Alperstein et al., 1994). When symptoms of lead intoxication occur, they are usually non-specific, e.g. fatigue, irritability, concentration difficulties, tremors, headaches, abdominal pain, vomiting, weight loss, constipation. Lead encephalopathy accompanied by fits, paralysis, coma and/or death only occurred at levels above 70µg/dL.

In 1985, lead in petrol in NSW was lowered to 0.013 g/L and all cars (imported and new) were required to use unleaded petrol (Inter-departmental Lead Taskforce, 1994). Lead in petrol was completely removed in 2002. In addition, lead in paint used on baby products was revised down from 0.22% to 0.09% (Williams et al., 1995). However, lead in paint on pre-1970 houses may still contain lead and be a potential source to children.

Since 2016, the NHMRC has recommended that if a person has a BLL greater than 5µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman (NHMRC, 2016). Exposure to lead in Australia has dropped significantly over recent decades as a result of measures restricting the use of lead in paint, petrol and consumer goods (Gulson et al., 2014). As a result, the average BLL in Australia is estimated to be less than 5µg/dL. Investigating the source of exposure where BLLs are greater than 5µg/dL has reduced the risk to individuals, particularly children (NHMRC, 2016).

3.5.2 Exposure Sources and Pathways

Of lead and other heavy metals and arsenic, lead has been the most important to consider because its ambient concentrations tend to be associated with mineral processing activity and concentrations found in dispersed dusts to surrounding houses and soil. However, arsenic and cadmium may also be important, as their specific toxicities are higher than other metals including copper and zinc.

The main pathway for lead absorption in children is ingestion from a range of sources, e.g. lead-based paints, soil and dust, air, food, and drinking water. Children under five years of age are at special risk of lead exposure because of their normal exploratory hand-to-mouth activity, and because children absorb a much higher proportion of ingested lead than adults (up to 50% versus 10%) (Alperstein et al., 1994).

The major sources of lead exposure in Australia that were identified in 1994 were (Alperstein et al., 1994):

- Industry: Children at greatest risk of high BLLs in Australia include those living near major lead industries such as Port Pirie (SA), Broken Hill (NSW) and Boolaroo (NSW). Other point sources include lead industry operations, such as breaking down old car batteries.
- Paint: Lead-based paint was used on many Australian homes up until 1970. Children living in these homes are at high risk of lead exposure from renovations, and/or peeling and flaking paint. The main exposure pathway is ingestion of dust or paint flakes. Dust may also be inhaled, particularly during or following renovations. Children may also be exposed to lead-based paint flakes and deteriorated powder from older cots and toys.
- Petrol: Lead emissions from motor vehicles contribute about 90% of lead in the air, in Australia's urban areas. Children (and pregnant women) living near major urban roads are at increased risk of exposure from inhalation of lead in air, or, more importantly for children, ingestion of dust fall-out.
- Workplace: Workers in lead industries can be occupationally exposed and can bring home lead dust on their work clothes. Such industries include: inorganic pigments manufacturing; lead mining, ore concentration and handling; primary and secondary metal smelting and processing; brass, bronze and copper foundries; manufacturing of batteries, machinery, electronic capacitors; auto repair services and garages; bridge, tunnel and elevated highway repairs; stone, glass and clay products manufacturing; munitions manufacturing; firing ranges.
- Other sources: Food manufactured and purchased in Australia generally has low lead levels (Alperstein et al., 1994). However, food can occasionally have elevated lead levels e.g. if root vegetables have been grown in contaminated soil, food has been cooked in lead-glazed ceramic ware, or food has been stored in (mainly imported) cans with lead-soldered seams. Water is thought to be an uncommon source in Australia; however, water may be delivered via lead or lead-soldered pipes. Children may be exposed to lead by virtue of their parents' hobbies, e.g. from lead sinkers and bullets, or from being around their parents making stained-glass or lead-glazed pottery.

Each of these sources may only contribute a small amount of lead; however, the cumulative result may be an elevated BLL in an individual child.

The results of the national blood lead survey conducted in 1994 (AIHW, 1994) showed that socially disadvantaged families had higher mean BLLs than advantaged families. Where the household income was >$20,000 and/or a member of the household had higher tertiary qualification, the lead levels tended to be lower. Families in rented accommodation also appeared to have higher levels which can possibly be attributed to two environmental factors: (1) the greater ages of rented homes, and (2) the poorer condition of the paintwork in them.

The main environmental factors that most strongly influenced BLLs of children were the cleanliness of the home, its age and whether any interior paint was in poor or flaking condition (AIHW, 1994). Where a member of a household smoked or was in an occupation that was exposed to lead, such as lead smelting or panel beating, or had a hobby involving lead, the levels of blood lead were correspondingly higher.

Blood lead measurement is the key data item of the ‘exposure assessment’ step in the health risk assessment of lead (Figure 1). ‘Hazard identification’ and ‘dose response assessment’ are undertaken using data from soil contamination studies and bioavailability measurement by animal uptake experiments or prediction with bioaccessibility measurement. In the absence of data from the ‘hazard identification’ and ‘dose response assessment’, the health risk assessment (enHealth, 2012) is not completed for that particular site.

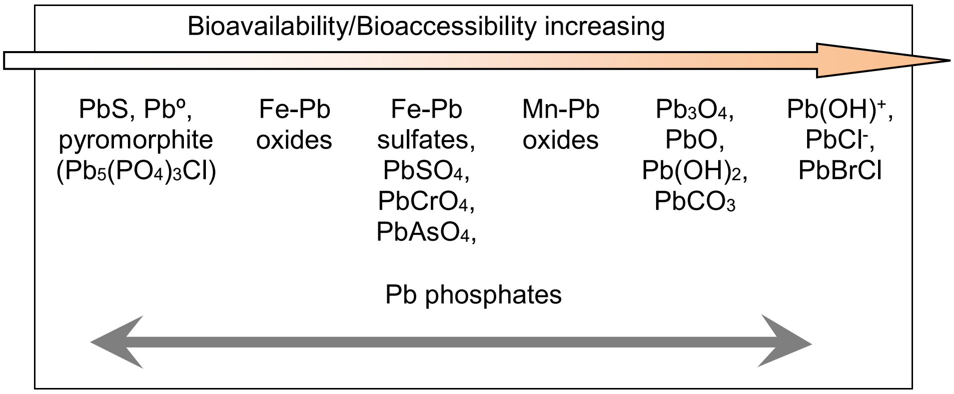
3.5.3 Speciation, bioavailability and bioaccessibility

A chemical ‘species’ is the specific form of an element defined by its oxidation (valency) state and/or complex or molecular structure. Some of these structural levels are more important for risk assessment than others. In particular, valency state and inorganic and covalent organometallic speciation are of great importance in determining the toxicity of metals and metalloids (WHO, 2006). Elements occur in soil in either the solid phase or in the soil solution. In the solid phase, metal ions can be bound to soil components by means of ion exchange or surface complexes, or they can occur as minerals or be co-precipitated as minerals in soil. In the soil solution, they can occur as free ions or complexes.

Standard chemical analysis provides a measure of ‘total’ metal or metalloid in soil, expressed as a concentration of the elemental form. This is not particularly informative as a means of assessing how toxic the soil could be with human exposure (Section 4.5.3). Furthermore, toxicological research rarely focuses on the metal species most likely to be present in soil. Typically, the focus is on the most toxic forms and those that are of particular health concern as a result of their presence in food, consumer products or in the workplace. This means that the available metal and metal compounds may significantly overestimate the toxicity of the metals in soil (NEPC, 2013; Schedule B4). Figure 3 shows how lead species in various lead compounds and minerals affect lead bioavailability.

Therefore, when predicting environmental transport and fate of metals and metalloids, it’s critical to have accurate and extensive chemical and physical characterisations of natural mineralisation, mining sources, mineral processing sources, and community environmental samples. This is also critical in understanding and minimising important human exposure pathways.

The key step in predicting the significance of human exposure to lead or its bioavailability is to know how widely the variation is among different lead minerals and compounds in various environmental settings (Figure 2).



Source: *modified from Ruby et al., 1999.*

Figure 2 *Schematic of how different lead species affect lead bioavailability with constant particle size.*

Understanding the detailed relationship between speciation and bioavailability necessarily begins with a complete, accurate and direct identification of lead species (or arsenic and cadmium species) in environmental media such as soils, natural mineralisation and mine waste. Lead chemical form in soils has traditionally been estimated by X-ray diffraction (XRD). However, XRD has limited sensitivity and cannot detect forms of lead below 0.01% or greater than 10,000mg/kg, which is far higher than the NEPM (2013) soil criteria for lead. Selective extraction techniques based on Tessier’s and the Community Bureau of Reference (BCR) methods are commonly used to measure ‘operationally-defined’ lead forms but do not measure the actual chemical form (Ure and Davidson, 2002). In addition, techniques based on SEM and SEM/EDS (Energy Dispersive Spectroscopy) can be used to examine and compare mineralogical and morphological characteristics of smelter slag (Morrison et al., 2016). However, there are limitations with distinguishing lead chemical forms when using these x-ray techniques.

A more accurate technique for determination of a range of metals and metalloids including lead chemical form in soils and mine waste is synchrotron-induced X-ray absorption spectroscopy (XAS) (Brown et al., 1999). This is a very sensitive technique performed at a synchrotron facility such as at Melbourne which can detect lead down to environmental concentrations of 0.001-0.002% (10-20mg/kg), including both crystalline and amorphous forms. Using X-ray absorption near edge spectroscopy (XANES), the lead chemical forms present in environmental samples can be identified by comparison with known lead compounds (Noller et al., 2012). Application of this approach to a range of metals and metalloids enables a better understanding of the role that chemical forms have in toxicology and bioavailability of site features. In the case of lead this includes identifying the occurrence of natural and historical residues from lead in petrol and paint.

The NEPM (Assessment of Site Contamination) provides the soil guidelines (Table 1) that are used in Australia to assess health and ecological effects on a site-specific basis (NEPC, 2013). A site may be assessed based on investigation levels, or a site-specific assessment can be undertaken. The NEPC provides a framework for investigation levels (NEPC, 2013; Schedule B4), which are principally described as ‘Investigation Levels’ or ‘Response Levels’. Soil NEPM can be applied if the contamination of soil by metals and metalloids in dust fall-out is considered to be a health issue, as is usually the case with children who may be exposed to up to 95% of lead in surface dust via ingestion and transfer to the gastro-intestinal system (Davies et al., 1990).

Investigation levels for human health exposure are generally the HILs. To accommodate the range of human exposure settings, a number of generic investigation levels have been set (NEPC, 2013) based on land use and human activity. HILs are defined as “the concentration of a contaminant above which further appropriate investigation and evaluation will be required” (NEPC, 2013). HILs are only used for assessing existing contamination and are intended to prompt an appropriate site-specific assessment where levels indicate there is the potential for adverse effects on human health values for that site. The site should be sufficiently characterised to provide a complete hazard assessment according to enHealth (2012) and the designated investigation levels to ensure the comparison is meaningful and appropriate e.g. for houses or recreation activities.

The human health risk assessment process for contaminated land is undertaken in stages or ‘tiers’ involving progressively more detailed levels of data collection and analysis. In the NEPM, guidance is given on the use of the tiers referred to as Tier 1, Tier 2 and Tier 3. The approach provides for assessment at a level of complexity that is appropriate for the problem under consideration; the degree of health protection achieved is equal at each tier (NEPC, 2013; Schedule B4) as follows:

- Tier 1 (or screening level) assessment is the first stage of assessment at the site. It includes a comparison of known site data with published risk-based guidance levels, such as the HILs.
- Tier 2 assessment includes a site-specific risk assessment and the development of site-specific target levels for comparison with site data. If one or more contaminants are present at the site at levels that significantly exceed Tier 1 guidance criteria, or if there are no appropriate Tier 1 criteria, or if there are unresolved and significant uncertainties identified in the Tier 1 assessment, then a Tier 2 assessment will typically be required.
- A Tier 3 assessment typically focuses on the risk-driving contaminants in more detail, although studies aimed at reducing the uncertainties inherent in the modelling of exposure pathways are also common at Tier 3. This assessment may be required where exceedance of Tier 2 site-specific target levels is perceived to be a potentially unacceptable risk to human health.

Oral ingestion is usually the most significant exposure pathway to the dermal or inhalation exposure route. This is particularly true for young children because their incidental ingestion of soil via hand-to-mouth activity is much higher compared to adults, both in absolute amount as well as intake per unit body weight.

A detailed review by Ng et al. (2015) as part of the revision of the NEPM in 2013 concluded that physiologically based extraction procedures were acceptable for use at Tier 2 to estimate the bioaccessibility of lead. Site-specific assessment of bioaccessibility for lead may be carried out using in-vitro tests such as the PBET in-vitro assay (Ruby et al., 1996), In Vitro Gastrointestinal Model (IVG) (Oemen et al., 2003; USEPA, 2007) or Unified BARGE Method (UBM) (Denys et al., 2012) (NEPC, 2013; Schedule B4).

Simply analysing the concentration of arsenic and cadmium-like lead in soils, dusts or other materials is usually not an accurate measure of the potential health effect of the contamination (Ng et al., 2015). The health effects depend, in part, on the body's ability to absorb the contaminating substance. The ability of the human body to absorb lead depends on the form(s) present. The solubility of metal or metalloid minerals and other compounds relate to their uptake or absorption in the human body and is described as bioaccessibility. The bioaccessibility of arsenic or cadmium as a free ionic species is higher than less soluble mineral forms (Ruby et al., 1999). The mineral types, and the matrix in which they reside, affect the bioavailability. The bioavailability of the metal or metalloid is the fraction of the element ingested and/or inhaled that reaches the circulatory system in the body and can therefore be measured in the blood or urine.

3.5.4 Relationship to human health effects

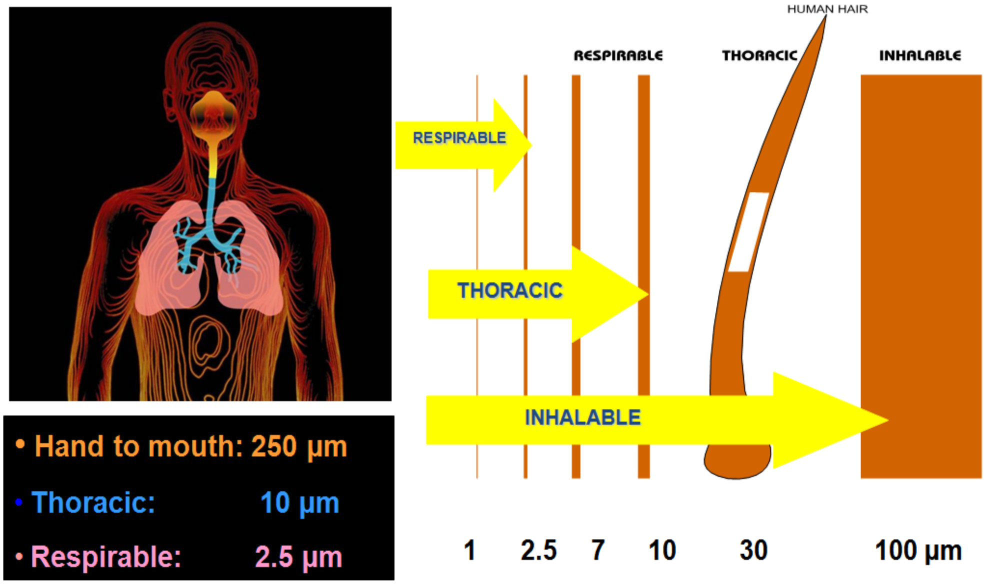
Human health risk assessments have found that ingesting soil and dust can be a major route of exposure to immobile soil contaminants. For example, direct correlations between blood lead and children's rates of hand-in-mouth and object-in-mouth behaviours have confirmed the direct relationship between hand-to-mouth activities and BLLs. There is also an association between the high contributions of soil or soil-borne materials and high blood lead in children. This is because ingestion via hand to mouth transfer (10µm to 250µm size dust) is responsible for up to 95% of exposure (Davies et al., 1990).

Particulate matter is categorised according to various diameters or sizes based on the physical property of airborne material (NEPC, 2002). PM_{10} and $PM_{2.5}$ can be mixtures of solid particles and liquid droplets found in the air, with particle size less than 10µm diameter and 2.5µm diameter, respectively (NEPC, 2002). They pose the greatest problems for human health because they can penetrate deep into the lung and get into the bloodstream (SKC, 2009). $PM_{2.5}$ gives an approximation for fine mode particles, and therefore alveolar deposition, while PM_{10} indicates the thoracic aerosol component (Raunemaa, 2002). Fall-out may be material <250µm that can be ingested by humans or animals (larger particles do not adhere as readily to the hands (Ng et al., 2015) once deposited to the ground).

Previous studies of dispersion of metal in dusts show that the primary pathways from various sources to the receptors are inhalation and ingestion of materials. Generally, it is recognised that 95% of exposure to dispersed lead material arises from ingestion and 5% from inhalation (Davies et al., 1990). Following enHealth's risk assessment approach (enHealth, 2012), a variety of guidelines, standards and procedures can be employed. In cases of minor exceedances of investigation levels or exceedances related to contaminants that have low human toxicity and limited mobility, a qualitative risk assessment may be sufficient. The risk assessment process (enHealth, 2012) may lead to the development of site-specific response levels generated by the risk assessment and agreement between the professionals assessing the site and regulatory authorities. The Tier 2 risk assessment process (see Section 3.6.3) described by NEPC (2013) allows for toxicity assessments when HILs for the designated category or land use are exceeded. For example, bioaccessibility giving a simulation of human gastro-intestinal uptake is now accepted by NEPC (2013) to assess lead bioaccessibility which helps predict bioavailability and gives comparative data for other metals and metalloids for health risk assessment purposes.

The inhalation pathway accounts for 5% or less of exposure from dust (Figure 2) and is restricted to fine airborne PM that can get into the airways and into the lungs depending on the volume of air breathed in during one day. Fine particles capable of penetration deep into the lung are believed to be completely absorbed into the blood stream. Particles larger than ~ 7µm tend to deposit on the walls of the airways (the thoracic region) and become part of the mucus that is moved up to the mouth and then swallowed.

People may be exposed to contaminants from sources such as food, air and water; collectively this exposure from other sources is termed 'background exposure'. For the majority of contaminants of concern from land contamination, the background exposure will primarily be from food and water. There are three potential exposure pathways for exposure of humans to contaminants, namely dermal, inhalation and ingestion. Particle size dependent and oral exposure have specific associations (Figure 3). For dust or fall-out, only <250 µm size particles can be ingested by humans (Ng et al., 2015); larger particles are excluded.



Source: *modified from SKC, 2009.*

Figure 3 *Demonstration of human respiration system and relative particle size (SKC, 2009).*

Generally speaking, the dermal exposure of lead, arsenic and cadmium are considered to be insignificant (IPCS, 2001; ATSDR, 2007a, 2008b; WHO, 2004). Dermal exposure from metals and metalloids in dust is generally considered to be insignificant while dust ingestion is the accepted major pathway of exposure.

The inhalation of dust containing lead, cadmium or arsenic is an important consideration in dust dispersion. Larger particles (1-5µm) will usually lodge at different regions along the respiratory pathway during inhalation and are eventually moved up into the oral cavity and swallowed. Smaller particles (<1µm) will often lodge as far as the alveoli and may also be moved out of the lungs and swallowed or alternatively absorbed directly into the lymphatics. Insoluble particles deposited deep within the alveoli may be retained for extended periods.

Inhalation exposure involving the inhalation of dust containing lead, cadmium or arsenic is an important consideration in industrial settings such as smelters, chemical plants and active mine sites. There may be airborne particles of arsenic-rich fine particles (<1µm) in the occupational environment (WHO, 1995). For assessing the health risk from metals and metalloids in dust from houses there are no Australian standards available, apart from PM_{10} and $PM_{2.5}$ in air (NEPC, 2002), soil concentration, drinking water intake and dietary ingestion. There are the US EPA 'lead clearance standards' (US EPA, 2001) for house floors, window sills and window troughs, and carpet dust surface but not the bulk concentration as mg/kg (Section 3.5.4).

The health risk from metals and metalloids in house dusts requires calculation of dose for the inhalation, ingestion and dermal pathways following the methodology of eNHealth (2012) using default values (adult or child) for daily ingestion of dust, volume of air breathed and measured concentrations of metal or metalloid in air, soil or dust, drinking water intake and dietary ingestion. The calculated doses for respective metal or metalloid are compared against recognised 'standard' values (NEPC, 2013; Schedule B4; Drew and Hagen, 2010).

In the case of lead (Section 3.5.5), the US EPA IEUBK model for lead in children is widely known and used to estimate uptake and circulation in blood (US EPA, 2004). There is no equivalent model for cadmium, arsenic or other heavy metals and therefore the significance of exposure to adults or children is assessed by using known thresholds established by the WHO, USEPA, or other bodies.

Following the review in 2011 of arsenic by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (JECFA, 2011), a threshold value for cancer from arsenic exposure was established as BMDL0.5 of 3.0µg/kg bw/day (2.1 to 7.0). The Benchmark Dose (BMD) was set at a 0.5% incremental lung cancer risk. The lower BMD of 2.1µg/kg/day is similar to the previous Provisional Tolerable Weekly Intake (PTWI) of 2.14µg/kg/day (WHO, 1989). This led to the withdrawal of the PTWI. Further, in the absence of a new PTWI during the setting of the current NEPM HIL for arsenic, the BMDL0.5 was considered. It is noted that the BMDL0.5 of 3.0µg/kg bw/day has a margin of exposure (MOE) less than 30 because a dose of 2.1µg/kg bw/day is believed to have an MOE of about 30, whereas for 7.0µg/kg bw/day is about one (near unity) noting that the dose response curve is not linear for the derivation of BMD or MOE. Therefore the BMDL0.5 of 3.0µg/kg bw/day would have a MOE of about 10 (i.e. higher than unity but lower than 30). MOE is best explained as the exposure (concentration) before one sees an effect from the dose response curve; the so-called point of departure that is to indicate the minimum dose required to detect where there is no effect. Therefore, when BMDL0.5 is used for setting a new guideline value or used for comparison with total daily intake in terms of deterministic risk assessment, the above uncertainty needs to be considered. The alternative way (common but more conservative way for carcinogen) is to apply the US EPA Integrated Risk Information System (IRIS) cancer slope factor to total daily intake for the risk characterisation (risk analysis) (ATSDR, 2007b).

In the case of cadmium, at its meeting in June 2010, JECFA withdrew the PTWI and established a provisional tolerable monthly intake of (PTMI) 25µg/kg bw (FAO/WHO, 2010). A monthly intake was established due to consideration of the long half-life of cadmium, and consequently the small to negligible influence of daily ingestion on overall exposure. This value is based on the lower bound of the 5th percentile dietary cadmium exposure (on a population level, 0.8µg/kg bw/day or 25µg/kg bw/month) that equates to a urinary cadmium concentration 'breakpoint' of 5.24 µg (confidence interval 4.94–5.57) of cadmium per gram creatinine based on toxico-kinetic modelling (Ministry for the Environment, 2011). The breakpoint point was considered to be the threshold below which urinary cadmium levels were not associated with an increased excretion of β2-microglobulin, and above which a steep increase in β2-microglobulin occurred in individuals who were 50 years and older. This breakpoint was based on meta-analysis of the dose-response relationship between the excretion of β2-microglobulin and cadmium in urine. The apparently long half-life of cadmium in kidneys of 15 years means that steady state is achieved after 45-60 years of exposure (Ministry for the Environment, 2011).

3.6 Extent and Limitations of Data and Information

3.6.1 Extent of data

The data generated from environmental and health studies conducted at the Wollongong LGA (Appendix A) can be grouped as follows:

- Studies prior to 1990 soil air plans and some blood lead measurement. Based on scientific curiosity about extent of contamination from understanding of similar situations elsewhere overseas.
- From 1990 to following the 1994 NSW LMAP to 1999, when guidelines emerged.
- Members of the public and a representative of Illawarra Residents Against Toxic Emissions (IRATE).
- Sporadic production of new data since 2000 and the lack of blood lead survey data in Wollongong LGA.

For this review, there appears to be limited access to company technical reports on environmental studies on the Port Kembla sites to meet regulatory requirements.

The literature review in Section 3.5 has reviewed the requirements in NSW for management of contaminated land and the guidelines that apply. Both Australian Government and NSW guidelines may apply. In a few cases where no guidelines exist it may be possible to make comparison with the international guideline as described (Section 3.6.4). The literature review in Section 4 identifies the transition that has occurred with the development of guidelines, supporting standards and other key guidance documents.

In addition, Australian standards for sampling and analysis, human health and ecological risk assessment follow the key areas of the objectives of the consultancy: to review literature relevant to programs aimed at 'reducing human exposure to lead' and to report on the following key areas (Section 2.1).

The re-emergence of lead as a public health concern in Australia in 1993 was largely due to the BLLs, which were once thought to be safe, were now considered to represent a risk for young children. This followed the recognition in North America and Europe that BLLs as low as 10µg/dL among young children may have detrimental effects on intellectual development and behaviour (Alperstein and Vimpani, 1994; Wigg, 2001). In June 1993, the NHMRC set a national goal for all Australians to have a BLL of less than 10µg/dL, with a particular urgency in achieving this goal for children aged 1-4 years old (Alperstein et al., 1994).

During the 1990s, a series of workshops examined contaminated soil and its management. This movement developed the concepts of soil contamination guidelines that became incorporated in the NEPC (1999).

The NEPM guidelines for soil contamination (Table 1) are the current guidelines in Australia for metals and metalloids (NEPC, 2013). A framework is provided for use of various levels in Schedule B1 (NEPC, 2013) of the NEPM guidelines. The extent of contamination of soil is evaluated by comparing total concentration against the NEPM HILs (Table 1) criteria for contaminated soil (NEPC, 2013). A site may be assessed based on investigation levels, or a site specific assessment can be undertaken. The NEPM also describe sample planning, analytical protocols, QA/QC and data analysis for soils, groundwater and air.

Standards Association of Australia has produced standard methods of analysis that are referred to through this report. Laboratories generally secure laboratory accreditation from National Association of testing Authorities (NATA) according to the International Organisation for Standardisation (ISO) 17025 and was originally developed in Australia (Standards Australia, 2018). A rule of thumb regarding reliability of environmental monitoring data is whether the laboratory in question was accredited against ISO 17025 by NATA. Historical data from laboratories that did not have accreditation according to ISO 17025 is best assessed by accompanying validation of results using external or certified reference materials and estimates of interferences with spiking techniques or incorporating steps known to reduce matrix interferences.

3.6.2 Limitations of data and information

There may be questions about reliability of monitoring data prior to 1990, especially if there has been no application of QA/QC practices with the measurements of the analytical data for lead and other heavy metals. The majority of publications reporting research in the field of metal speciation devote too little effort to ensuring quality, reliability or traceability of data (Sturgeon and Franscesconi, 2009). The current state of practice is discussed and a proposal to adopt a minimum set of standards or benchmarks is given to which such studies should be held accountable (Sturgeon and Franscesconi, 2009). There is a general limitation of study following current NEPM criteria and recommended practices.

Area wide distribution for lead and other heavy metals tends to be limited and is most extensive for lead in the Wollongong LGA. The collective of data from references and reports in Appendix A give a reasonable idea of the extent of contamination, which probably still exists in the Wollongong LGA because the lead and other heavy metals do not degrade. The study by Jafari (2009) covers a detailed sampling of the soils and sediments in Port Kembla, including selective extraction of soil and sediment samples. Selective extraction techniques give operationally-defined forms in the sample but do not measure lead or other heavy metal speciation. Importantly, selective extraction techniques does not measure bioavailability or bioaccessibility for health risk assessment purposes.

Definition of the current extent of lead and other heavy metal contamination in the Wollongong LGA can be achieved by following the current NEPM practices and guidelines, the NHMRC, the enHealth Human Risk assessment for site contamination of human health and ecological cases and ANZECC/ARMCANZ (2000)/ANZG (2018) and FSANZ guidelines (Sections 3.5.5.and 3.5.6). Some application of overseas guidelines may be appropriate in the absence of suitable Australian guidelines (i.e. USEPA, the German air pollution control regulation Technische Anleitung zur Reinhaltung der Luft and New Zealand guidelines).

4. Review of Literature on Wollongong LGA and Port Kembla

4.1 Potential Sources of Lead and Other Heavy Metals in Wollongong LGA

The City of Wollongong is a LGA in the Illawarra region of NSW, Australia (Figure 4). Located 80 kilometres south of Sydney it covers 714 square kilometres with a population of around 208,000 people. It occupies a narrow coastal strip bordered by the Royal National Park to the north, Lake Illawarra to the south, the Tasman Sea to the east and the Illawarra escarpment to the west. The LGA contains an industrial complex (one of the largest in Australia) centred on Port Kembla. Port Kembla is a coastal suburb located 8km south of Wollongong. It covers an area of approximately 800 hectares and has a population of around 5,000 people. It includes residential, commercial and industrial precincts and extensive recreational/parklands. There are two primary schools, one secondary school and one preschool in the suburb.

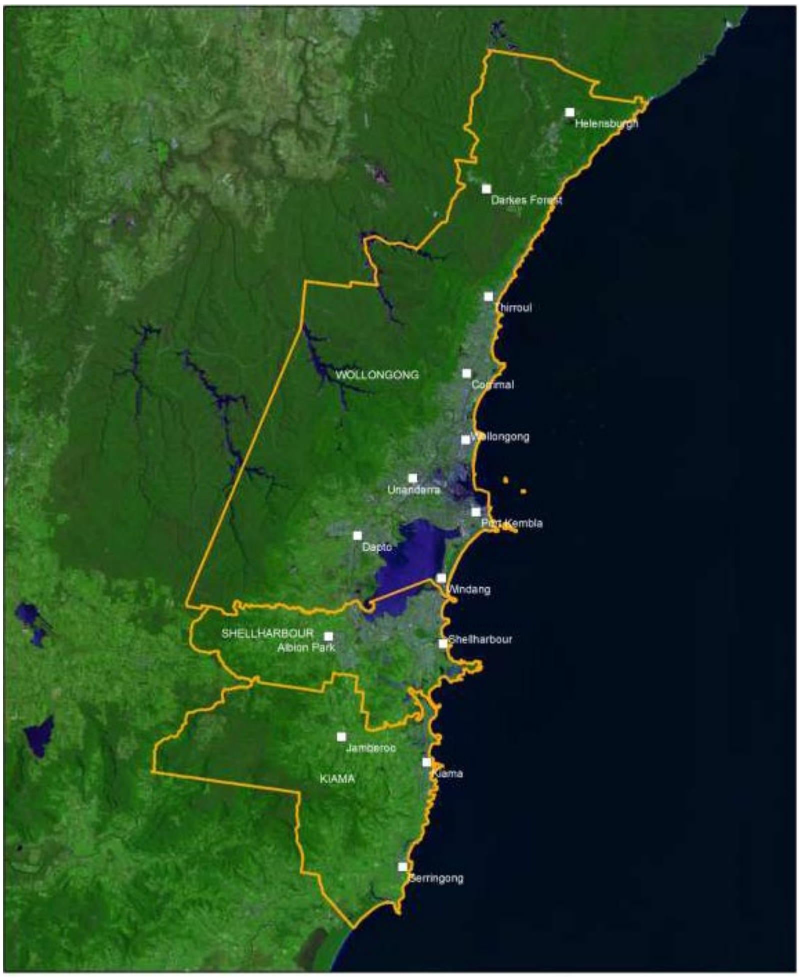


***Figure 4** Location of Wollongong (ID 2019).*

Industry has been a feature of Port Kembla for over 100 years (Chiaradia et al., 1997; Jafari, 2009). A copper smelter commenced operation around 1908 and ceased in 2003 following operations by several companies. Nearby, a large integrated steelworks (coke ovens, sinter plant, iron and steel making, metal finishing) that commenced in the 1930s has continued to the present day as Bluescope Steel. Figure 5 shows the location of the Lake Illawarra area (NSW), the historical Port Kembla industrial complex, including the BHP steelworks and Southern Copper smelter (SC), the Kanahooka base-metal smelter and the coal fired Tallawarra power station (Chiaradia et al., 1997). Port Kembla Copper ceased production in 2003 and the stack once dominated the city skyline before it was demolished in 2014. Figure 6 shows the stack at Port Kembla before demolition (ABC, 2015).

A considerable body of literature exists on the nature, extent and distribution of heavy metals in soils, lake sediments and roof dust in the Wollongong LGA, in particular in and around Port Kembla. Lead has been a key parameter for investigation, but other metals include cadmium, zinc, copper and chromium and arsenic.

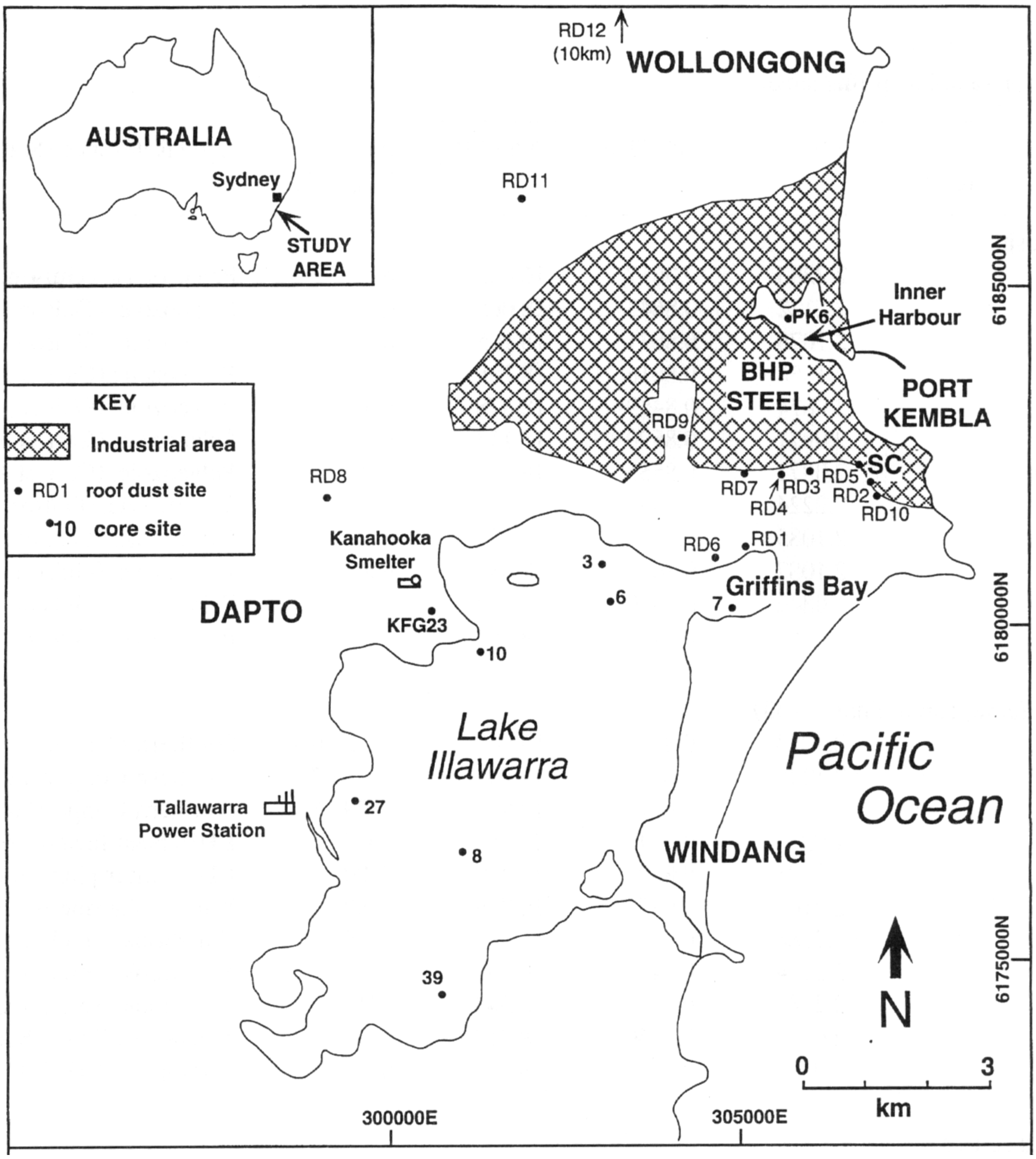


__Figure 5__ Location of the Lake Illawarra area, NSW, Australia showing the location of the historical Port Kembla industrial complex, including the BHP steelworks and Southern Copper smelter (SC), the Kanahooka base-metal smelter and the coal fired Tallawarra power station (Chiaradia et al., 1997).

A number of distinct phases of metal processing occurred at Port Kembla and nearby surrounding locations (Chiaradia et al., 1997; Jafari, 2009). The Smelting Company of Australia Ltd established a base-metal sulphide smelting plant on the western foreshore of Lake Illawarra in 1896 till 1910 (Kanahooka site; Figure 5). The company ceased operations in 1906. The principal ores processed originated from Australian deposits, mainly from the British Mine (Pb-Zn) at Broken Hill (Chiaradia et al., 1997). The base metal Cu refining plant reopened in 1910 and operated till 1954. From 1989-2009, companies and industries that continued operations were BHP Billiton-Steel International group, Slab and Plate products Division, Incitec Ltd., Port Kembla Copper formerly Southern Copper ERS Ltd (decommissioned in August 2003), John Lysaghts (Aust) and the Port Kembla Coal Loading Facility (Jafari, 2009). Steel making activities by Bluescope Steel continue to the present day and is the current likely source of particulate emissions at Port Kembla. The Port Kembla Copper smelter 198-metre stack was felled in 2014 (; ABC News, 2015).

Figure 6 *The stack at Port Kembla before demolition in 2014 (ABC, 2015).*

Follow up of children with moderately elevated BLL, indicated that the usual cause was 'multifactorial', i.e. likely to have resulted from multiple small exposures to lead from a number of sources. The main pathway for lead exposure among children was considered to be ingestion. The probable main sources/pathways contributing to elevated BLL in Port Kembla were as follows:

- Lead-based paint in pre-1970 houses with deteriorating paint and/or following unsafe renovations; and
- Soil lead: from paint and airborne lead (from industrial emissions and petrol); and household dust from lead-based paint, soil lead and air-borne lead (with a negligible contribution from roof dust where ceiling spaces are sealed and undisturbed).

Several BLL screening programs were conducted in the LGA in the 1980s and 1990s (ILMP, 1999). In some instances, a small percentage of children tested had blood lead levels higher than the recommended level and populations at risk of lead exposure were identified. Some studies found lead in air did not correspond to increased BLL; however there was correlation between soil lead levels and BLL. There was no clear correlation between location and distances of residences and schools from specific industrial sources, such as the smelter.

4.2 Lead and Other Heavy Metals in Soils, House Roof Dust and Sediments

4.2.1 Comparison of soil data with NEPM HIL

The current soil HILs (Table 1) provide a direct method for initial screening of levels of lead, other heavy metal and arsenic concentration data in soil. In nearly all cases the bioavailability of heavy metals for health consideration is assumed to be 100%, in the absence of bioaccessibility measurement (Section 3.5.2). Soil concentration data for lead and other heavy metals and arsenic from Port Kembla is summarised in Table 9.

Summary of findings

Lead levels in soil in the Port Kembla area were relatively well understood because of the available soil sampling results from relatively small surveys or, in response to requests and/or checks, ad-hoc sampling of soil lead levels at places where young children spend a lot of time (e.g. preschools). While these results are not entirely representative, they do provide a reproducible pattern of the levels and distribution of lead and other heavy metals in the Port Kembla area:

- At least 90% of soil lead levels had soil lead levels below 1,000mg/kg, with the vast majority being below 300mg/kg, the current HIL Level A for houses (Table 1).
- All samples from high contact areas for young children, e.g. play pits, have had levels below 300mg/kg.
- Soil lead levels, on average, are highest closer to the smelter (Beavington, 1973).

The available results from soil testing for arsenic and cadmium, did not exceed the current (NEPC, 2013) soil contamination guidelines, beyond 1km from the smelter, and indicate that soil levels of these heavy metals are not a cause for concern.

The ICBLS Follow-up Study 1995 (Williams et al., 1995) sampled 59 soil samples from 29 house yards in the follow-up on the 36 children who were found in the ICBLS to have blood levels above 10µg/dL (20 92%; n=54) for lead levels below 1,000mg/kg, with 70% (n=41) having lead levels less than 300mg/kg. All but two houses (5,270mg/kg and 50,980mg/kg) had lead levels less than 2,000mg/kg. The highest concentrations were from soil contaminated by lead based paint flakes.

A comparison of soil lead levels were obtained by judgemental sampling from the yards of children with and without high BLLs as part of the ICBLS Case-Control Study 1995-96 (Williams et al., 1995) (Table 9). It was found that soil lead levels were higher for the contamination cases compared with control (Lonie et al., 1992); this difference was significant for the maximum, but not the mean, levels (Table 9). Soil lead levels tended to correlate with BLLs; however these correlations were not significant (geometric mean soil levels: p = 0.24; maximum soil levels: 0.07). Lead concentration (mg/kg) measured in soil samples were obtained by judgemental sampling from cases and controls for the ICBLS case-control study, 1995/1998 (Williams at el., 1995).

Table 9 Summary of soil concentration data.

Site/ Sampling period	Copper (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)	Zinc (mg/kg)	Other (mg/kg)	Reference and details
1972							Beavington (1973)
Rural (n=21)	1-20 (5.3±0.94)	-	-	-	0.5-8 (2.7±0.44)	Depth /conc Contaminated site	Cu EDTA extractable
Farmland (n=166)	4-78 (11.3±0.57)	-	-	-	1-33 (7.17±0.39)		Cd, Pb, Zn Acetic acid extractable
Recreational (n=124)	3-1378 (58±17.3)	-	-	-	0.5-350 (23.4±3.77)		No total conc.
Industrial (n=30)	3-168 (25.3±8.1)	1.0 (0cm)	17.0 (0cm)	-	0.5-55 (14±2.80		
Roadsides (n=78)	4-505 (31±7.0)	-	-	-	1-190 (28±5.4)		
Soil, Port Kembla area 1990-93 (n=16)			90%>1000 most<300 Mean 333 <1000 n=15 (94%) <300 n=6 (38%) Mean Port Kembla P/S 284 (70-590)				Pre 1995 IPHU (ILMP., 1997)
1990-94 (n=34) Port Kembla area 2.5km from smelter			<600 (all samples) 91% (n=31) <300				IPHU
1995 (n=59) 29 yards			92%(54)<1000 2 samples 5270 & 50,980 (Pb paint)				ICBLS follow up study 1995 (ILMP., 1997)
Soil samples 1995-1997 n=49 Port Kembla Public school n=26			Mean 344 (<1 <1km of Cu smelter Mean 26 >1km of Cu smelter <700 (n=24) <300 (n=13)	Mean 24 <1km of Cu smelter) Mean 4 (>1km of Cu smelter)			IPHU 1995 – 1997 Pb school mean 180mg/kg (Graeme Waller and Assocs., 1996) Highest levels 1581 and 1115mg/kg
Wollongong Lead Study 1989 Port Kembla children's homes (n=164) Bellambi area (location of old smelter (n=799)			Mean 157 (2-1903) Mean 49 (0-661)				Young et al.(1990) Sieved <2 mm

Site/ Sampling period	Copper (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)	Zinc (mg/kg)	Other (mg/kg)	Reference and details
24km S and SW from Port Kembla (n=24) Dec 2000-Feb 2001 0-5cm and 5-20 cm	Mean 49 (12-599) Mean 38 (9-1597)		Mean 20 (12-117) Mean 18 (10-295)	Mean 3.2 (0.91-19) Mean 3.0 (0.51-26)	Mean 42 (27-150) Mean 36 (14-180)		Martley et al., (2004) Background levels (total concs.) Extent of contamination of Port Kembla industrial complex 1-13km, but mostly <4km (element depended).
2001-2003							Martley et al. (2004) Total (given here) and selective extraction concs. Each site 3 cores. Sequence of Mobility (Cd)>Zn=Cu>Pb>Cr gives some indication of potential bioavailability
C1 70m from Cu smelter							
0-5 cm	135		68		165		
0-20 cm	104	0.81	48		120		
0-50 cm	88		26		105		
C2 contaminated/undisturbed 1km from Cu smelter							
0-5 cm	599	1.65	117		150		
0-20 cm	1348	2.8	251		173		
0-50 cm	784	3.8	193		325		
C3 uncontaminated/undisturbed 22km from Cu smelter							
0-5 cm	14		13		28		
0-20 cm	15		12		27		
0-50 cm	21		10		33		
Port Kembla soil	>330	1.22	>150	8.8	471		Kachenko & Bal Singh (2006)
Port Kembla soil near smelter n=95							Jafari, (2009)
Total concentration	39.35-5309 Mean 324	<0.1-673.3 Mean 12	2-4157 Mean 115	<0.5-182.6 Mean 9	<0.3-5328 Mean 358		Highest values are attributed to slag heaps at S58, S34 and S33
Sample S33 (slag)	6613	49.4	884.8	66.2	1255		
Sample S34 (slag)	5309	64.8	178	59.1	348.9		
Sample S58 (slag)	8112	5.7	4157	<0.5	2833		
0.1M Hydrochloric acid extractable concentration	Mean 195	Mean 3.8	Mean 50.8	Mean 5	Mean 162		
0.05M EDTA extractable concentration	Mean 210	Mean 4	Mean 70	Mean 6	Mean 129		

During 1995-1997, the IPHU took 73 soil samples for analysis from 18 individual premises located in the Port Kembla area. The average soil lead samples were 344mg/kg within 1km of the copper smelter (11 premises, 49 samples) and 26mg/kg more than 1km from the copper smelter (seven premises, 24 samples). With three exceptions, all soil lead levels were below 1,000mg/kg, with the vast majority being below 300mg/kg.

The average arsenic levels were 24mg/kg and 4mg/kg within 1km and more than 1km from the smelter, respectively. The average cadmium levels were 4.5mg/kg and 0.2mg/kg within 1km and more than 1km from the smelter respectively. With one exception, all arsenic and cadmium levels were well below the 'investigation levels' of 100mg/kg for arsenic and 20mg/kg for cadmium. One arsenic level was 129mg/kg.

All samples from preschools and childcare centres, including 'high contact' areas such as play pits, had levels below 'investigation levels'. All 12 samples taken from at St Patrick's Primary School had lead levels below 600mg/kg, with ten samples (83%) having lead levels below 300mg/kg. The lead levels at the school averaged 180mg/kg.

At the end of 1996, a report on soil lead levels at Port Kembla Public School was released. This survey was commissioned by the Department of School Education (Graeme Waller and Associates, 1996). Of the 26 samples taken, 24 samples (92%) had lead levels below 1,000mg/kg (actually 700mg/kg), and 13 samples (50%) had lead levels below 300mg/kg. The highest lead levels were 1,581mg/kg and 1,115mg/kg.

Between 1990 and 1993, 16 soil samples were taken from seven premises close to the copper smelter, including four samples from the Port Kembla Fire Station and five from Port Kembla Primary School. The average soil lead levels were 333mg/kg. Overall 15 samples (94%) had lead levels less than 700mg/kg, with six samples (38%) having lead levels less than 300mg/kg (Williams et al., 1995). The highest level, at the Fire Station, was 1,113mg/kg. The average soil lead level at Port Kembla Primary School was 284mg/kg (range 70-590mg/kg).

Between 1990 and 1994, the Public Health Unit took 34 soil samples from childcare centres and pre-schools in the Port Kembla area, up to a distance of 2.5km from the smelter. All samples had lead levels less than 600mg/kg, with 91% (31) having lead levels less than 300mg/kg. The highest level was 522mg/kg. The three samples with lead levels above 300mg/kg (302mg/kg, 416mg/kg, and 522mg/kg) were taken within 0.5km of the smelter. All samples taken from play areas were lower than 300mg/kg. Several soil samples were also taken from premises in the northern suburbs, e.g. Bulli; all of these samples had lead levels less than 300mg/kg. All arsenic and cadmium levels were also well below the 'investigation' levels (Table 1).

In 1989, 164 soil samples were collected from children's homes in Port Kembla and 799 samples from the Bellambi area (Young et al., 1990). These homes were those of children who had their BLL tested as part of the Wollongong Lead Study (undertaken by UoW, in collaboration with Healthy Cities Illawarra and IPHU) (Young et al., 1990). The average soil lead level in Port Kembla was 157mg/kg (range 2-1,903mg/kg) and in Bellambi 49mg/kg (range 0-661mg/kg). With the exception of one sample, all samples taken in Port Kembla were less than 1,000mg/kg, with more than 80% being less than 300mg/kg. The soil lead levels increased towards the copper smelter. In the Port Kembla area, trend surface analysis demonstrated that soil lead levels increased towards the copper smelter main chimney. The soil lead levels were also shown to increase towards the general industrial area of Port Kembla and towards the south-west (towards Lake Heights and Dapto). The increase towards Dapto was unexplained but it was thought that it may have been due to the lead smelter in this area last century (Young et al., 1990). In the case of Bellambi, no spatial pattern was evident.

Soil concentration data for lead and other heavy metals from Port Kembla is summarised in Table 9. The following comments are provided for the limited soil data against respective HIL Level A or Level B (Table 1).

- Copper shows no measured levels exceeding HIL Level A or Level B.
- Cadmium does not generally exceed HIL Level A (20mg/kg) and HIL Level C (90mg/kg) but the study conducted in 2009 does show levels exceeded HIL Levels A and C (up to 840 mg/kg; excluding data for slag heaps – see Table 9).

- Lead at the Port Kembla area within 2.5km of the former copper smelter may exceed HIL Level A (300mg/kg) and HIL Level C (600mg/kg) 1-13km from the industrial complex site and mostly <4km (Martley et al., 2004). Better resolution of distance from the copper smelter is discussed in the following section.
- Arsenic does not exceed HIL Level A (100mg/kg) and HIL Level C (300mg/kg).
- Zinc shows no measured levels exceeding HIL Level A or Level C; even the maximum level in Port Kembla soil near the former smelter up to levels of 5328mg/kg did not exceed the HILs.

Observation of distance from smelter

Better resolution of dispersion distance of heavy metals and arsenic from the copper smelters is observed from the data in the study by Jafari (2009).

Between July and December 2008, 95 topsoil surface samples were collected within 4500m distance from the copper smelter stack within four regions (Port Kembla, Warrawong, Lake Heights and Cringilla) across the Illawarra region (Jafari, 2009). The soil samples were analysed by X-ray Fluorescence Spectrometry (XRF) for 37 elements, including arsenic, cadmium, copper, lead and zinc for total concentration, dilute hydrochloric acid extraction and EDTA extraction. The detection limit for cadmium was 10-20mg/kg and thus only high values (exceeding HIL Level A) can be compared against the soil contamination guidelines.

Highest concentration values of arsenic, cadmium, copper, lead and zinc were attributed to samples (S58, S34 and S33) collected from slag heaps (Jafari, 2009). When data from the slag heaps we excluded were excluded from the data set for total concentrations, the geographical distribution of copper together with arsenic, lead and zinc decreased with increasing distance from the copper smelter (Jafari, 2009). In particular, the copper in soil in close proximity (<1.5 km) to the copper smelter stack contain higher amounts of copper (>1500 mg/kg at (<1.5 km).

Table 10 *Percentile values for metals and arsenic in soil (mg/kg).*

Metal or Metalloid	N	No. < Values	Mean (SD)	Minimum	Median	75th percentile	Maximum	HIL Level A
Copper	95	0	556 (1246)	39	161	535	1999	1000
Zinc	95	2	373 (417)	0.4	220	432	2833	7000
Arsenic	95	1	14 (24)	0.5	7	12	183	100
Cadmium	95	52	89 (189)	12.5	29	39	840	20
Lead	95	3	178 (479)	2	64	126	667	300

Source: Jafari (2009)

The presentation of the raw data from Jafari (2009) for total concentrations in soil as percentile values (Table 10) enables features of the soil data set to be observed more easily. The values of arsenic, cadmium, copper, lead and zinc that exceed HIL Level A investigation levels are all greater than the 75th percentile values. In the case of cadmium, when the detection limit values (52 out of 95) are removed, soil concentrations exceed HIL Level A at the median (50th percentile) corresponding to 22 samples. Two of the slag samples S33 (49.4mg/kg) and S34 (64.8mg/kg) are included in the 22 soil samples, but were not the highest concentrations of cadmium measured (Table 9).

Plots of total arsenic, lead and zinc concentrations versus distance showed a similar finding compared with copper in soil in close proximity (< 1.5km) to the copper smelter stack contain higher amounts of total arsenic (> 10-15mg/kg), lead (> 150-200mg/kg) and zinc (> 400-600mg/kg) with some outliers but excluding the slag samples (Jafari, 2009).

Significant correlations were found between As, Cu, Pb, and Zn and attributed to a common source but not necessarily a unique source (Jafari, 2009). This agreed with previous work by Beavington (1973), Martley et al., (2004), Kachenko and Singh (2006). Contamination of soils surrounding the Port Kembla copper smelter particularly to a distance of 1-4km but specifically in the area <1km from the smelter stack.

Single extraction techniques were used by Jafari (2009) to determine 0.1M Hydrochloric acid and 0.05M EDTA extractable concentrations of elements and showed that copper, lead and zinc decreased with the increase of distance from the stack. Although these extracted concentrations are described as 'bioavailable' this is incorrect for human health risk assessment as the bioavailability is not measured by selective extraction (Section 3.5.2). In the case of 0.1M Hydrochloric acid extractable metals or arsenic, the measured value gives an approximate assessment of bioaccessibility (gastro-intestinal simulation) which gives a prediction of human bioavailability. The 0.05M EDTA extractable concentrations are relevant to plant uptake from soil and not human health risk assessment. Table 11 gives the mean percent extractable metals and arsenic in soil (Jafari, 2009).

***Table 11** Mean percent extractable metals and arsenic in soil.*

Extractant	% Arsenic	% Copper	% Lead	% Zinc	% Cadmium
0.1M HCl	35.7	22.0	28.0	43.0	4.27
0,05M EDTA	42.9	32.0	37.0	33.0	4.5

Source: Table 4.11 (Jafari, 2009)

The 0.1M Hydrochloric acid extractable metals or arsenic in Table 11 gives a measure of the gastric phase but overestimates the bioaccessibility because the intestinal phase is not considered (Section 3.5.2). The intestinal phase is about pH 7 and is the site where metal and arsenic absorption takes place, not from the stomach as gastric phase is where solubilisation of food occurs. Therefore, gastric phase alone overestimates % bioaccessibility but the 0.1M Hydrochloric acid extractable metals or arsenic is a conservative measurement. In context of Illawarra soils, the mean 0.1M Hydrochloric acid extractable lead concentration of 28.0% indicates that the bioaccessibility is low (compared with < 100%) and similar to bioaccessibility of soil at other mining centres in Australia (Drew and Hagen, 2010; Noller et al., 2017) and elsewhere (Ruby et al., 1996).

From the HIL Level A levels (Table 10) that are assumed to be for 100% bioavailability, the following estimates of 'bioaccessibility-adjusted' levels of metals and arsenic can be made using the data in Table 11.

The HIL Level A 300mg/kg for lead and 0.1M Hydrochloric acid extractable lead is equivalent to a site specific level of 1,071mg/kg (bioaccessibility-adjusted), i.e. by assuming that the bioaccessibility is conservatively 28.0%. Comparison with Jafari (2009) data in Figure 4.6(b) plotted for lead concentration versus distance from the copper smelter shows that using 'bioaccessibility-adjusted' concentration to compare against HIL Level A would indicate no exceedances of HIL A excepting for the highest slag sample S58 (Table 9; 4157 mg/kg lead).

The HIL Level A 100 mg/kg for arsenic and 0.1M Hydrochloric acid extractable arsenic is equivalent to a site specific level of 280 mg/kg (bioaccessibility-adjusted). Comparison with Jafari (2009) data in Figure 4.6(c) plotted for arsenic concentration vs. distance from the copper smelter shows that using 'bioaccessibility-adjusted' concentration to compare against HIL Level A would indicate no exceedances of HIL A including for the highest slag sample S58 (Table 9; 66.2 mg/kg arsenic).

The HIL Level A 6000 mg/kg for copper and 0.1M Hydrochloric acid extractable copper is equivalent to a site specific level of 27,300 mg/kg (bioaccessibility-adjusted), i.e. by assuming that the bioaccessibility is 22.0%. Comparison with Jafari (2009) data in Figure 4.4(b) plotted for copper concentration vs. distance from the copper smelter shows that using 'bioaccessibility-adjusted' concentration to compare against HIL Level A would indicate no exceedances of HIL A including the highest slag sample S58 (Table 9; 8112 mg/kg lead).

The HIL Level A 7400 mg/kg for zinc and 0.1M Hydrochloric acid extractable zinc is equivalent to a site specific level of 27,300 mg/kg (bioaccessibility-adjusted), i.e. by assuming that the bioaccessibility is 43.0%. Comparison with Jafari (2009) data in Figure 4.4(a) plotted for zinc concentration vs. distance from the copper smelter shows that using 'bioaccessibility-adjusted' concentration to compare against HIL Level A would indicate no exceedances of HIL A including the highest slag sample S58 (Table 9; 2833 mg/kg zinc).

Similar estimates for 0.1M Hydrochloric acid extractable cadmium and the HIL Level A Cd 20 mg/kg can be made but Jafari (2009) did not plot cadmium data vs distance from the copper smelter.

The HIL Level A 20 mg/kg for cadmium and 0.1M Hydrochloric acid extractable cadmium is equivalent to a site specific level of 468 mg/kg (bioaccessibility-adjusted), i.e. by assuming that the bioaccessibility is 4.27%. This shows that using 'bioaccessibility-adjusted' concentration to compare against HIL Level A would indicate no exceedances of HIL A for the 22 samples above detection limit for total concentration including the slag sample (Table 9). This indicates that some of the samples exceeding the 75th percentile concentration (Table 10) would exceed the 'bioaccessibility-adjusted' concentration to compare against HIL Level A.

Lead isotope studies

A useful measurement which has some application to source identification is the measurement of stable lead isotopes (Chiaradia et al., 1997; Elias and Gulson (2003). The principal ores processed originated from Australian deposits, mainly from the British Mine (Pb-Zn) at Broken Hill, and have accurately measured lead isotopic compositions (Chiaradia et al., 1997). The potential pollutant sources of Southern Copper smelter, BHP Steel/ Bluescope Steel, Tallawarra Power Station, Konahooka smelter and coke works (Figure 5) could all be identified from existing source samples. When the specific sources are mixed with lead in paint and lead in petrol from automobiles, resolution of sources is constrained when more than two components are present in the sample for measurement of lead isotopic ratios. This makes source identification unclear. This is in contrast with Mount Isa where all lead of local geological origin has a single set of lead isotope ratios and is easily mixed with non-lead bearing dust or lead from petrol (Noller et al., 2017). Thus identifying the source of lead contamination at Illawarra is of limited use from the existing historical studies.

Table 12 *House and roof data concentration data for lead, other heavy metals and arsenic.*

Site/ Sampling period	Copper (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)	Zinc (mg/kg)	Other (mg/kg)	Reference
Accumulated roof dust Port Kembla (km from reference point, n=55)	**Mean Cu (range)**	**Mean Cd (range)**	**Mean Pb (range)**	**Mean As (range)**	**Mean Zn (range)**	**Mean Fe (range)**	Port Kembla homes in 1992 selected along concentric arcs commencing at 0.5km from the smelter and then 0.5km intervals out to 5.5km. IPHU (Willison, 1993)
0.3	23,405 (20700-28336)	70 (35-70)	3391 (1172-4921)	307 (202-555)	12770 (3810-28700)	94683 (79000-120500)	
0.5	5798(1868-12381)	38(17-58)	1862(1112-3040)	241(187-388)	21085 (1900-69300)	111138(42100-297000)	
1.0	781(547-1049)	13(8-19)	1185(503-2161)	88(41-140)	7421(870-18868)	56000(15000-61000)	
1.5	1052(298-1700)	7(5-10)	614(331-912)	53(24-73)	12718(1435-30338)	63000(61000-92000)	
2.0	657(224-2075)	3(1-9)	545(295-1005)	65 (38-124)	1534(8875-3393)	68600(56000-86000)	
2.5	421(124-1157)	4 (1-11)	377(272-593)	50(41-61)	1407 (975-2412)	64250(40000-81000)	
3.0	387(173-387)	8(6-10)	711(383-1467)	51(39-62)	16297(1460-59000)	67540(44390-85300)	
3.5	325(151-800)	8(5-11)	554(409-730)	47(35-62)	13600(1460-60690)	74330(49610-101100)	
4.0	249(128-431)	6(5-8)	594(433-774)	53(40-66)	14035(1080-1265)	63155(37280-80730)	
4.5	453(169-846)	7(6-7)	645(584-739)	26(20-34)	13600(1980-26900)	24767(22700-28800)	
5.0	391(203-610)	6(5-8)	545(367-890)	62(29-117)	1161(1080-1265)	39067(28000-49200)	
5.5	431(43-1482)	6(4-8)	518(322-800)	48(28-64)	4054(925-9875)	45252 (21000-76100)	
					13108(890-53500)		
House Keira Street Port Kembla	12381	30	2471	308	3414		IPHU (Willison, 1992) Resampled
House dust							IPHU (Lonie, 1992) Lead was from lead in petrol
Windang Beach			90-900				
Shellharbour			700				
Ceiling dust							
Port Kembla Public School 1990			2300-4300				
Port Kembla area							ICBLS Follow-Up Study 1995 (Williams et al., 1995)
Children's bedroom carpets (n=9)			100-740				
Living room carpets (n=14)			<100-2280				
Living room carpets (n=6)			300-1000				
Carpet from outbuildings (n=4)			100-12,700				
Dust non-carpeted floors (n=6			<100-5,440				
Interior shelves and window sills (n=10)			600-1,000				
Wall vents, ceiling vents and cracks (n=4)			450-5,630				

Site/ Sampling period	Copper (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)	Zinc (mg/kg)	Other (mg/kg)	Reference
Warrawong (n=3)			275-735				Chiaradia et al., (1997)
Port Kembla (n=5)			658-3275				Lead isotope data for each sample
Brownsville (n=1)			500				
Cringila (n=1)*			1400				**Contains lead paint flakes*
Figtree (n=1)			440				
Thirroul (n=1)			938				
Industrial sites							
Copper smelter			1.47%, 2.16%, 29.3%				
Base metal smelter			310, 346, 3780, 6%				
Coal-fired power station (TPS)			30				
BHP steelworks			900, 7800				

4.2.2 Comparison of house and roof data for lead, other heavy metals and arsenic with current guidelines

Background

Table 12 summarises house and roof concentration data for lead and other heavy metals. Roof and gutter dust were collected externally at houses in Port Kembla and other locations in Wollongong LGA. Whilst concentrations of lead and other metals and arsenic in dust in houses can be compared for similarity of values to relate to the source, it is not possible to undertaken direct comparison with the soil contamination guidelines (Table 1).

Dust in houses can contain high levels of lead as a result of a number of sources including past or current industrial activities, unsafe lead paint management, unsafe renovations, leaded petrol and lead light windows (Lead Group, 2002). It is the most common medium for lead poisoning, as a result of being ingested or inhaled. Accumulated cavity dust is of particular concern as it can be released into the living areas through cracks in ceilings, or released into the environment in large quantities during demolition or renovation work. Lead dust brought home on clothes of parents or other adult co-residents working in the lead industry is also a source of lead exposure in children.

Lead dust loadings for various surfaces are given in AS 4361.2-1998 *Guide to lead paint management Part 2: Residential and Commercial Buildings*. These were originally based on 1995 US guidance for investigation of lead poisoning (Section 3.5.4). In the US the "clearance" level for bare and carpeted floors was lowered in 2000 to 0.4mg/m^2 but the Australian standard is yet to change to this more rigorous clearance level. NSW EPA recommends the use of lead dust standards to determine the safety of the premises for re-occupancy after renovation and clean-up are completed (Section 3.4.4; CLP Tool Kit, 2010). These are: (i) bare and carpeted floors 1 mg/m^2; (ii) interior window sills: 5 mg/m^2; and (iii) exterior surfaces: 8 mg/m^2.

Thus, there are no Australian standards available to assess health risk from metals and metalloids in dust from houses (Section 3.6.4). The health risk from metals and metalloids in house dusts requires first principles calculation of dose for the inhalation, ingestion and dermal pathways following the methodology of eNHealth (2012) (Section 3.6.4). However, there is an extensive number of publications that provide guidance on managing clean-up of lead in houses (Lead Group, 2002).

Summary of findings

As part of the 1995 ICBLS follow-up study to evaluate lead in dust levels in the Port Kembla area, lead concentration in nine dust samples taken from the children's bedroom carpets ranged from <100-740mg/kg (0.07%), with five samples having <300mg/kg lead (Williams et al., 1995). Lead concentration in 14 dust samples from living room carpets ranged from <100-2,280mg/kg (0.23%). The lead concentration of six samples was <300mg/kg, and of a further six samples was 300-1,000mg/kg. In addition, the lead concentration of four carpet dust samples from outbuildings were <100, 590, 1,930, and 12,700mg/kg.

The lead concentration in three dust samples from non-carpeted floors were: <100, 344 (0.03%) and 5,440mg/kg (0.54%) (Williams et al., 1995). The lead concentration in samples from ten interior shelves and window sills ranged from 600-4,340mg/kg, with three samples being <1,000mg/kg and the other seven samples being >1,000mg/kg. In addition, the lead concentrations of two dust samples from the floors of outbuildings were 605 and 2,040mg/kg. Roof dust escaping from wall vents, ceiling vents and cracks in the cornices of four homes were found to have lead contents of 450, 1,670, 2,100 and 5,630mg/kg.

In 1992 the IPHU undertook a sampling of accumulated roof dust in 55 randomly selected houses situated along concentric arcs, commencing at a distance of 0.5km and thence at 0.5km intervals out to a distance of 5.5km from the Southern Copper stack (Willison, 1993). Highest levels of arsenic, cadmium, copper and lead were found within 1km of the stack with a drift towards the southwest (consistent with prevailing north-easterly winds) with levels increasing markedly within 0.5km of the stack.

These results showed that more than 1km from the main industrial complex, lead levels in roof dust were generally less than 1,000mg/kg. Within 1km lead levels began to increase and within 0.5km levels generally exceeded 1,500mg/kg. A similar pattern occurred for arsenic and cadmium. Iron, copper and zinc were the predominant metals, however at levels not considered to be harmful (Willison, 1993), at that time.

In addition to Port Kembla, as part of the investigation of lead and other heavy metal exposure in 1992 (Willison, 1993), the IPHU took samples of dust from five houses in the Windang Beach Garden Estate, (dust from window sills, door channels and light fittings), as well as a house further to the south, for comparative purposes. The lead in dust levels from five Windang houses tested by the IPHU ranged from 90-900mg/kg, the highest level being in a house closest to Windang Road. The lead in dust level in the house tested at Shellharbour was 700mg/kg (Willison, 1993). Because there were no other apparent sources of lead in Shellharbour, it was assumed that the lead source for this sample must have been leaded petrol. Similarly, it was thought that the main source in Windang was probably motor vehicle emissions. However, examination of house dust samples taken from a house less than two years old in Windang by the NSW EPA showed that the slag dust detected had the same source as the soil slag. The source of traces of flue dust found in the house was uncertain. The soil slag was shown to be composed of 1.0% lead, 1.5% copper, 6.8% zinc, 0.05% chromium and 0.3% arsenic. Lead concentrations in two ceiling dust samples collected from two main school buildings at Port Kembla Public School in 1990 (Willison, 1993), following the fallout incident (Section 4.3), were 2,300 and 4,300mg/kg. Other potential sources of lead exposure in 1995 included: refined lead (sheet lead, scrap lead and fishing sinkers, presumably of 100% lead content), which was found in three homes/backyards where children played, and lead solder (58% lead content) from the work clothes of one child's parent who worked in a vehicle radiator repair shop (Williams et al., 1995).

Comparison is made with lead and other heavy metals concentrations in soils.

- Cadmium and copper shows measured levels which are highest within 0.3km and extending to 1.0km of the copper smelter with similarity to soil levels
- Cadmium shows accumulated roof dust was highest up to 0.5km from Port Kembla copper smelter.
- Lead shows accumulated roof dust at high concentrations up to 1.0km from the copper smelter and similar to soil levels. Beyond 1.0km house dusts show decreasing levels that tend to be higher than found in soil.
- Arsenic shows accumulated roof dust 0.5km from the copper smelter that decrease following 1.0km from the copper smelter. The accumulated arsenic in house dust tends to be higher than found in soil at respective locations.
- Zinc shows accumulated roof dust beyond 5.0km and reflect that zinc is more volatile in air than copper or lead.

These results indicate that high concentrations may exist in houses which were closest to the Port Kembla smelters, particularly within 1.0km. The sample concentrations for houses can also be compared against the data for industrial sites and the copper smelter (Chiaradia et al., 1997) included in Table 12. The houses that remain intact, may have never been cleaned.

Clean up of house dust

Health risk management was focussed on lead and its effect on people in Port Kembla, particularly children. A Fact Sheet was developed by IPHU for cleaning up house dust by wearing a face mask (ILMP, 1998). Ceiling dust was removed by vacuum cleaner and also with lead paint removal (Balding, 1998). Site remediation was undertaken during the care and maintenance phase with particular attention to fugitive emissions from the copper smelter. In 1996 the copper smelter had discussed with the IPHU on how to manage cleaning up dust in house ceiling cavities but there was a storage problem for the removed dust 1998). Vacuum cleaning of cavity dust was ineffective because of fine dust passing through the vacuum cleaner filter and back inside the houses (ILMP, 1998). Later, HEPA filter enclosed vacuum cleaners were introduced that could prevent fine particles being redispersed in houses during the cleanup (Lead Group, 2002). See also Section 4.4.

4.2.3 Review of lead and other heavy metals in home-grown fruit and vegetables

Lead levels in home grown food were examined in the Port Kembla area. Generally, very little lead is absorbed through the roots of plants from soil (ILMAP, 1997). However, soil adhering to harvested root crops can be ingested, if not washed off before eating. Lead fall-out can also adhere to leaves and other above ground parts of plants, especially broad leafy vegetables.

In response to requests from residents near the copper smelter, in 1996-97 the IPHU collected 20 samples of home grown vegetables for analysis of lead and other heavy metals (carrot, onion, potatoes, capsicum, leek, zucchini, beans) and fruits (passionfruit, lemon, babaco, peach) (ILMAP, 1997). Although the sampling was limited, and two samples were above the maximum permissible concentration (MPC) for lead and one for cadmium, overall the results indicate that heavy metal uptake by and consumption of home-grown vegetables are not at a high enough level to pose a health threat. All samples had lead concentrations below the maximum limit set by the Food Standards Code 412, Food Act 1989 (MPC of 0.5mg/kg[5]), apart from one of two carrots (0.2 and 1.4mg/kg), and one of two potatoes (less than 0.5 and 0.6mg/kg).

Cadmium levels were within the food standards MPC, apart from one of three carrots (0.16mg/kg, the others being 0.07 and 0.09mg/kg) (ILMAP, 1997). Although there was no MPC of cadmium in vegetables (apart from leafy vegetables and root and tuber vegetables), all cadmium concentrations for the other fruit and vegetables were below 0.1mg/kg, apart from a cadmium concentration of 0.15mg/kg in a leek, and 0.40mg/kg and 0.30mg/kg in passionfruit. All arsenic levels were below 0.2mg/kg, i.e. well within food standards MPC.

The ICBLS Follow-up Study 1995 was undertaken to follow-up on children with high BLLs identified by the ICBLS (Williams et al., 1995). Four vegetables grown in backyards showed lead concentrations of up to 3.2mg/kg lead on the outside of leaves, and up to 0.7mg/kg lead within the plant (Williams et al., 1995).

In the Windang Beach Garden Estate in 1992, samples were taken from 14 households which grew vegetables, fruit and/or herbs (Lonie et al., 1992). Analytical results were compared with the maximum limit set by the Food Standards Code 412, Food Act 1989, and showed that 19% exceeded the maximum limit for lead; 19% exceeded the maximum limit for lead at that time, 33% for cadmium and 5% for copper. In one case, a Chinese Pear tree grown in slag exhibited heavy metal uptake at a sufficient level to pose a health threat, if eaten in very large quantities. Residents were advised not to eat it.

In April 1974, levels of copper, zinc, lead, cadmium, nickel and iron in leaf vegetables, and their supporting soil in a zone of 0.5km radius, were investigated around the Port Kembla smelter site (Beavington, 1975a,b). Within this 0.5km there were 189 houses with vegetable gardens, some only 150-200m from the main smelter stack. Twenty one samples of leaf vegetables were collected from 17 different gardens located in seven different streets. Twelve of these samples were lettuce, with the remaining nine comprising of cabbage, garlic leaf, mint, plus two samples of chillies. At each site where vegetables were collected, a soil sample (0-10cm) was taken. The mean lead levels were as follows: lettuce 23mg/kg; other leaf vegetables 10.3mg/kg; chillies 1.0mg/kg; and soil 13.3mg/kg. In all cases, the levels of metals in lettuce were considerably higher than those for other vegetables. The vegetable samples with the highest metal levels were from gardens nearest the smelter. In one garden, 150m from the main stack, there were no mature vegetables at the time of sampling, but a mature flowering plant contained in leaf, 71.4mg/kg lead. The vegetable samples were washed before they were analysed. Highly significant correlations were found between distance from the stack and the levels of easily extractible copper, zinc, lead and cadmium in the soil.

[5] The Australian New Zealand Food Standards Code maximum levels of lead in foods is 0.5 mg/kg (FSANZ 2010).

Dietary exposure to heavy metals, namely cadmium, lead, zinc and copper, has been identified as a risk to human health through the consumption of vegetable crops (Kachenko and Balwant Singh, 2006). This study investigated the source and magnitude of heavy metal contamination in soil and vegetable samples at 46 sites across four vegetable growing regions in NSW, Australia. The four regions Boolaroo, Port Kembla, Cowra and the Sydney Basin were a mix of commercial and residential vegetable growing areas. The extent of metal contamination in soils sampled was greatest in regions located in the vicinity of smelters at Boolaroo and Port Kembla. Cadmium, lead and zinc contamination was greatest in vegetables from Boolaroo, and copper concentrations were greatest in vegetables sampled from Port Kembla. At Boolaroo, over 63% of the samples exceeded the Australian Food Standards maximum level (ML) (0.1mg/kg fresh weight) of both cadmium and lead in vegetables (Kachenko and Balwant Singh, 2006). Vegetables at Port Kembla showed exceedance for both cadmium and lead. All vegetables sampled from Cowra, which is a relatively pristine site, had cadmium and lead levels below the Australian and international food standards guideline values. This study highlighted the danger of growing vegetables in the vicinity of smelters.

Following 1996-97, St Patrick’s Primary School developed a simpler plan to remove and cover bare soil and minimise children’s exposure. Other local greening activities were performed.

Table 13 *Summary of sediment concentration data.*

Site/ Sampling period	Copper (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Arsenic (mg/kg)	Zinc (mg/kg)	Other (mg/kg)	Reference
Lake Illawarra (n=8) total **Mullet Creek (n=1) total** **Port Kembla Inner Harbour (n=1) total**			11-82 33 95				Chiaradia et al., 1997 (Sediment samples at various depths) 1M HCl leach can be compared directly with ISQG-LOW Lead isotope ratios measured on every sample
Lake Illawarra (n=40) total Background concentrations Sand-rich sediment Southern Griffins Bay	 33±8 18-23 >60		 17±5 2-6 61-148		 68±13 14-33 >400		Payne et al., 1997
Lake Illawarra Mean background Upper sediment cores	 11.9 15.8-88.0	 2.3 1.8-5.8	 3.6 13.4-81.5	 4.4 4.8-12.4	 11.3 68.1-375.0		Jarafi (2009)

4.2.4 Comparison of historical sediment data with ANZECC/ARMCANZ-ANZG ISQGs

A number of studies have been undertaken to measure lead and other heavy metals in sediment from Lake Illawarra at the water sediment interface and at different depths below the interface. Table 8 gives the ANZECC/ARMCANZ (2000)/ANZG (2018) sediment quality values for protecting aquatic species from effects of uptake of lead and other heavy metals. The concentrations of lead and other heavy metals are compared against the Interim Sediment Quality Guidelines (Section 3.5.6; Table 8). In addition, the significance of lead and other heavy metal concentrations in the water column on aquatic species can also be assessed using the guideline values for protection of aquatic species given in Table 5. At sites where ISQG-High values for sediment are exceeded, it is potentially the case that bioaccumulation of lead and other heavy metals may occur. If aquatic species are caught and consumed by people, there may be a significant health risk and therefore needs to be part of the health risk assessment.

The concentrations of lead and other heavy metals in sediment from Lake Illawarra and estuary sites at Port Kembla are summarised in Table 13.

- Copper: only sediment from Southern Griffins Bay has copper concentrations of 60mg/kg to a maximum of 88.0mg/kg and exceed the ISQG-Low (65mg/kg) but not ISQG-High (270mg/kg) for copper.
- Cadmium: mean background for Lake Illawarra sediment is 2.3mg/kg which exceeds the ISQG-Low (1.5mg/kg) but not ISQG-High (10mg/kg) for cadmium. There may be effects on aquatic species from cadmium.
- Lead: mean background for Lake Illawarra sediment is 3.6mg/kg which does not exceed the ISQG-Low (50mg/kg). Some sediment upper core levels in Lake Illawarra and Port Kembla Inner Harbour exceed ISQG-Low but not ISQG-High (220mg/kg) for lead. There may be effects on aquatic species from lead.
- Arsenic: mean background for Lake Illawarra sediment is 4.4mg/kg which does not exceed the ISQG-Low (20mg/kg) or ISQG-High (70mg/kg) for arsenic.
- Zinc: mean background for Lake Illawarra sediment is 11.3mg/kg which exceeds the ISQG-Low (0.2mg/kg) but not ISQG-High (410mg/kg) for zinc. There may be effects on aquatic species from zinc.

Lake Illawarra has a long history of sediment contamination, particularly by metals, as a result of past and current industrial operations and land uses within the catchment (Schneider et al., 2015). The history of metal contamination in sediments was assessed by using metal analysis and 210-Pb and 137-Cs dating. The distributions of copper, zinc, arsenic, selenium, cadmium and lead concentrations within sediment cores were in agreement with historical events in the lake, and indicated that metal contamination had been occurring since the start of industrial activities in Port Kembla in the late 1800s. Most metal contamination, however, has occurred since the 1960s. Sedimentation rates were found to be 0.2cm year^{-1} in Griffins Bay and 0.3cm year^{-1} in the centre of the lake. Inputs from creeks bringing metals from Port Kembla in the northeast of the lake and a copper slag emplacement from a former copper refinery on the Windang Peninsula were the main sources of metal inputs to Lake Illawarra. The metals of highest concern were zinc and copper, which exceeded the Australian and New Zealand Environment and Conservation Council (ANZECC) sediment quality guideline values (Table 8) at some sites. Results showed that while historical contamination persists, current management practices have resulted in reduced metal concentrations in surface sediments in the depositional zones in the centre of the lake.

Contamination from lead and other heavy metals may apply to soil and the terrestrial part of the ecosystem and the aquatic ecosystem as Lake Illawarra is a key environmental feature in the Wollongong LGA.

Chiaradia et al. (1997) undertook extraction of sediment for lead with dilute hydrochloric acid and ammonium acetate solutions. The extracted concentrations with dilute hydrochloric acid can also be compared against the ANZECC/ARMCANZ (2000) Interim sediment quality guidelines (Table 8) and are considered to represent more ‘bioavailable concentration’ to aquatic species. For example, Site L16 sediment from Lake Illawarra (Chiaradia et al., 1997) had total lead concentration of 43mg/kg (depth 0-5cm) and dilute hydrochloric acid extractable concentration of 41mg/kg (depth 5-10cm), indicating that the lead was all ‘bioavailable’ to aquatic species. In this case, comparison with the ISQG-Low for lead (50mg/kg) shows that the ‘bioavailable’ concentration of lead at Site L16 was not significant. Only limited data for lead in sediment was given (Chiaradia et al., 1997). Examples of wider application of this ANZECC/ARMCANZ (2002) - ANZG (2018) guideline approach to downstream water and sediment contaminated with lead and other heavy metals from legacy mining activity is given for the Leichhardt River at Mt Isa in Noller et al. (2012).

The significance of sediment concentrations of heavy metals and arsenic at Lake Illawarra are important issues because of (i) the effects on aquatic biota that may limit the number of species as part of the ecosystem; and (ii) occurrence of bioaccumulation of lead in species like fish and shellfish species that may be consumed by the local population (especially Indigenous people).

***Table 14** Summary of air concentration data.*

Site/Sampling period	Copper (µg/m³)	Cadmium (µg/m³)	Lead (µg/m³)	Manganese (µg/m³)	Zinc (µg/m³)	Fe (µg/m³)	Reference
			Air particulates				
a. 32 Swan Street, Wollongong (24 hr TSP samples) n=13	Mean (0.887) Range 0.225-2.47	Mean (0.0056; n=5) Range 0.0034-0.0086	Mean (0.381) Range 0.251-0.676	Mean (0.188; n=8) Range 0.094-0.243	Mean (0.411) Range 0.120-0.965	Mean (4.68) Range 1.35-8.95	Crisp (1986) Chemical analysis of airborne particulates January 1984 - June 1984
b. AIS Duplicating Department, Warrawong (24 hr TSP samples) n=11	Mean (0.191) Range 0.122-0.306	Mean (0.0032; n=4) Range 0.0034-0.0086	Mean (0.514) Range 0.167-0.831)	Mean(0.327; n=7) Range 0.296-0.464	Mean (0.381) Range 0.217-0.484	Mean (7.93) Range 7.17-13.8	
c. 32 Jarvis Road, Cringila (24 hr TSP samples) n=12	Mean (0.654;) Range 0.410-0.958	Mean (0.0020; n=2) Range 0.0023-0.0038	Mean (0.332) Range 0.152-0.575)	Mean (0.1657; n=5) Range 0.0936-0.348	Mean (0.339) Range 0.208-0.701	Mean (4.29) Range 2.02-7.88	
d. 61 Princes Highway, Corrimal (24 hr TSP samples) n=9	Mean (0.266; n=7) Range 0.125-0.679	Mean (0.0022; n=1)	Mean (0.564) Range 0.152-1.18)	Mean (0.023; n=4) Range 0.0153-0.238	Mean (0.139; n=7) Range 0.0445-0.348	Mean (1.16;n=7) Range 0.555-2.66	
e. Huntley Road, Dapto (24 hr TSP samples) n=8	Mean (0.266; n=3) Range 0.25-0.281	-	Mean (0.143) Range 0.0514-0.311)	-	Mean (0.057; n=3) Range 0.0381-0.0779	Mean (0.607;n=2) Range 0.394-0.920	
1 December 2015 to 31 December 2019			Mean <0.06				
Bluescope Steel, Unanderra							
Point 141 Old Scout Hall (S of Site)-Flagstaff Road Warrawong (Monitoring Frequency every 6 days with Actual No. of Times measured during month from 1Dec2015 to 30Nov2019 varies from 3-6)			Min (Range, n=48 months) <0.05-<0.11) Mean (Range, n=48 months) 0.03-<0.11) Median (Range, n=48 months) 0.03-<0.06) Max (Range, n=48 months) <0.054-<0.11)				
Point 152 Old Scout Hall (N of Site)-Near North Gate Visitors Centre Coniston (Monitoring Frequency every 6 days with Actual No. of Times measured during month from 1Dec2015 to 30Nov2019 varies from 3-6)			Min (Range, n=48 months) <0.021-<0.11) Mean (Range, n=48 months) 0.021-<0.11) Median (Range, n=48 months) 0.03-<0.06)				

Point 153 (W of Site)-Bluescope Stainless premises, Unanderra (Monitoring Frequency every 6 days with Actual No. of Times measured during month from 1Dec2015 to 30Nov2019 varies from 3-6)			Max (Range, n=48 months) <0.054-<0.11) Min (Range, n=48 months) <0.053-<0.0.06) Mean (Range, n=48 months) 0.021-<0.11) Median (Range, n=48 months) 0.03 Max (Range, n=48 months) 0.054-0.14)				

4.3 Lead and Other Heavy Metals in Air

In NSW, the Department of Environment, Climate Change and Water (DECCW) operates a comprehensive air quality-monitoring network throughout NSW (Figure 7) which also includes the Illawarra (NSW DECCW, 2010). Air quality monitoring in NSW began in the early 1950s. As part of the Metropolitan Air Quality Study (MAQS) undertaken from 1992 to 1995, the monitoring network was expanded to include the Illawarra and monitor lead. The Illawarra (Wollongong) region has a thin coastal strip with a steep escarpment to the west. The width of the coastal strip increases from north to south until it terminates in a ridge of hills running from the escarpment to the sea. The escarpment is a major influence on meteorology and hence on air quality in the region: a temperature inversion can form at the top of the escarpment, limiting the dispersion of pollutants within the Illawarra region.

In 1973, the State Pollution Control Commission (SPCC) initiated sampling of dust in air at two sites in Port Kembla, one in Military Road and one in Flagstaff Road. A third sampling site was established at Church and Kembla Streets in 1980 (ILT, 1997). The yearly averages chart shows that in 1974 and 1975 there was a dramatic reduction in the levels of lead in the Port Kembla air mass from 5µg/m^3 down to 1.5µg/m^3 that coincided with the introduction of air pollution controls on the smelter. A sharp increase in 1980 followed the smelter changing to an ore material with a much higher lead content. The 90-day average chart showed that the copper smelter has had a major impact on the lead in air levels at Port Kembla ranging from 5µg/m^3 in 1980 down to 1.5µg/m^3 in 1990 (ILT, 1997).

The reduction in lead levels to below the NHMRC goal from mid-1990 to mid-1991 coincided with the major shutdown of the smelter, followed by levels of lead up to 6µg/m^3 after production resumed. The high levels recorded were indicative of problems encountered by the smelter in commissioning the new equipment installed during the shutdown. However, this was followed by two years of lead levels below 1.5µg/m^3 as the major problems were resolved and the new equipment achieved its full potential. It was also evident that there was rapid fall-out of the lead dust from air declining beyond 5km. The lead levels at the Flagstaff Road site had met the NHMRC goal since 1973 and this site was considered to show the background lead levels, as lead in petrol for vehicles was in use at that time. Monitoring stations at the Church and Kembla Street site only met the NHMRC goal from mid-1992, following the 1991 upgrade of pollution control equipment, while those at the Military Road site are scattered with some slightly above and several below the NHMRC goal since mid-1992.

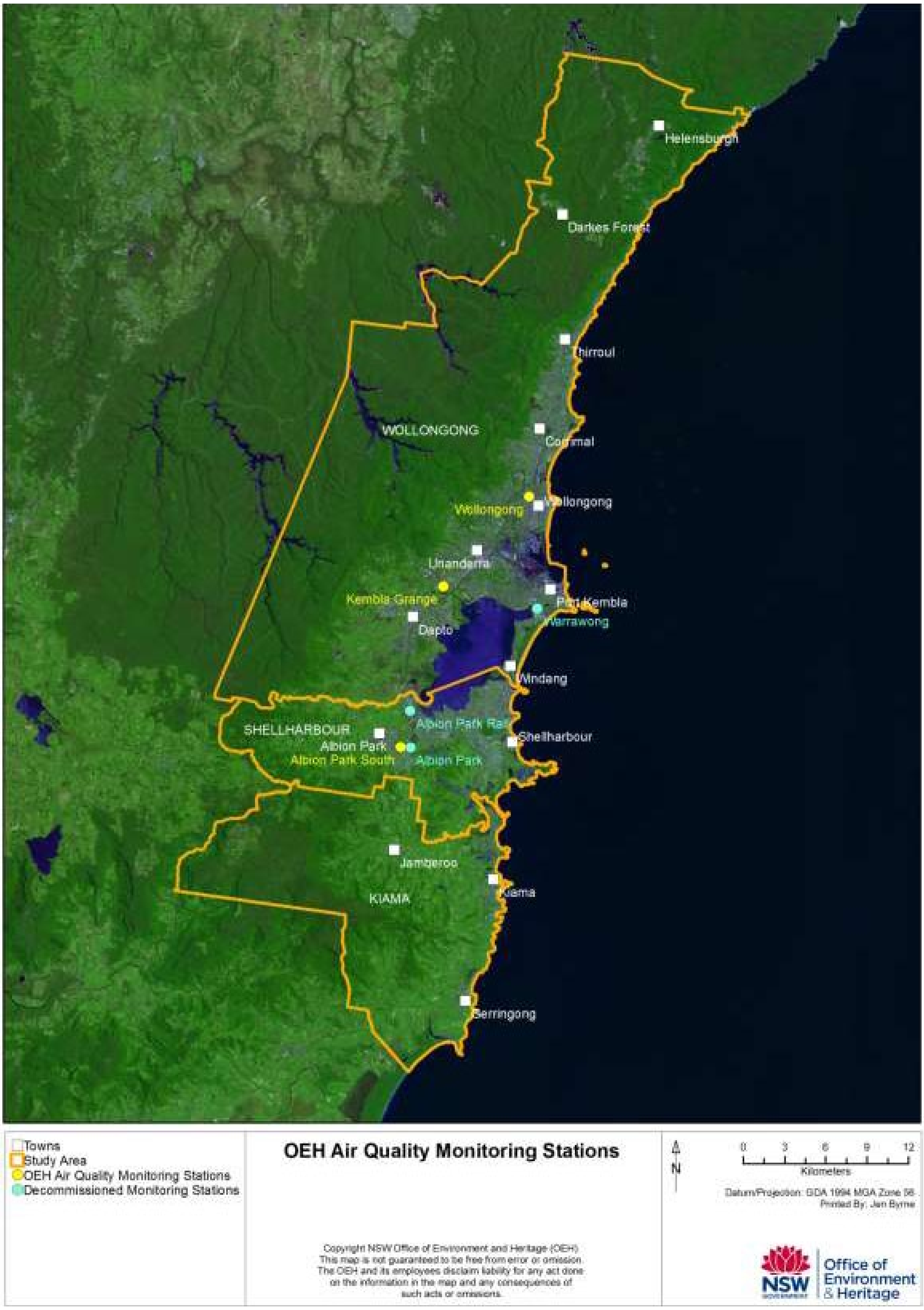


Figure 7 *Location of Wollongong Air Quality Monitoring Stations (ID 2019) (NSW OEH, 2015).*

The standard for lead in air was reduced to 1.5µg/m^3 for a 1 year average at the 115th Session of the NHMRC held on 2 June 1993 (Alperstein et al., 1994). The Select Committee on Lead Pollution from the

Lead Task Force NSW LMAP for Southern Copper was also set at a slightly lower level of 1µg/m^3 for lead with continuing reductions in air level to be achieved (Senate, 1994).

Prior to the closure of the Port Kembla copper smelter in early 1995, the Pollution Reduction Program of the Southern Copper license specified an emission goal of 1.0µg/m^3 for lead in air averaged over 1 year (corresponding to TSP), and was below the standard recommended by the NHMRC. This goal was incorporated into the Conditions of Consent (and modified Conditions of Consent), issued by the NSW Minister for Urban Affairs and Planning, for the upgrade of the smelter, in 1996.

The NSW EPA's 1999 licence conditions for the copper smelter, when it reopened, required that lead-bearing particulate emissions from the premises must be minimised so that a three-monthly rolling average of 1.0µg/m^3 of lead in air is not exceeded at the monitoring site at the Port Kembla Fire Station. However, this goal was not met and the smelter moved to a care and maintenance program and was eventually closed. Following 1999, ambient lead air concentration was consistently low and met the NEPM 1998 guideline.

A summary of air concentration data (Table 14) shows the air particulate collections of TSP for copper, cadmium, lead, manganese, zinc and iron for the period January 1984 to June 1994. The air guidelines prior to 1994 for lead was to 1.5µg/m^3 mean lead and was not exceeded. Current standards (Table 2) would be exceeded for lead, cadmium, manganese (slightly), arsenic, copper, zinc (Appendix D; note very poisonous to birds). The Air NEPM of 1998 specified air quality standards which the NSW Government and other jurisdictions had adopted (NEPC, 1998) and uses a yearly average for PM10 collection. In 2003 the Air NEPM was varied (NEPC, 2003) to include advisory reporting standards for particles as $PM_{2.5}$.

In 2004 the national framework for monitoring, assessing and reporting the concentrations of selected air toxics was agreed to in the National Environment Protection (Air Toxics) Measure (NEPC 2004) (the 'Air Toxics NEPM'). The Air Toxics NEPM establishes monitoring investigation levels (MILs) for five air toxics relevant to human health. The MILs are chosen conservatively so that, on current information, exposure at these concentrations is unlikely to result in adverse health effects (NSW Health, 2004). The inventory accounts for over 90 air pollutants with criteria pollutants (those covered by the Air NEPM) – including lead and various metal air toxics, e.g. antimony, arsenic, beryllium, chromium and nickel. It is not clear if the metal toxics in air were monitored following 2004 in Wollongong.

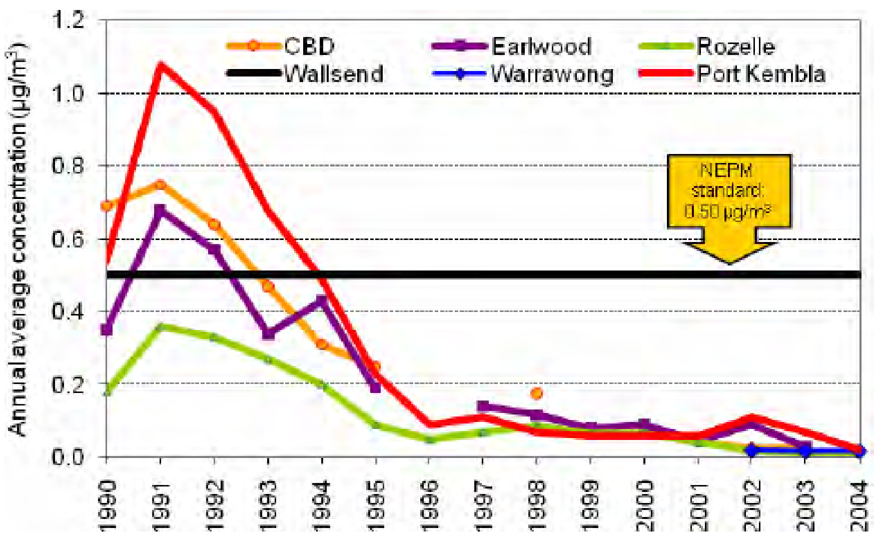


Figure 8 *Annual average lead concentrations in NSW (1990-2004) (NSW DECCW 2010).*

The NSW EPA monitoring station at Warrawong in the Illawarra region monitored lead between 1998 and 2004. However, lead air monitoring was phased out in 2004 with no further routine monitoring from 1

January 2005, following a decrease in ambient lead levels to well within the national standard, largely as a result of the introduction of unleaded petrol (NSW EPA, 2015). A report summarising the case for discontinuing lead monitoring was presented to the NEPC.

Figure 8 shows the significant fall in annual concentrations of lead throughout the Greater Metropolitan Region (GMR) of NSW from 1990 to 2004. By 2004, annual average data throughout NSW had decreased to typically less than 0.03µg/m^3 and many 24-hour average data were below the minimum detection limit. Thus following 2004 there was no further a PM_{10} emission issue from Port Kembla regarding human health and exposure via inhalation.

The highest annual average since 2000 was 0.11µg/m^3, recorded at Port Kembla during 2002. This annual average was only 22% of the national standard despite the Port Kembla monitoring site being located close to industrial sources of lead emissions at the time.

Since December 2015 through to November 2019, lead in air monitoring has been conducted every six days at the Bluescope Steel works site Unanderra, south of the site and north of the site. The levels (min, mean, median and max monthly average of 24 hr collections) from 1 December 2015 to 30 November 2019 have not exceeded 0.06µg/m^3, excepting for maximum values 0.054-0.14µg/m^3 recorded between 30 September 2016 and 30 April 2019 (Table 14).

***Table 15** Summary of air fallout concentration data for lead and cadmium.*

A. Data from Beavington (1977) collected mid-January 1974 to mid-January 1975.

Detail	Lead (µg/cm^2.year)	Lead (µg/m^2.day)	Cadmium (µg/cm^2.year)	Cadmium (µg/m^2.day)
Sites 100m, 380m, 610m nearest smelter	47 34 9	1288 932 247	1.9 1.7 0.7	52.1 46.6 19.2
Sites nearest works 320m, 480m	10 3.6	274 98.6	0.3 0.2	8.2 5.5
Inner suburbs2.5km to 8km	3.6	98.6	<0.2	<5.5
Outer suburbs 9-15km	1.6	43.8	<0.2	<5.5
Rural site 56km from smelter	0.9	24.7	<0.2	<5.5

B. Data from Crisp et al., (1983) and Archibold and Crisp (1983) Moss bag technique.

Detail	Crisp et al., (1983)					
	September 1980		October 1980		November 1980	
	Lead (ng/cm^2.day)	Lead (µg/m^2.day)	Lead (ng/cm^2.day)	Lead (µg/m^2.day)	Lead (ng/cm^2.day)	Lead (µg/m^2.day)
Wollongong City	17	170			12	120
Coniston	40	400			22	220
Mt St Thomas	25	250			40	440
Mangerton	14	140			8	80
West Wollongong	29	290			15	150
Figtree	22	220			20	200
Unanderra	3	30			33	330

Detail	Crisp et al., (1983)					
	September 1980		October 1980		November 1980	
	Lead ($ng/cm^2.day$)	Lead ($\mu g/m^2.day$)	Lead ($ng/cm^2.day$)	Lead ($\mu g/m^2.day$)	Lead ($ng/cm^2.day$)	Lead ($\mu g/m^2.day$)
Farmborough Heights	3	<40			6	60
Kembla Grange	<0.4	260			5	50
Berkeley	3	30	20	200		
Cringilla	17	170	89	890		
Lake Heights	3	30	24	240		
Warrawong	39	390	157	1570		
Port Kembla	104	1040	487	4870		
Archibold and Crisp (1983)						
Site 37 **Port Kembla** **May 1981 n=7 replicates for same time**	Lead 376.3±26.6	Lead 3760±266	Cadmium 9.4±0.8	Cadmium 94±8		

Table 15 gives a summary of fall-out concentration data at Port Kembla and other Wollongong sites for lead and cadmium. Other metals measured were copper, iron, manganese, zinc but not arsenic. By converting the measured fall-out in units of $\mu g/cm^2$.year or ng/cm^2.day to $\mu g/m^2$.day it is possible to compare historical fall-out data for lead and cadmium with the current dust and metal/metalloid deposition guidelines of TA LUFT (1990, 1991) given in Table 3. This enables a retrospective evaluation to be performed and an idea of the significance of the historical levels of lead and cadmium. Extensive reference is made to the study of lichen bags used to collect fall-out dust at Wollongong (Archibold and Crisp, 1983; Crisp et al., 1984) as an alternative to standard dust fall-out monitoring, but was not adopted following that time.

The comparison of data converted to units of $\mu g/m^2$.day in Table 15 shows:

- **Lead:** Sites near smelters exceed TA LUFT 'Protection of human health and crop land integrity' but only Port Kembla for 'Grassland integrity'. Following the trend of air particulate monitoring during the 1970s and 1980s (Archibold and Crisp 1983) seasonal deposition pattern was observed. Moss bag blank levels were sufficiently low to detect lead and cadmium. Site 37 (Archibold and Crisp 1983) had highest lead (>150$\mu g/m^2$.day for 'Protection of human health' Table 3) compared with Site 45 at September, but at the main highway to Sydney was >3.3 in moss bags.
- **Cadmium:** All sites exceed TA LUFT 'Protection of human health' except when <5.5$\mu g/m^2$.day (Beavington 1977), and Port Kembla (Archibold and Crisp 1983; Crisp and Archibold, 1983) was 94$\mu g/m^2$.day and exceeds 47 times. The contour diagrams of dust fall-out showed that lead deposition extended in a belt across the north central part of the study area in September 1980, rose to a peak in a more confined pattern around the smelter and decreased in April 1981 (Archibold and Crisp, 1983).

Thus, retrospective exposure to heavy metals from dust deposition can be assessed (Table 15) and indicates that people were exposed to elevated lead and cadmium in fall-out when close to the smelter locations. Although emission of lead is not a current issue in Wollongong for human health exposure from inhalation, it is likely that remobilisation of surface soil with lead may be an ingestion issue, particularly for children.

The historical record of lead emissions from the Port Kembla copper smelter and steelworks indicates that the extent of dispersion of air particulates and fall-out that occurred was real.

In 1994, the Lead in Air Working Group of the NSW Inter-departmental Lead Taskforce estimated lead emissions, from the copper smelter at Port Kembla, as being 25,000kg/year as stack emissions and 21,500kg/year as fugitive emissions (Alperstein et al., 1994). These estimates assumed annual production of 44,000 tonnes of cathode copper and 71,000 tonnes of blister copper (CRA Annual Report, 1992); US EPA's AP-42 lead emission factors, allowing for fugitive and process emissions from roasting, smelting and converting; and a control efficiency of 95%. At this time the estimated stack, and particularly fugitive, emissions from Southern Copper were considerably higher than those estimated for Pasminco Metals-Sulphide at Boolaroo (stack: 21,000kg/year; fugitive: 9,000kg/year).

In late 1993, the NSW EPA and Southern Copper agreed on a number of pollution reduction programs (PRPs), which were aimed at achieving improvements related to lead in air, sulphur dioxide stack and fugitive emissions, visible stack emissions and liquid effluent treatment. The lead PRP aimed to reduce the concentration of lead in air in areas adjacent to the smelter site to 1.0$\mu g/m^3$, 90-day average, via a system to capture fugitive lead emissions. Southern Copper proposed an environmental upgrade in conjunction with the expansion of capacity of the smelter and refinery to increase copper production from 80,000 tonnes per year to 120,000 tonnes per year (Dames and Moore, 1994a). Stack and fugitive emissions of lead were modelled separately:

- **Stack:** Lead emissions were estimated to be reduced to 5 tonnes per year, from 21 tonnes in 1992. The maximum three-month average ground level lead concentration was predicted to be

0.004μg/m^3. This prediction used the AUSPLUME model and assumed that the lead concentration was directly proportional to TSP concentration in a ratio of 0.12. This prediction represented a significant reduction in the impact of the main stack emissions.

- **Fugitive:** Lead emissions were estimated to be reduced to 3.3 tonnes per year (at 80% collection efficiency, or 1.7 tonnes per year at 90% efficiency), from 5.0 tonnes in 1992. For an assumed collection efficiency of fugitive emissions of 80%, the environmental impact study (EIS) estimated that the 90-day running average limit of 1.0μg/m^3 (as per the PRP in the license) would be met 84% of the time at the Fire station with a collection efficiency of 90%, it was estimated that the 1.0μg/m^3 90-day running average would be met 96% of the time.

In late 1994, a Commission of Inquiry into the environmental upgrade and expansion of the copper smelter at Port Kembla was called by Southern Copper to address all issues raised during the approvals process for the upgrade. The proposed improvements to capture fugitive sulphur dioxide and lead emission would reduce wind-blown concentrate dust containing lead leaving the site and substantially meet the lead in air goal of 1.0μg/m^3 from the Lead Task Force NSW LMAP for Southern Copper Licence (OCIEP, 1995). Following a management decision later that year, the smelter and refinery was closed and put on a care and maintenance basis.

In early 1996, the Minister for Urban Affairs and Planning issued the Conditions of Consent for the upgrade of the smelter, which included that the lead concentration in ambient air did not exceed 1.0μg/m^3 as a running 90-day average. An application for modifications to the Conditions of Consent with modifications of the technology was submitted, and modified consent conditions were granted in November 1996 for a new operation, Port Kembla Copper Pty Ltd, which included the same lead in ambient air goal. The capacity of the smelter and refinery was now 120,000 tonnes per year of copper cathode with a future review to increase to a possible 150,000 tonnes per year. This was an increase from the previous capacity of 80,000 tonnes per year.

The approval conditions included metal emission limits from the plant equipment, specifically the acid plant stack, the main stack, and the concentrate gantry/conveyor dedusting unit, of "...10 mg/m^3, as the total mass of lead, arsenic, antimony, cadmium, mercury and vanadium and any of their compounds expressed as the element.". This limit applied to each individual piece of plant equipment. A dust management plan must be prepared and submitted to the NSW EPA for approval, and is to detail measures to prevent or minimise all potential dust emissions. Continuous monitoring was required for lead, in addition to several other elements, and strict reporting criteria are laid down in the licence. Excessive ambient lead levels had to be reported within 28 days of the Incident and include meteorological conditions and actions taken to reduce the likelihood of further exceedances. Port Kembla Copper was decommissioned in August 2003 and the 198-metre stack was felled in 2014 (Figure 1; ABC News, 2015).

4.4 Blood Lead Levels

The re-emergence of lead as a public health concern in Australia in 1993 was largely because BLLs, which were once thought to be safe, were now considered to represent a risk for young children. This followed the recognition in North America and Europe that BLLs as low as 10μg/dL among young children may have detrimental effects on intellectual development and behaviour (Alperstein and Vimpani, 1994; Wigg, 2001). In addition, BLL measurement was the only way to assess human health risk from lead exposure at that time. A summary of BLL data for Port Kembla and elsewhere in the Illawarra is given in Table 14.

In June 1993, the NHMRC set a national goal for all Australians to have a BLL of less than 10μg/dL, with a particular urgency in achieving this goal for children aged 1-4 years old (Alperstein et al., 1994). Public health action was required when BLL was >15μg/dL and was 5% at 15μg/dL for children aged 1-4 years old. In December 1996, Schedule 1 Notifiable Diseases BLL >15μg/dL Guidelines Role of Stakeholders.

The Illawarra Child Blood Lead Study 1994 showed the increasing BLL peaked at the age of 2 (arithmetic mean 6.9μg/dL) then declined with age. The proportion of children aged 1-4 years old in Port

Kembla/Kemblawarra with high BLLs was 11% above 10µg/dL and 4.9% above 15µg/dL (Cowie C Eastern Sydney Public Health Unit in ILMAP, 1997). A summary of results from Illawarra blood lead studies carried out between 1973 and 1994 (ILMAP, 1997) shows that since the 1970s blood lead of children has been declining.

The identified difficulty was that neither of these measures adequately evaluates the long term effectiveness of remediation (see also Section 4.5.2). The issues identified by Elias and Gulson (2003) are identified as important to consider in the review. The concept of markers of remediation effectiveness as measured by specific monitoring activities is given (Elias and Gulson, 2003; Table 2, p9). Best practice remediation effectiveness was also discussed and is part of current mine remediation practice (Department of Industry, Innovation and Science, 2016).

The most recent blood lead testing of children in Wollongong took place in 1994 and it was discovered a significant number of children had elevated BLLs and the population was at risk.

Various guidance documents have been released:

- 1994 – A guide to health professionals was provided (Alperstein et al., 1994).
- 1997 – Further comprehensive guidance for healthcare professionals was provided (NSW Lead Reference Centre, 1994).
- 1998 – Illawarra Lead Management Plan 1998-2001 (ILMP, 1998).
- Lead Hazard management in Children's Services (NSW Children's services)
- 2002 and 2010 – Lead Safety Tool kit for Councils (CLP Tool Kit, 2010).
- 2003 – Managing Lead contamination in Home Maintenance, renovation and Demolition Practices: A Guide for Councils (NSWEPA, 2003)
- 2016 – Lead Alert: the six step guide to painting your home, Fifth edition (Australian Government DofE, 2016)
- 2015 – NHMRC Information paper to provide a summary of evidence on the health effects of lead and how these health effects can be minimised (NHMRC, 2015) based on an independent review (Armstrong et al. 2014).

Section 3.5.5 describes that in 2016 the NHMRC recommended that if a person has a BLL greater than 5µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman (NHMRC, 2016). This followed 22 years to have a BLL of less than 10µg/dL. Exposure to lead in Australia has dropped significantly over recent decades as a result of measures restricting the use of lead in paint, petrol and consumer goods (Gulson et al. 2014). As a result, the average BLL in Australia is estimated to be less than 5µg/dL. Investigating the source of exposure where BLLs are greater than 5µg/dL will reduce the risk to individuals, particularly children (NHMRC, 2016).

Measurement of blood lead should be considered when symptoms or health effects associated with lead are present and/or a source of lead exposure is suspected, but is the gold standard for assessing lead exposure. Specifically for lead, a risk assessment technique has been developed to assess the uptake of lead into the blood, which effectively applies an a priori uptake factor to an estimated dose to estimate blood lead concentration (NEPC, 2013 Schedule B4). The US EPA IEUBK model for lead in children is widely known and used in this respect (USEPA, 2004). This approach, with the appropriate justifications, is considered suitable at Tier 2 for assessing risks from lead. The US EPA IEUBK model (USEPA 1994) is now commonly used to predict blood lead concentration from lead ingestion and is permitted for NEPM assessment of contaminated soil, but it is only applicable to young children (NEPC 2013, Schedule B4).

Certain health effects can occur at particular levels of lead in children's blood, following the dose-response of lead by human health risk assessment process described by enHealth (2012). Given the common concern of public health and the management goal of the NHMRC with regard to certain levels of lead in the study area, prediction of blood lead concentrations in children for particular levels of lead exposure from the environment is a crucial approach to enable an integrated understanding of potential community exposure to be assessed from the local mining activities.

A number of models have been developed to predict human blood lead concentrations from exposure to lead (O'Flaherty, 1998, Pounds and Leggett, 1998, US EPA, 2010). The IEUBK model was developed and updated by US EPA and has been in use for about 20 years (USEPA, 2010). Besides the availability and validation capability, the IEUBK model has been widely used in regulatory decision making in relation to children's health risk assessments (Díaz-Barriga et al., 1997; Dong and Hu, 2012).

The IEUBK model was designed to predict blood lead concentration for children from the age of 1 month up to 7 years old since they are particularly sensitive to adverse health effects from lead exposure (USEPA, 2010). Briefly, the IEUBK blood lead modelling for children was undertaken with the inputs of a number of site-specific data. The model is designed to mimic lead exposure from air, water, soil, dust, diet, and alternative sources to predict BLLs in young children. The IEUBK program used in this study is Windows version 1.1 build 11, downloaded from the US EPA website (USEPA, 2010).

Four major components have been incorporated in the IEUBK model (IEUBK, 2007). These are:

1. **Exposure module:** It involves lead concentrations of environmental media to calculate the amount of lead entering a child's body. The lead input parameters are age dependent intake via inhalation and ingestion pathways.
2. **Uptake module:** It relates to the bioavailability of lead containing materials and expressed as the gastrointestinal and lung coefficients to calculate the amount of lead that enters a child's bloodstream with site-specific data;
3. **Biokinetic module:** The biokinetic module of the IEUBK model is a mathematic expression of the metabolism of lead in the human body. It converts the total lead uptake rate from the uptake component into an input to the central plasma-extracellular fluid (ECF) compartment; and
4. **Output (probability variability module of exposure):** It describes the population distribution variability of a certain outcome, for example, blood lead concentrations >10µg/dL.

The IEUBK model inserted default values whenever site-specific information is not used. The additional site-specific parameters that were used for the blood lead simulation for 67 houses at Mount Isa (IEUBK, 2007) are summarised in Table 16 in Section 5.4.1.

Table 16 Summary of blood lead data for Illawarra.

Site/ Sampling period	Lead (µg/dL)	Reference
Port Kembla area schools **1973**	All school age n=88 Geometric Mean 9.9 9.1% > 20µg/dL	Gan et al., (1982); Young et al., (1992) 15,16
Port Kembla area schools **1978**	15 yr approx. age n=74 Geometric Mean 12.9 5.4% > 20µg/dL	Gan et al., (1982); Young et al. (1992) 15,16
Port Kembla area schools **1979**	10-12 yr age n=34 Geometric Mean 13.9 5.9% > 20µg/dL	Gan et al., (1982); Young et al. (1992)
1980	5-17 yr age n=398 (within 1km of smelter and residence within 8km of smelter) Arithmetic Mean 11.9, Geometric Mean 11.3, 2.5% > 20µg/dL	Gan et al., (1982) 16
1989	1-3 yr age n=83 (Pre-schools Port Kembla area, Port Kembla, Cringila and Warrawong) Arithmetic Mean 16.9, 92.8% > 10µg/dL, 26.6% > 20µg/dL 1-3 yr age n=30 (Pre-school volunteers Bellambi/ E. Corrimal) Arithmetic Mean 14.3, 80.0% > 10µg/dL,13.3% > 20µg/dL 1-3 yr age n=113 (Both areas) Arithmetic Mean 16.3, 89.4% > 10µg/dL, 23.0% > 20µg/dL	Young et al., (1990) 17

Site/ Sampling period	Lead (µg/dL)	Reference
1994	1-6 yr age n=198 (Total population residents in Port Kembla) Arithmetic Mean 6.4, 5.7% > 10µg/dL, 1.0% > 25µg/dL 1-6 yr age n=26 (Kemblawarra) Arithmetic Mean 7.1, 15.4% > 10µg/dL, 0% > 25µg/dL 1-6 yr age n=143 (Warrawong) Arithmetic Mean 5.9, 7.0% > 10µg/dL, 0% > 25µg/dL 1-6 yr age n=76 (Cringila) Arithmetic Mean 5.9, 5.3% > 10µg/dL, 0% > 25µg/dL 1-6 yr age n=443 (All areas) Arithmetic Mean 6.2, 6.8% > 10µg/dL, 0.5% > 25µg/dL	Kreis et al., (1994)
National average	1-4 yr Age Number of children n=1575 Arithmetic Mean 5.8, 7.3% > 10µg/dL, 0.3% > 25µg/dL	Donavan (1995) 5

5. Review of Literature on Comparative Sites

5.1 Australian Sites

5.1.1 Lake Macquarie / Boolaroo (reference sites)

The relationship of BLLs of people with exposure to various lead sources has been studied at lead smelting sites all over the world (ATSDR, 2004). Previous studies reviewed by the Agency for Toxic Substances and Disease Registry (ATSDR) provided evidence of the high risks for children living in the vicinity of a lead smelter from the ingestion or inhalation of lead from (i) airborne emissions; (2) lead-bearing soils; (3) dust (including household dusts, entrained dusts by wind or human-oriented events); (4) water supplies; and (5) food. Studies on high concentrations of lead in the environment resulting from stack emissions, fugitive emissions (Ohmsen, 2001) and the use of slag at Lake Macquarie, NSW (Morrison, 2003) showed that a range of artificial lead compounds may be present in environment close to mine sites and lead processing facilities (Noller and Unger, 2016).

Apart from a limited study of cadmium, lead and zinc uptake in home-grown vegetables in gardens at Boolaroo houses (Kachenko and Singh, 2004), there appears to have been no comprehensive study of home-grown vegetables since that time. The limited results of Kachenko and Singh (2004) showed that predominantly leafy vegetable samples (n=40) exceeded the ML food standard guidelines for cadmium and lead at that time. Thus lead and other heavy metal levels accumulated in home-grown vegetables from residential houses at Boolaroo.

A graph of BLL at various smelters over time has been prepared by Interior Health (2015) to put the Trail BLL in context with other BLL data (Figure 9).

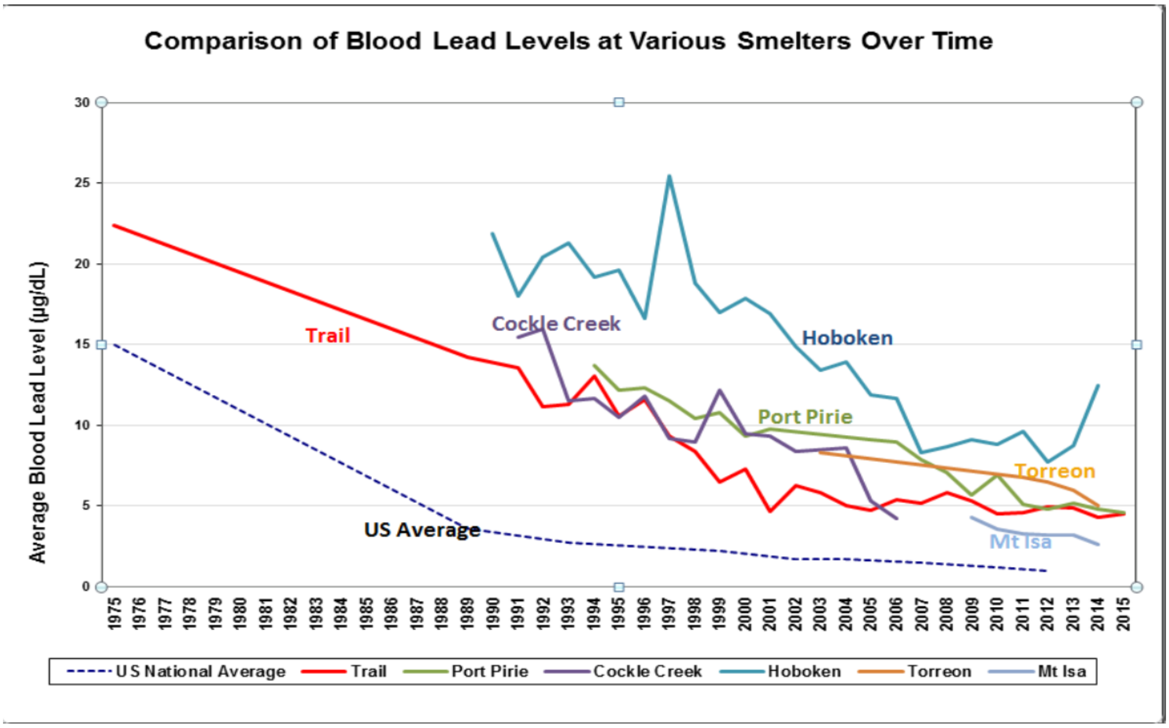


Figure 9 *Comparison of BLLs at various smelters over time (Interior Health 2015).*

Willmore et al. (2006) undertook a study using a geographic information system (GIS) to map soil lead levels and BLLs over time within the Lead Abatement Strategy (LAS) area. The study showed the soil lead levels in and around the Boolaroo smelter site in 1992 within which the Nominated Properties were located based on the lead contamination survey grid. The overall pattern was aligned with emissions from the smelter then improvement in BLL when emissions ceased. These images showed the relationship between lead emission distribution from the former Boolaroo smelter and soil lead with BLL and changes over time in BLL associated with the LAS and elimination of emissions due to the shut-down of the smelter. The relative importance of each source of lead cannot be quantified on the basis of these data alone. Site investigations of soil lead concentrations were undertaken at Boolaroo in 1992 through to 2003.The practice of free access to smelter waste was promoted as it was deemed to be non-hazardous.

A number of blood lead surveys were accompanied by other studies of soil. In particular, changes in the BLLs were apparent following changes in smelter design. The most recent sampling program for North Lake Macquarie (NLM) (HNELHD, 2015) has confirmed the downward trend in BLLs. It is noted that the Hunter New England (HNE) Population Health reminded general practitioners servicing this area to continue to check BLL of children less than five years of age with factors for lead exposure. Any future screening to verify that BLL remain below the investigation level should take care to avoid sample bias identified in other studies. For example, a poor voluntary representation from those who perceive the risk to be low and therefore not engaging with screening. The timing of the screening is likely to be important (summer versus winter) and the program may need to be mindful of cultural aspects which have led to different results in BLL in indigenous and non-indigenous community members elsewhere.

The 2015 study at NLM (HNELHD, 2015) was undertaken on 72 children who were between six months and less than five years of age in winter at a time when there is less outdoor play and less exposure to dust due to moist climate conditions. This was the first cohort of children to be screened who had grown up in the area since the closure of the smelter in 2003. The 2015 study assessment also corresponded with the NHMRC releasing its advice that adverse conditions can occur in BLLs greater than 10μg/L, but there was insufficient evidence to determine whether health effects occur at levels greater than 5μg/L but less than 10μg/L (NHMRC, 2016). It was considered that the basis for the reduction of BLL from the previous North Lake Macquarie survey in 2005/06 was that the closure of the smelter resulted in greater than 80% reduction in lead in air levels between 2002 and 2004.

Lead contamination assessments were undertaken on 1,226 accepted properties with 437 properties recommended for abatement work while 359 have been completed since the closure of the smelter. However, 731 property owners did not accept the offer for testing. Residents need to remain aware that potential sources of lead still exist such as pre-1970 paint which may be a risk during any home renovations (Gulson et al., 1995). While the BLLs show no need to investigate further, there may be a need to confirm that BLLs do not increase above the health investigation level in the future, for example in five years. The remediation of all properties surrounding the smelter site is not yet complete and further examination is needed to determine if measures are adequate. There is as yet, no completion of remediation that has been validated for soil contamination.

It is in the context of experience and outcomes from the studies cited above that enables the following observations to be made. This comment posed a question for NLM on the site specific nature of soil ingestion rates (van Lindern et al., 2016) and whether there is a probabilistic distribution of BLLs in a population that is sufficiently representative to identify if remedial attention to any site is needed. The Butte, USA evaluation study (Schoof et al., 2015) shows the importance of conducting representative long-term evaluation of BLL in children.

In addition to the significance of dust ingestion rates, investigations of a single acidic extraction show that the slag at NLM easily releases lead. This property of slag poses a long-term threat because of a lack of inertness of the slag (Morrison and Gulson, 2007). An important detail to recognise in the context of understanding population BLL at NLM and soil lead concentration is that gastric-only bioaccessibility measurement will over-predict bioavailability of lead and should be confirmed by using the USEPA IEUBK model to predict blood lead increase from ingestion of slag dust or soil by children. Lead uptake occurs via the intestinal phase and not from the gastric/stomach phase where solubilisation occurs. Site specific clean up levels can be derived from IEUBK model BLL predictions and be supported by site-specific measures of total and bioaccessible lead (Noller et al., 2017).

The concept of a lead budget is posed as a useful tool to estimate the total lead to the environment and to map its fate (Figure 10). As remediation is undertaken, the budget can be updated to reflect the removal and safe encapsulation of a proportion of that lead. This could help to quantify the significance of residual un-remediated lead contamination in the environment and whether it requires further investigation to verify its significance from a human health perspective.

A range of data exists in reports concerning the NLM location which could help to develop such a 'lead budget'. One such source is shown in Figure 10 where lead in mass emissions were estimated (EPA, 1999; Dames and Moore, 1994b; PMS, 2000 in Morrison, 2003).

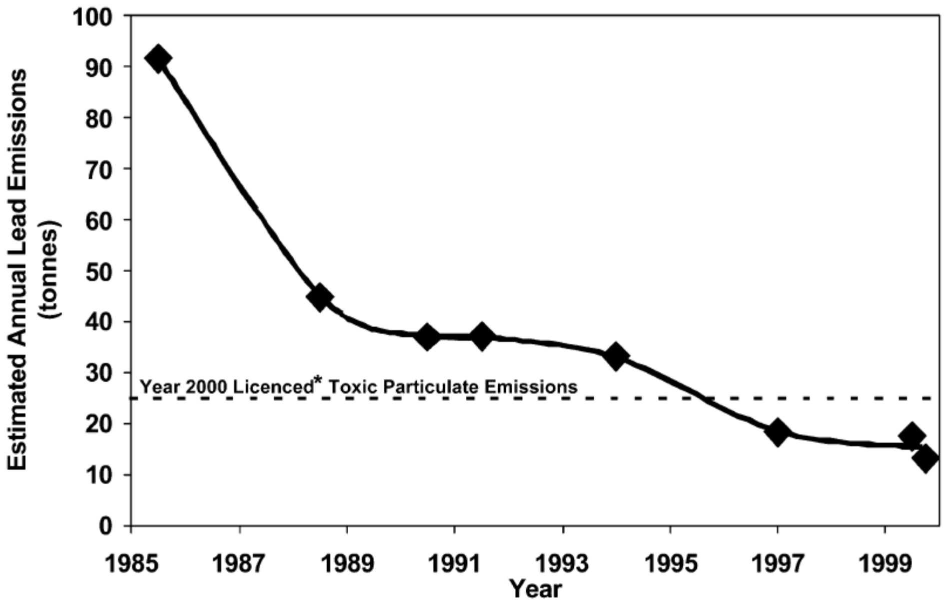


Figure 10 *Estimates of smelter lead mass emissions in the period 1985/1986-2000 (EPA 1999; Dames and Moore, 1994b; PMS 2000; in Morrison, 2003).*

An estimate of the volume of remaining lead in the environment at NLM may be needed in order to prepare appropriately for planning and designing future repositories of lead-contaminated materials. A plan for a future repository as residual black slag from playing fields, road sides and other locations was considered a necessary step. This literature review does not report on the progress toward developing such a repository for these wastes.

From studies of lead in the aquatic, estuarine and lacustrine sediments at NLM it was possible to estimate the volumes of lead-contaminated sediments; however, this required further study and updated data was required considering the sediment mobility in Cockle Creek and Bay. Where cores were taken there were indications of historic contamination with less contaminated sediments overlaid.

River sediment coring may be required further upstream from Lake Macquarie up into Cockle Creek to define the risk of exposure of contaminated sediments through natural fluvial processes including extreme events. It is not clear if there were institutional controls for lake sediments to minimise their re-disturbance and contamination. The review found some studies of the food chain about 13 years ago (Batley, 1992) and occasional examination of lead and other metal accumulation in fish and other aquatic species (Alquezar et al. 2006; Roach et al. 2008). From five fish species collected in Lake Macquarie, higher lead concentrations were found in samples from Cockle Bay when compared to reference estuaries (Roach et al., 2008). In addition, the magnitude of the lead bioaccumulation was greatest in bottom-dwelling species that burrow into the sediment seeking food. Further studies are required to investigate the pathways through the food chain to humans (via fish and shellfish) and also to study bioaccumulation. An adaptive management approach as a whole to ensure links between management objectives, management options, performance benchmarks and quantitative monitoring indicators for habitats and ecological communities. In addition, an understanding of speciation of metals is essential to characterise risk more effectively and ascertain the effectiveness of potential remedial actions: 'Speciation information should be collected and examined to elucidate the potential for metal transport and the effect of transformation processes on the fluxes and bioavailability of metals' (NRCNA, 2005).

Remediation plans at Boolaroo were considered to cover a range of issues and variables:

- Government policy regarding mechanisms for decisions and supporting funds.
- Company policy / viability to survive the economic impact of remediation cost.
- Community relationship with participation in decision-making and expectation of improvement to living conditions and benefits.
- Topography that will influence the dispersion plume being on flat land, in a valley or a slope.
- Climate whether hot dry or cold wet climate will influence dispersion characteristics.
- Land use whether there is compatibility with the soil lead remediation if they increase human exposure.
- Population density – not all residents will receive benefits of remediation.
- Metal species – the finding was that there was some information available about different forms of lead and their harm but the symposium did not have sufficient information to clarify this issue.

Elias and Gulson (2003) identified the following goals:

- Protect human health, including both children and adults.
- Restore the environment.
- Retain the social fabric of the community.
- Maintain viability of the industry.

Possible options to consider align with the available examples:

- strategies for remediation discussed were from the key sites considered below; and
- evaluation of remediation effectiveness considered collective experience.

According to Elias and Gulson (2003) the key statement of measure of remediation success is the reduced risk to lead exposure and this can be assessed in two ways:

1. a reduction in blood lead concentrations of the most susceptible subpopulation of residents (usually children); or
2. a reduction in lead concentration of soil and dust which were the major pathways of lead exposure.

5.1.2 Port Pirie

The primary lead–zinc smelter in Port Pirie, South Australia (SA), currently operated by Nyrstar NV, is the major source of lead contamination in that city (Maynard et al., 2005). The smelter has been operating since 1889 and has the capacity to smelt 300,000 tonnes of ore concentrates annually and to produce approximately 230,000 tonnes of refined lead. Lead levels in airborne materials, dust falls, surface soils, and rainwater tanks were assessed (Wilson et al. 1986; van Alphen, 1999). The important factors identified were age, pica habits, ingestion of paint and soil or dust through inhalation pathways, and the success of decontamination programs in some areas in Port Pirie.

Lead exposure and absorption by children in Port Pirie have been reviewed, showing that children, in particular, from the population in Port Pirie have been exposed to lead from several sources and via multiple environmental pathways (Maynard et al., 2005). The highest concentrations of lead in surface soil and air at Port Pirie were found within 2km of the smelter and the concentration decreased with distance from the smelter (Landrigan, 1983). Lead emitted from the smelter reached children at Port Pirie by a variety of pathways. Two major routes were identified: (1) inhalation of airborne lead; and (2) ingestion of lead deposited from air in dust and soil (Landrigan, 1983). The relative importance of these two routes varied with the age of children. Ingestion was not particularly important for older children, whereas younger children, because of their normal hand-to-mouth behaviour, were at risk of exposure by both routes (Landrigan, 1983).

Thus airborne deposition of lead-contaminated dust appears to be the important pathway of contamination for children in Port Pirie (Maynard et al., 2005; van Alphen, 1999). BLLs and spatial air lead distribution between two high-risk sites near the smelter were compared (Calder et al., 1994). Although the results showed a progressive decline in the proportion of children above the recommended BLL, an analysis of the blood lead data by risk area in Port Pirie suggested that the reduction in BLLs appeared to be greater in the low risk area, farthest from the probable source of continuing contamination, compared with high risk areas in the northern part of Pirie West, relatively close to the smelter (Calder et al., 1994). In addition, the two high risk areas showed different patterns of reduction from each other. Air monitoring data clearly showed that the air lead levels declined rapidly with distance from the smelter and associated works in Port Pirie (Calder et al., 1994). These results indicated the significance and importance of air pathway to the children's BLLs in a community near a lead smelter facility. Dust at Port Pirie was transported mainly through wind, primarily re-entrainment, from the lead smelter and new fugitive emissions. Human, vehicle and material handling activities also assisted dust to rise (Maynard et al., 2005).

The prevalence of elevated BLLs in children in the 3-5 year age group (16.1% with >30µg/dL; mean 22.0µg/dL) from a total of 1,239 children at Port Pirie in 1982 was more than three times higher than for the older 6–14 year age group (5.0% with >30µg/dL; mean 17.9µg/dL) (Landrigan, 1983). From a total of 230 children in the 3-5 year age group exceeding a BLL of 30µg/dL, the number of children from the high risk area was 32 out of 78 examined (41.0%) compared with 5 out of 152 examined (3.3%) from the other (low risk) areas. Thus there was a clear connection with blood lead >30µg/dL from the high risk area.

Positive associations of BLLs of two-year-old children with surface soil lead concentrations also suggested a strong influence from ingestion of soil-borne dust on blood lead concentrations in early childhood at Port Pirie (McMichael et al., 1985).

The distribution of elevated soil lead concentrations around the smelter at Port Pirie was roughly concentric. The mean dust lead concentrations in the homes of 23 children with elevated BLLs examined in the control case study was 4,470mg/kg (Landrigan, 1983). Rainwater tanks had two contributory sources of lead: (1) lead dust; and (2) lead paint from roofs and gutters. As many as 47.5% of the rainwater samples collected contained more than WHO guidelines for lead concentrations in drinking water (0.05 mg/L) (Landrigan, 1983).

Lead decontamination programs have been conducted in Port Pirie since 1984. Abatement programs involved identifying children with elevated BLLs, decontaminating houses, treating soils, general city greening, family and community education, and support (Calder et al,. 1994). The general strategy developed for the decontamination program was based on the premise that the major source of lead in Port Pirie was a substantial lead sink in the city, from which lead-contaminated dust readily re-entrained, although substantial contributions also came from lead-based paint and contaminated rainwater. The blood lead monitoring program showed the most significant decrease in children's mean BLLs were in areas that were remote from the smelter (Calder et al., 1994). An intensive study of newly borne infants from Port Pirie through to 36 months of age confirmed that ingestion was the most likely route for 95% of the dose of lead based on hand lead load and related measurements compared against BLL (Simon et al., 2007).

Elevated BLLs in children was initially considered to be due to ingestion of lead-based paints (Chisolm and Harrison, 1956). It was not until the mid-1970s that environmental lead and its possible effect on human and particularly young children's health was investigated extensively. Lead-contaminated dust and soils have been increasingly recognised as potential sources. Lepow et al. (1975) investigated into sources of lead in the environment of urban children and found that the ingestions of lead-contaminated dirt and dust by children with pica could not only increase elevated BLLs in the children but also maintain BLLs at 40 to 60µg/dL. Several case studies from both overseas and domestic are critically reviewed and compared (Table 17).

***Table 17** Summary of selective environmental studies.*

Site	Operation time	Sampling time	Materials	Environmental situation	Notes
Mount Isa, Queensland, Australia	1931 - present	1997	soil	3.4-456mg/kg	Parry (2000)
		1997 - 1998	air PM_{10}	4-27 ng/m^3 (TSP 1 year)	Parry (2000)
Port Pirie, South Australia	1889 - present		air lead	Air lead decrease from 3.18µg/m^3 (1974) to 0.6µg/m^3 (1982) (TSP 1 year))	Landrigan (1983)
		1981	dust fall	6.61mg/m^2/d (1.4km) and 1.4mg/m^2/d (3.0km)	Landrigan (1983)
			soil	4-2,100mg/kg	Landrigan (1983)
Broken Hill, New South Wales, Australia	1885 - present	1994 - 1996	entry floor wipes	Pre-remediation 3,775-7,535µg/m^2 and ten months following remediation 155-304µg/m^2	Boreland and Lyle (2006)
			internal window sills	Pre-remediation 301-677µg/m^2 and ten months following remediation 1,387-2,494µg/m^2	Boreland and Lyle (2006)
		Not specified	vacuum dust	40-12,100mg/kg	Gulson et al. (1995)
		1992	soil	Broken Hill City Council survey geometric mean range 245-2305 mg/kg (n=246); No differences in lead isotope ratios for bulk soil and soil fine fractions (38-53µm)	Boreland et al., 2002; Gulson et al. (1995)
Boolaroo, New South Wales, Australia	1897 - 2003	1991	soil	Mean 1,430mg/kg (20-2,1460mg/kg)	Dalton and Bates (2005)
		1991	carpet dust	Range 631 -2,328mg/kg	Dalton and Bates (2005)
		1991	air	0.1µg/m^3 (TSP 1 year))	Dalton and Bates (2005)
El Paso, Texas, USA	1887 - 1985		air	92µg/m^3 (1974) to 0.13µg/m^3 (1994)	Landrigan (1975)
		1994	soil	1,791mg/kg (geometric mean)	Landrigan (1975)
Trail, British Columbia, Canada	late 19th century		air	1.1µg/m^3 (1996) to 0.28µg/m^3 (1998)	Hilts (2003)
Midvale, Utah, USA	1910 - 1971	1993	soil	Mean soil concentration >500mg/kg	Lanphear et al. (2003)
Bunker Hill, Idaho, USA	late 19th century	early 1980s	soil	Mean soil concentration >2,500mg/kg	Sheldrake and Stifelman (2003)
Port Kembla	1908 - 2003	1989	soil	Mean 157 mg/kg n=164	This report
		1990	soil	<1000 mg/kg n=15	
		1993	soil	<600 mg/kg n=164	
		1993	dust	Mean 1185mg/kg 503-2161 mg/kg	
		1984	air	0.381µg/m^3	
		2015-2019	air	Mean 0.021 - <0.011 µg/m^3 monthly average of 24 hr collections	
		1992	dust fall	1040 µg/m^2.day	

In 2012 an extensive soil sampling survey from 353 sites was undertaken to confirm the historical lead contamination in soil and determine if the SA Health abatement program needed to be modified (SA Health, 2013). The survey also sought to identify if the gradient of lead concentrations extended across Port Pirie city. The results indicated that the Port Pirie Regional Council's footpath remediation strategy reduced lead contamination of footpaths. SA Health recognised that sites exceeding HIL lead concentrations that are accessible to the public would require further attention. Only total lead concentrations were measured and there was no testing for bioaccessibility (Ng et al., 2015) which is applicable as a step in a Tier 2 assessment (NEPC, 2013; Schedule B4).

The geographic clustering of children with elevated BLLs in Port Pirie are closest to the lead smelting facility (Landrigan, 1983). This fact, accompanied with geochemical results, strongly indicated that the lead smelter was the major source of lead contamination at Port Pirie. The prevalence of elevated blood levels in children aged three-to-five-years old was found to be more than three times higher than older age groups. Five behavioural factors of 16 were found to be distinctively associated elevated BLL. The relative importance of environmental and behavioural factors as determinants of children's BLLs is discussed by Landrigan (1983) (Table 18). Similar concerns of behavioural factors were identified (Wilson et al., 1986). The highest concentrations of lead in surface soil and air at Port Pirie are found within 2km of the smelter and decrease with distance (Landrigan, 1983). Lead emitted by the smelter reaches children at Port Pirie by a variety of pathway; two major routes have been identified as (1) inhalation of airborne lead and (2) ingestion of lead which precipitated from air to be deposited in dust and soil (Landrigan, 1983).

Table 18 *Relative risk of children's behaviour in Port Pirie.*

Factor	Relative Risk
Residence in polluted area near smelter	12.4
Placing objects in mouth	4.0
Nail biting	2.3
Dirty clothing	2.7
Dirty hands	3.0
Eating lunch at home	2.2

The fact that positive association of BLLs for two year old children with surface soil lead concentrations suggested strong influence from soil borne dust blood lead concentrations in early childhood at Port Pirie (McMichael et al., 1985). Further lead decontamination programs have been conducted since 1984 with a ten year mandate. The abatement program involves identification of children

5.1.3 Broken Hill

History of mining

Broken Hill, NSW was founded in 1883 to commence mining of the 'line of lode,' the world's largest and richest silver-lead-zinc (Ag–Pb–Zn) mineral deposit (Solomon, 1988). More than 200 Mt of ore have been mined since the discovery of ore in 1883 (Morland and Webster, 1998). Smelting of ore was conducted at Broken Hill to extract silver, lead and zinc, including the production of waste, between 1886 and 1897. Broken Hill was very isolated and water and fuel for the smelters were difficult to obtain. The demand for resources led to widespread environmental degradation, resulting in erosion and periodic dust storms over Broken Hill. Following 1897, smelting was relocated to Port Pirie due to a lack of local fuel sources (Woodward,1965; Solomon, 1988). An estimated 11,000-18,400t of lead was emitted by smelting activities between 1886 and 1897 (van Alphen, 1991). A boom-time mentality and the lack of planning and environmental laws decades ago have left an environmental legacy that is still being dealt with (Balding, 1997).

History of Lead poisoning in Broken Hill

Since the Broken Hill Proprietary Company Limited was established in 1885, lead poisoning had been evident among early miners and their families (Lead Report, 2018). Despite this evidence, lead poisoning was seen mainly as an occupational rather than population health issue. Mining also took its toll on the residents of Broken Hill and lead poisoning among the early miners and their families was common. This presented as clinical plumbism with anaemia, nephropathy arid encephalopathy, and sometimes resulted in death (Lead Report, 2018). The incidence of lead poisoning was estimated to be as high as 2 per 100 miners in 1895. A committee convened by the NSW Government in 1892 heard that the high infant mortality rate in Broken Hill might have been attributable to lead poisoning (Lead Report, 2018). Although lead exposure among miners is no longer a major health issue, lead toxicity in children emerged as a major public health issue over the past decades.

History of Lead screening initiative

A survey of school-aged children in 1982 found all had BLLs below 40µg/dL, the then level of concern in Australia (Lead Report, 2018). Local concern was increased in Broken Hill by the recommissioning of open-pit mining in the centre of town, a drought in the late 1980s and the birth of three babies with delayed visual maturation (usually caused by exposure to high lead levels in utero) between 1988 and 1990 (Gulson et al.,1998).

A 1991 survey of 1-4 year-old Broken Hill children found that 86% had BLLs of 10µg/dL or above (the level of concern at that time) and that 38% had very high lead levels of 20µg/dL or above (Woodward-Clyde, 1993). In 1991 the first comprehensive testing undertaken on children under five years of age revealed that more than 80% had BLLs over the current guideline level of 10µg/dL.

Since 1991, parents/carers in Broken Hill have been offered voluntary blood lead screening for children under the age of five years old (Lead Report, 2018). From 1996, newborn umbilical cord blood has been tested to determine the impact of lead transfer from the mother to the child.

In 1994, the NSW State Government funded a lead management program to address the situation of high lead levels in Broken Hill children (Lyle et al., 2006). The Broken Hill Environmental Lead Centre was established in 1994 by the NSW Government (Lead Project, 2018). The centre developed a strategy with five elements: (i) education and awareness-raising; (ii) clinical monitoring; (iii) environmental testing of children's home environments (lead in paint, dust and soil); (iv) remediation of children's home environments (where appropriate); (v)and the remediation of contaminated public land. Activities included an active research and evaluation project coupled with extensive land remediation work which began in 1997, with final works completed in 2003 and 2004. This funding allocation also included health promotion campaigns, active case finding and management, remediation of land, planting of hardy native shrubs and grasses, and urban development of vacant blocks and cemented footpaths (Boreland et al., 2008).

Outcomes of Lead screening program

The Broken Hill Environmental Lead Centre's programs, with extensive site works undertaken by mining companies to control fugitive emissions, have been a major cause of the decline in average of the BLL in the population aged under five years in Broken Hill. The average BLL dropped from 18.4µg/dL in 1991 to 10.8µg/dL in 1996. At this time, the number of children exceeding the 10µgl/dL guideline for blood lead in Australians determined by the National Health and Medical Research Council (NHMRC) was 44% (Figure 11).

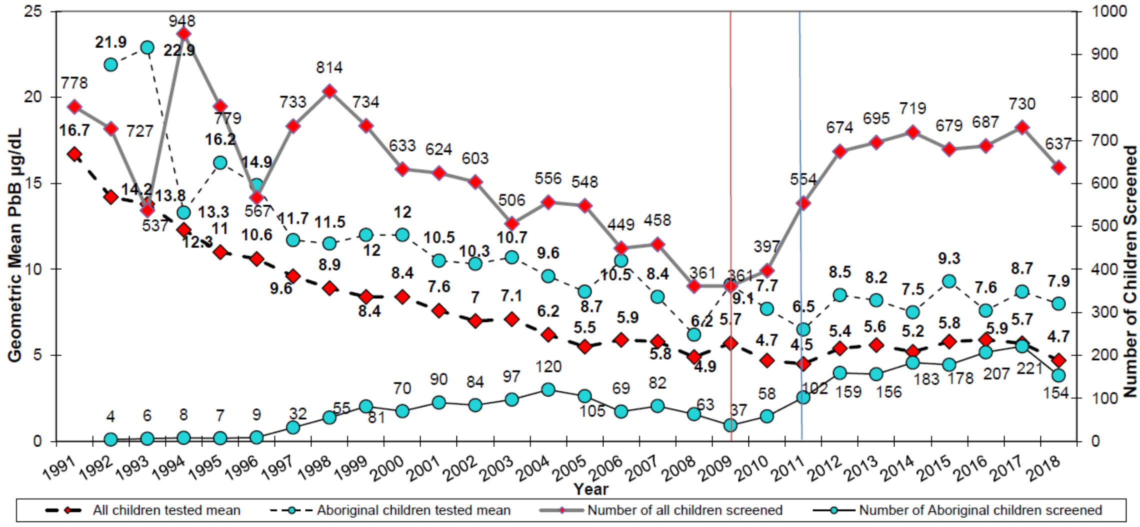


Figure 11 *Population age-sex standardised geometric mean blood lead concentration and number of all children and Aboriginal* children screened aged between 1 to <5 years in Broken Hill, 1991-2018.*

*Source: Lead Report (2018 ; Figure 6 p22). The red vertical line indicates the point in which both venous and capillary samples are reported together and the blue the inclusion of screening with childhood immunisation. *There were no recorded tests for Aboriginal children in 1991. Standardisation applied only from 1997 onwards, due to small sample size. Additionally, Aboriginal status was only consistently collected from 1997. The geomeans reported since 2016 cannot be compared to previous geomeans as recording of results and use of the capillary method affects geomeans.*

The effort of the Broken Hill community and the NSW Government resulted in a major reduction of BLLs among young children during the 1990s. But it was realised that participation in screening was falling, more than just reflecting the decreasing population, and BLLs were starting to plateau (8-10µg/dL).

The Broken Hill Community Lead Reference Group, founded in 2008, is a multi-agency group led by the Broken Hill City Council. It consists of community interest groups, mining companies and government agencies representing and advocating for the Broken Hill community regarding lead. The Broken Hill Lead Health Steering Committee, also founded in 2008 (and reconvened in November 2018), was constituted to focus on the health issues related to elevated BLLs in children. Both groups have an interest in minimising the impact of lead exposure whilst maintaining a viable mining industry in Broken Hill.

From July 2015, following significant planning and advocacy, the NSW Government funded the Broken Hill Environmental Lead Program (BHELP) over five years (Lead Report, 2018). The Broken Hill Lead Steering Committee is made up of representatives from NSW EPA, Far West Local Health District and the Broken Hill Lead Reference Group. With this NSW government funding BHELP came additional promotion around prevention of lead poisoning and updated Broken Hill lead website.

NSW Health set the blood lead notification level at 10µg/dL from 1993, however, in May 2015, the NHMRC (2015) completed an evidence review and issued a statement for a revised blood lead notification level of 5µg/dL. The evidence review found an association between levels less than 10µg/dL and health effects. The effects include: reduced Intelligence Quotient and academic achievement in children; behavioural problems in children; a delay in sexual maturation in adolescents and increased blood pressure in adults (Lead Report, 2018). Although the population mean for children aged 1 to <5 years was below the notifiable level of 5µg/dL, nearly half (49%) of the population is above this level. The non-Aboriginal population, with a mean of 4.0µg/dL, had 39% of children with BLLs ≥ 5µg/dL. Even with a geomean of 2.7µg/dL, children aged < 12 months still had 15% with a notifiable BLL.

Progressive reduction of lead in houses

In Broken Hill, the prevailing argument had been that current mining operations were not the dominant source of lead contamination compared to other sources (Woodward-Clyde Pty Ltd., 1993). Stable lead isotope composition analysis conducted in the early 1990s showed that childhood blood lead in Broken Hill was mainly derived from the local orebody, but some individuals had a dominant source (up to 50%) of Pb from gasoline or paint at the time (Gulson et al., 1994a). The application of lead flux measurement and passive wiping methods in houses have been very effective in understanding lead distribution inside houses (Gulson et al., 1995). Despite extensive research examining the lead problem at Broken Hill, there remained a knowledge gap regarding whether current mining emissions affect childhood blood lead exposure risk in the city.

This has important implications for the effectiveness of remediation programs aiming to reduce Pb exposure in Broken Hill. Yang and Cattle (2015) reported that Broken Hill soil Pb, an indicator of legacy emissions, and its bioaccessibility were elevated. According to the Yang and Cattle (2015) study, soil lead appeared to be the main contributor of childhood blood lead concentrations according to Integrated Exposure Uptake Biokinetic (IEUBK) modelling. Moreno et al.(2009) found that particles < 10µm (PM_{10}) collected from the surrounding area of Broken Hill were sourced from local desert soils, indicating that soil resuspension processes are active and an important component of particulate sources. In addition, contemporary atmospheric Pb in Broken Hill remain elevated, lead based paint to blood lead exposure is not fully controlled.

Current (in 2019) environmental exposure to lead appears to be related more to historical mining and mine management practice than current activities (Dong et al., 2019). Lead contamination of the broader community arises from sources including: naturally occurring surface ores; past smelting and mine waste management practices; entrapment of dust in linings of domestic buildings and the re-entrainment over time of this dust back into the living spaces; open-cut mining activities (undertaken in the centre of Broken Hill city until the early 1990s); the handling and transportation of ore concentrates; dust from tailings dams and the contamination of open spaces; off-site use of mining by-products for private use, such as landfill and driveways; and carry-home occupational health problems, such as contaminated dust in clothing and in vehicles. However, environmental health investigations and programs managed jointly by the NSW Health Department and the NSW EPA in consultation with Broken Hill Council, industry and the community have been very successful in reducing the impact of environmental lead contamination in Broken Hill (Lead Report, 2018).

Lead monitoring in Broken Hill has been business as usual since 1991. Although the population mean lead levels for children under the age of 5 are below 5µg/dL, there is still opportunity to implement community initiatives to increase the number of children with BLLs below 5µg/dL as opposed to the population mean. There is a need for ongoing work to reduce BLLs for all children in this age group in Broken Hill, particularly those with an Aboriginal background. Hence, maintaining the child blood lead monitoring program and having responses for the outcomes determined will be an important public health initiative in Broken Hill.

The lead monitoring and evaluation team has identified as necessary the establishment of targets to assess the improvements made in reducing lead blood levels (Lead report, 2018). Two measures are being recommended based on literature:

1. Measure 1: greater or equal to 80% of children aged 1 to < 5 years with a BLL <5µg/dL.
2. Measure 2: lower than or equal to 150mg/kg mean topsoil Pb concentration across Broken Hill (USEPA's Integrated Exposure Uptake Biokinetic (IEUBK) model) (Yang and Cattle, 2015).

5.1.4 Mount Isa

A geochemical survey on metals and metalloids (Cd, Cu, Pb, Zn, As and S) in soils, PM_{10} aerosol and surface water in the vicinity of Mount Isa has been conducted by Parry (2000). Both concentration of elements and lead isotopes were analysed. Soil samples from 42 sites around Mount Isa out to a distance of more than 100km were collected, but mostly west of the copper smelter. The topsoil (0-2 and 0-10cm) heavy metals and arsenic concentrations were highest adjacent to the mine and smelters, and decreased exponentially with distance from the smelter in a north westerly direction (downstream of the wind). XRD analysis of clay separations indicated that all near surface soils except for the cracking clay soils (smectite dominant) were kaolinite, illite and goethite dominant, sometimes with small amounts of smectite. There are slight differences showing $^{208}Pb/^{206}Pb$ decrease from 2.2 to the mean level of 2.05 with increasing distance from the copper smelter. Samples from four PM_{10} aerosol samples sites were collected and analysed from October 1997 to September 1998. Metal concentration and lead isotope ratio data were compared for PM_{10} aerosol samples from three sites, all of which are north-west of Mount Isa mineral processing facilities. The mean PM_{10} concentrations of lead from these three sites decreased with distance from the mineral processing facility, 27ng/m^3 (20km from copper smelter) to about 4ng/m^3 (100km from copper smelter). Significant seasonal differences were monitored not only in lead concentration (higher in dry season) but also in lead isotopic ratios ($^{208}Pb/^{206}Pb$ were 2.1370 and 2.0351 for PM_{10} samples 20km north-west of the copper smelter during dry and wet season, respectively, compared with 2.2150 for Mount Isa ore-derived lead). Surface water samples were also collected as close as practically possible to soil sampling sites (28 sites) in December 1997 and March 1998, early and late wet season, respectively. Mean filtered (<0.45µm filterable) lead concentrations show slight decrease from December to March, which is reasonable during the wet season in Mount Isa (Parry, 2000).

One ceiling dust and four high volume air filters collected from Mount Isa were analysed for lead isotopic compositions using thermal ionisation mass spectrometry (Gulson et al., 1997a). Under two-component mixing model (lead from mine and petrol), Gulson et al. (1997a) indicated that Mount Isa mine source of lead contributed 14-41% for high volume air filters and 86% ceiling dust based on the results of lead isotope ratios (Gulson et al., 1997a).

Sadler et.al. (1990) conducted a complete study at St Paul's Lutheran Church, Mount Isa. Surface and depth soil samples, roof gutter and vegetable samples were analysed for heavy metals and arsenic. Lead, zinc, and copper had been recorded as exceeding levels for all the sites but with no obvious correlation between the presence of one trace element and another. Unlike the results from the study in the west of the city (Parry, 2000), Sadler et. al. (1990) found that depth soil samples contained higher levels of heavy metals than did the corresponding surface layer at St Paul's Lutheran Church site, which was around 3km from the copper/lead smelting facilities. Evidence of significant movement of lead and other heavy metals in the airborne particulates was also provided, with 9,900mg/kg, 4,000mg/kg and 890mg/kg lead found in roof gutter, church cooling system and on indoor furniture, respectively.

Runoff in the Leichhardt River is captured downstream in Lake Moondarra, which is 19km downstream of Mount Isa city. The water in the lake is naturally filtered via a lagoon-reed bed system for potable purposes by the residents of Mount Isa city. In addition to the mineral processing activities on the western edge, the town disperses and reuses its treated effluent on local paddocks and gardens on the other edge of the city, with some of it being discharged into channels that drain into the Leichhardt River, upstream of Lake Moondarra. These present sources were not affecting drinking water quality according to a recent report (Noller et al., 2012).

The solubility of lead and lead minerals is controlled by pH of water (Chester et al., 2000). Generally, lead becomes much less soluble with increasing pH (>6) and alkalinity of the water (Chester et al., 2000). A neutral and slightly alkaline pH of the water in the Leichhardt River prevents dissolution of trace metals into the water, particularly for lead (Noller et al., 2012). The potential environmental risk and impact of trace metals affecting Leichhardt River water and sediment in Mount Isa were examined (Noller et al., 2012). The tissue of seven fish from Lake Moondarra were analysed for their cadmium, copper, lead and zinc concentrations. Total concentrations of metals and metalloid in water and sediments from Leichhardt River indicated certain levels of exceedance when compared with guidelines (ADWG, 2004; ANZECC/ARMCANZ, 2000; QWQG, 2009). Aquatic toxicity assessments in water and sediment showed various effects at different locations and generally there were no toxic effects to aquatic test species for background sediments (Noller et al., 2012).

Diet as a contribution to BLL has been recognised for many years and since the lead contaminant is either dissolved or finely divided and suspended. The transfer from the lead source into the blood would be expected to be more efficient when there is either complete dissolution of a solid source in the stomach or sufficient transfer of inhaled lead-bearing particles in the lungs. Lead concentrations in food and drinking water are regulated according to the recommendations of various authorities such as FSANZ (2004) and ADWG (2004). Diet is generally a minor contributor to blood lead in the Australian context (Gulson et al., 1999; Gulson et al., 1997b) and universal distribution of lead from foodstuffs in a community is expected. Thus it is not normally considered in investigations as a distinct lead source except for the contamination of foods within the home during their food preparation in Mount Isa, as found in other studies (Body et al., 1991).

Lead mining, processing, smelting and concentrate handling facilities are identified as the key sources of lead pollution in Australia (DEH, 2006). These sources may contribute some or all of the blood leads of people who live or work near lead facilities such as at Mount Isa. Lead, widely present in mineralised areas and associated sites, is identified as a potential contaminant, therefore attracts the public attention in BLL, particularly for the vulnerable young age group.

The last national survey of BLLs in Australia for children aged 1-4 years old was conducted in 1995 by the Australian Institute of Health and Welfare (Donovan, 1996). Final results for 1,575 sampled children indicated that 92.7% had BLLs <10µg /dL, 7.3% had BLLs ≥10µg /dL, and 0.25% had BLLs ≥25µg /dL, with the maximum BLL being 32.7µg /dL. The arithmetic and geometric mean BLLs were 5.72µg/dL and 5.05µg/dL, respectively. Of 270 children from Mt Isa sampled Queensland children, 95.2% of the sample had BLLs <10µg/dL with the arithmetic mean being 5.59µg/dL (Donovan, 1996). Table 17 includes a summary of blood lead data from Mt Isa.

Since 1923, lead, copper and zinc mining activities in Mount Isa have been actively mined and played an important role in the Australian mining industry. Because there are naturally occurring lead minerals in the area, it means there are elevated levels of lead in parts of the urban environment of Mount Isa. The potential to elevate BLLs in people who live and work in the city, in the presence of natural lead in the Mount Isa area, has been noticed for many years.

In September 2006, due to increasing interest from the general Mount Isa community, Queensland Health launched a blood lead screening program of Mount Isa children for those aged between one and four years old . The main purposes of the survey were to identify children with elevated BLLs, to work with the families of these children to improve the BLL situation, and provide key data to promote further community action (Queensland Health, 2008). The recommended BLL by NHMRC is <10µg/dL for all Australians (NHMRC, 2009). There were 400 children recruited for the 2008 Mount Isa study and they were found to be representative of the general population of one to four year olds in terms of age, sex and indigenous status. Results of the survey indicated that the mean BLL for the children tested was 5.0µg/dL (geometric mean value), with the minimum level of 1.3µg/dL and the maximum of 31.5µg/dL (Queensland Health, 2008). About 11.3% of the study group (45 children) had BLLs greater than or equal to 10µg/dL. Of these, two children (0.5% of the study group) had BLLs greater than 20µg/dL. Indigenous children were reported to be about four times more likely to have a BLL over 10µg/dL than non-indigenous children. The results also showed that for all children tested, those aged under three years were much more likely to record an elevated BLL than children aged three years or over. This demonstrated age as a common influence and it is likely to relate to general play activities and hand-to-mouth behaviour (e.g. playing in soil and sand, and with pets). The results did not show significant links between elevated BLLs and gender, or length of time living in Mount Isa.

As a follow-up study, Queensland Health released the Mount Isa Community Lead Screening Program 2010 report (Queensland Health, 2008; Queensland Health, 2011), which sampled 167 children of the same age group. It showed a significant improvement in the lead levels of children in Mount Isa, compared with the 2006-07 screening program (Queensland Health, 2011). The 2011 report indicated a decline in both mean BLLs and percentage of children's BLL above 10µg/dL between the two surveys. Eight (or 4.8%) of the total sample had BLLs greater than 10µg/dL. Of these, one child had a BLL higher than 20µg/dL. The 2010 report also indicated an improvement in children's blood lead after successful environment intervention with communities who lived nearby the mining and mineral processing activities at Mount Isa.

For both surveys, there were no distinct spatial patterns of elevated BLLs within Mount Isa city though the participated children were evenly distributed across the community. Household tests carried out for children with elevated BLLs (>10µg/dL) for both surveys showed that chewing, sucking or eating non-food items, living in a property with bare soil, and pet ownership were common in this blood lead elevated group (Queensland Health, 2008; Queensland Health, 2011). Although care should be taken in declines in data interpretation, this improvement in the lead levels of children indicated the importance of community education and wiping surfaces in houses that relate to living safely with lead. Particularly, the improving state of house hygiene environment and hand-mouth behaviours are significant approaches as reported in studies of young children at other locations (Maynard et al., 2005; Lanphear et al., 2003; Sheldrake and Stifelman, 2003).

The Lead Pathways Study undertaken at Mt Isa (Noller et al., 2017) made extensive use of the IEUBK model (Section 4.4) to predict BLLs for site specific bioaccessibility data for lead in soil (Figure 12 and Figure 13; Table 19). Of all the age groups, 1-3 year olds are much more vulnerable. The IEUBK modelling of the estimation for all 67 houses indicated that the BLL for one house exceeded 10µg/dL, the NHMRC guideline at the time this study was undertaken (NHMRC, 2009), for all age groups except children aged 5-7 years old. The plot of the geometric mean of predicted BLLs and their exceedances showed that 52% of the houses exceeding the NHMRC guideline (10µg/dL). The exceedance level was much lower when the predicted BLLs were low.

***Table 19** Summary of IEUBK predicted blood lead level (µg/dL) for different age groups in Mount Isa city (Noller et al., 2017).*

	Blood lead geometric mean	Exceedance	0.5-1 y	1-2 y	2-3 y	3-4 y	4-5 y	5-6 y	6-7 y
N	67	67	67	67	67	67	67	67	67
Mean	3.8	5%	4.1	4.6	4.4	3.8	3.5	3.4	3.2
SD	1.8	0.10	1.6	2.0	1.9	1.9	1.8	1.7	1.6
Minimum	1.5	0.000	1.9	1.9	1.8	1.3	1.1	1.1	1.1
25th percentile	2.6	0. 2%	3.0	3.2	3.1	2.5	2.3	2.2	2.1
Median	3.4	1%	3.7	4.2	3.9	3.4	3.1	3.0	2.8
75th percentile	4.6	5%	4.8	5.5	5.2	4.6	4.3	4.1	3.9
Maximum	10.2	52%	10.1	11.9	11.2	10.6	10.2	9.7	9.1

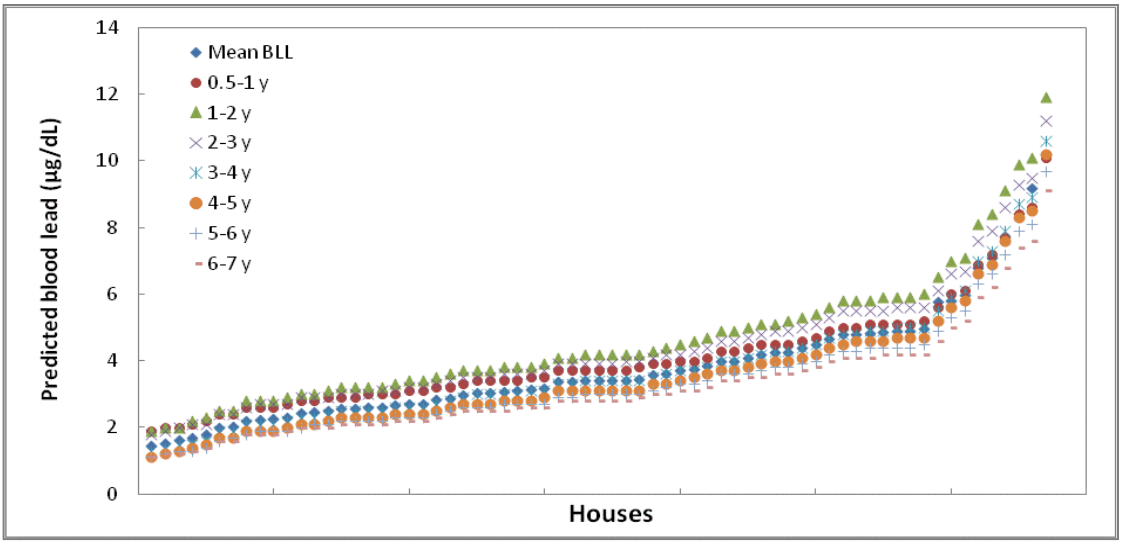


__Figure 12__ IEUBK predicted BLL (µg/dL) for different age groups in Mount Isa city. Mean BLL: geometric mean of blood lead level (Noller et al., 2017).

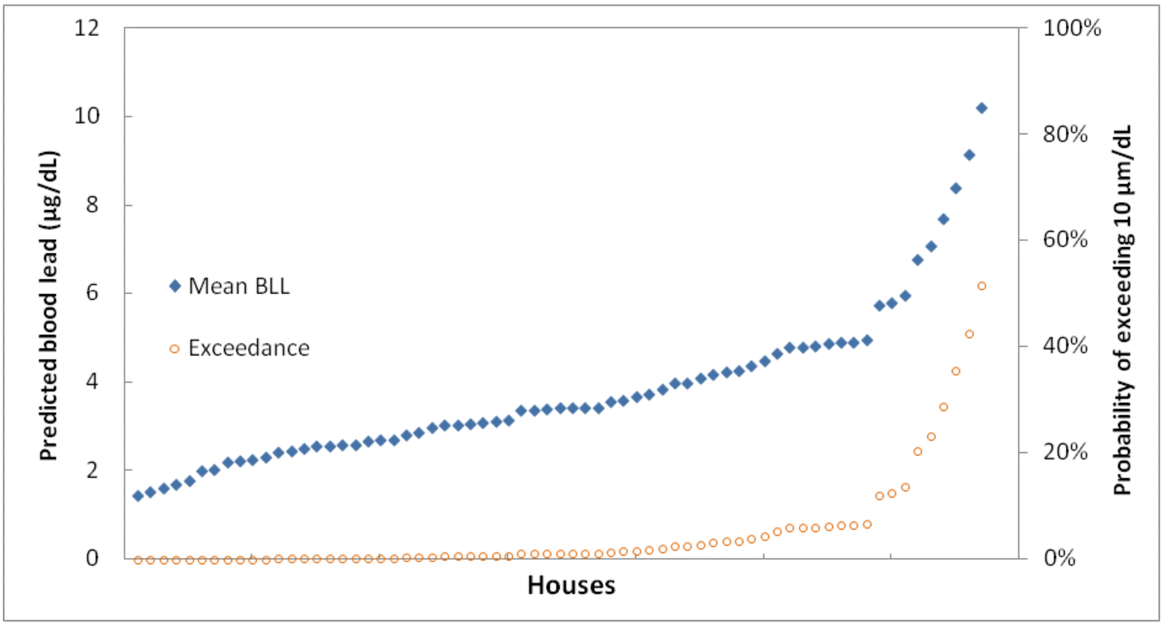


__Figure 13__ IEUBK predicted blood lead level geometric mean (µg/dL) and exceedance for 67 houses in Mount Isa city. Red line indicates the blood lead level of concern (10 µg/dL) (Noller et al., 2017).

5.2 Overseas Sites

5.2.1 Canada / USA sites

Several former lead mining and smelter sites exist throughout the world with varying degrees of success in terms of remediation effectiveness. There was a particular focus during the last 30 years and the sites that were examined are effectively the benchmarks for the current time. Following extensive remediation programs of Superfund sites in the USA, a symposium was held at Coeur d'Alene, Idaho, USA in May 2000 to review several such sites.

The findings of the Coeur d'Alene symposium are presented as a review (Elias and Gulson, 2003). Whilst this review draws on the findings from a range of other lead smelter remediation projects, the reviewers found that the most comprehensively documented programs from across the range of remediation case studies were primarily focussed on Coeur D'Alene River Basin, Idaho, USA (NRCNA, 2005), Trail, British Columbia (BC), Canada (Hilts, 2003) and Butte – Silver Bow (BSBHD, 2014). Therefore, it is considered useful to examine the findings of these sites. The dispersion of lead throughout the surrounding community is dust from lead-contaminated soil that becomes mobilised by size-reduction processes. The study sites considered in this paper are closely aligned with those being considered in the current review and therefore it provides a reasonable basis for comparison of remediation issues with the current site.

Remediation plans were considered to cover a range of issues and variables:

- Government policy regarding mechanisms for decisions and supporting funds.
- Company policy / viability to survive the economic impact of remediation cost.
- Community relationship with participation in decision-making and expectation of improvement to living conditions and benefits.
- Topography that will influence the dispersion plume being on flat land, in a valley or a slope.
- Climate whether hot dry or cold wet climate will influence dispersion characteristics.
- Land use whether there is compatibility with the soil lead remediation if they increase human exposure.
- Population density – not all residents will receive benefits of remediation.
- Metal species – the finding was that there was some information available about different forms of lead and their harm but the symposium did not have sufficient information to clarify this issue.

The Bunker Hill site comprises 5,400ha in the Silver Valley of the South fork of the Coeur d'Alene River (SFCDR) and includes the 150 abandoned industrial complex of the former Bunker Hill company lead/zinc mine and smelter in Kellogg, Idaho. A US EPA plan to clean up this contamination under Superfund proposed spending millions of dollars on contamination clean up in the Coeur d'Alene River basin (NRCNA, 2005). More than 7,000 people in five residential areas were examined. In addition to smelter-related lead contamination there was also mill tailings discharged to the river or confined in piles onsite (adding to the contaminant sources).

The Bunker Hill review (NRCNA, 2005) characterised the need for careful design, implementation, and perpetual maintenance of a community-wide lead clean up.

Future action was required on:

- infrastructure;
- institutional controls for homeowner projects (post-clean-up);
- erosion control for undeveloped hillsides with potential to impact the developed valley floor;
- drainage improvements and flood control; and
- waste piles and increasing the rate at which clean-up proceeds.

Focusing on these areas was considered crucial to minimising recontamination at a large scale lead clean-up.

Studies found that interior dust clean-up alone was not effective where, within a year, they were re-contaminated by outdoor sources, (CH2MHill, 1991 in Sheldrake and Stifelman, 2003) so clean-up efforts were directed toward residential yard soils, commercial properties and rights of way.

The 1993 Panhandle Health District (PHD) Lead Health Study identified several co-factors which influence the soil/dust pathway and were related to excessive BLLs. These included parental income and socioeconomic status, parental education level, home hygiene practices, smokers in the house, nutritional status of the child, use of locally grown produce, exposed soil in the yard, number of hours spent outside, pica behaviour and age (PHD, 1986 in Sheldrake and Stifelman, 2003).

An extensive database has been maintained by Idaho Department of Health and Welfare which relates BLL, environmental media contaminant concentrations, environmental exposures, health intervention and remedial activities on an individual basis. This is confidential with only summary info released (due to the personal nature of medical records) (Sheldrake and Stifelman, 2003)

Responsible Party agreements in 1994 enabled implementation of clean-up in the communities – residential yard soil, well closures in contaminated aquifers, financing an ICP, including provision of a disposal area. Priority clean-up for residents was for pregnant women or young children (and those with BLL >10µg/dL living on yards with soil lead concentrations >1,000mg/kg) who have highest priority needs with at least 30cm clean soil barrier for yards, and 60cm for garden areas.

A study by Ngueta et al. (2014) on cold-to-warmer weather changes in Canada for children's BLL was undertaken and related it to previous blood lead status. The study highlighted "the major influence of previous blood lead concentration in the colder-to-warmer changes in BLLs. The magnitude of increase in BLLs from colder to warmer months is more important in children with BLLs <10µg/dL during colder months. While not reducing the important role of soil and dust (strongly established in the previous studies), we suspect that the deleterious influence of BLLs on the vitamin D metabolic sites/pathways could explain such observation." This study was undertaken in a cold climate (Canada).

Summary features of this project are:

- A durable fabric marker installed where contamination at depth with the ICP ensuring barrier integrity.
- 'Responsible Party' agreements ensure residential clean-up to be funded (200 residential parcels per year).
- Periodic reviews are needed in perpetuity (due to contamination at depth).
- There is a need to repair after flooding, erosion, or deposition of contaminated soils (this becomes the responsibility of the property owner).
- Record of Decision requires ICP long term stability of barriers and to enforce the property owners' obligations.

Several comments on site characterisation and remedial investigations are provided for Bunker Hill (NRCNA, 2005).

ICP as defined for Superfund sites is as follows:

> "*The ICP is a locally adopted set of rules and regulations incorporated into land use and zoning codes to ensure barrier integrity throughout the site. The purpose of the ICP is to protect public health and assist local land transactions within the Superfund site. The ICP has been established to oversee real estate transactions, certify contractors to work safely within the BHSS, to enforce rules and regulations, and to help residents comply with the Institutional Controls*"
>
> (Sheldrake and Stifelman, 2003)

The ICP enforcement is linked to building departments and land use planning activities and include:

- contaminant management rules;
- barrier design and permitting criteria;

- ordinances requiring PHD;
- building permit approvals;
- ordinance amendments to comprehensive plans;
- ordinance amendments to zoning regulations;
- model subdivision ordinances;
- storm water management requirements; and
- road standards and design criteria.

Sheldrake and Stifelman (2003) analysed the following in their review:

- BLLs;
- house dust lead levels;
- barrier effectiveness;
- institutional controls program;
- fugitive dust;
- recontamination sources; and
- infrastructure and disposal.

Sheldrake and Stifelman (2003) found the following:

> *Education for two year olds accounted for a 3.9µg/dL reduction due to intervention without yard clean-up in a study of ages kinder to grade 3 (p117). A vacuum cleaner loan program was of value. Improvements to ICP (from surveys) require a closer disposal site and pre-project sampling (p118).*
>
> *Local zoning laws do not prevent removal of soil/rock from base of slopes – making erosion inevitable (p119, Section 3.6.3). They recommended gabion walls and zoning changes and further recommended the following ICP standards:*
>
> - *all county and city crews are trained and licensed by the ICP;*
> - *rock pit operators sample materials that are used at the site;*
> - *ICP implementers go to currently operating rock pits and sample them to supplement owner sampling, if necessary; and*
> - *material being placed on roads is tested on an intermittent basis.*

Throughout the ICP there was an ongoing need for disposal of lead contaminated materials.

Bunker Hill and Coeur d'Alene River basin

In 2005, the National Research Council of the National Academies (NRCNA) published the document 'Superfund and mining mega sites, lessons from the Coeur D'Alene River Basin, Committee on Superfund Site assessment and remediation in the Coeur d'Alene river Basin'. In this document the link was made between the introduction of legislation in 1980, which is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, 1980) in USA, and the process of identification of Superfund sites in the USA, of which Bunker Hill was one.

This lessons learned document found that the technical basis for decision making for this project was generally sound. However, for EPA's decision making regarding environmental protection, the committee has substantial concerns, particularly regarding the effectiveness and long-term protection of the selected remedy.

It was also noted that 'characterisation did not adequately address groundwater – the primary source of dissolved metals in surface water – or identify specific locations and materials contributing metals to groundwater' (NRCNA, 2005). The review also noted that there were no appropriate repositories to hold the proposed amount of contaminated materials. Reviewers felt that frequent flooding could impact remedial actions and potentially lead to re-contamination.

'Overall, EPA's evaluations provide a useful depiction of the location of contaminated soils, sediments, and surface waters over the large spatial scale of the basin. The data have been used to estimate average mass loading of metals in the Coeur d'Alene River and Lake and to provide an adequate description of contaminants moving through much of the system.' (NRCNA, 2005).

Figure 14 and Figure 15 show distribution pie charts for the fate of lead contamination from mill tailings, thereby providing valuable knowledge for planning remediation.

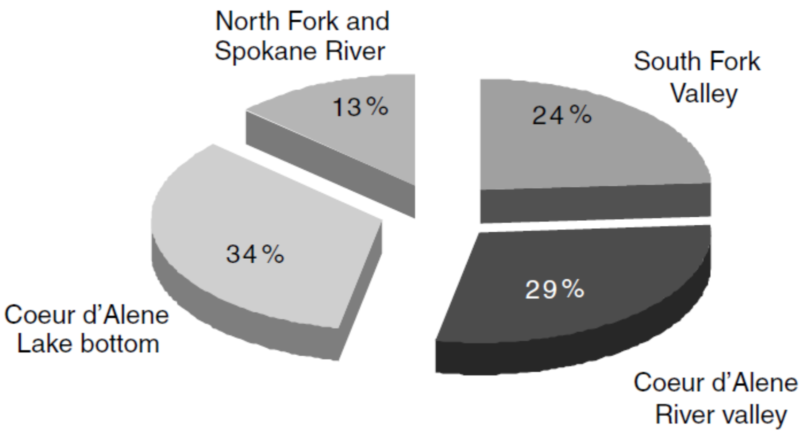


***Figure 14** Distribution of ~880,000 tons of lead from mill tailings released to streams (Bookstrom et al., 2001, in NRCNA, 2005).*

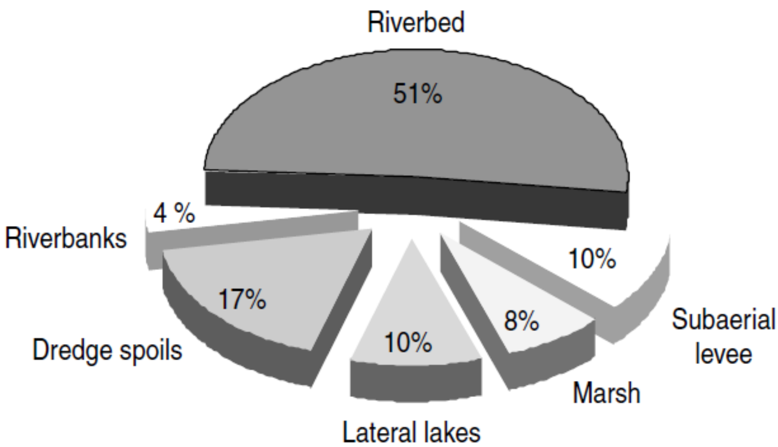


***Figure 15** Distribution of lead by depositional environment in the lower reach (Cataldo to Harrison) of the Coeur d'Alene River (Bookstrom et al., 2001 in NRCNA, 2005).*

Also learned was that aggregate data for 0-9 year olds is misleading and underestimates the risk for the target group of the population (NRCNA, 2005). This review also highlighted that knowledge gaps existed around the human health impacts of contaminants other than lead; in this instance arsenic and zinc.

NRCNA (2005) also recommended that site specific bioavailability and ingestion rates be used as they 'would have improved the application of the IEUBK model' (USEPA, 2007). Other models and epidemiological studies could have helped to assess the reliability of the IEUBK model predictions and better characterise the physical-chemical properties of the exposure source materials. In essence, they noted that IEUBK should not be the sole criterion for estimation for health-protective soil concentrations. Geographically complex sites need improved methods and a decision making structure that follow the appropriate health risk assessment procedures.

NRCNA (2005) recommended long-term support of ICPs 'to avoid undue human health risks from recontamination and to maintain the integrity of remedies intended to protect human health'. They also recommended that the 'effectiveness of remedial actions for human health protection needs to be further evaluated. This evaluation should be supported by ongoing environmental and blood lead monitoring efforts'.

Trail BC has been the site of a major lead and zinc smelting facility for over 80 years (Hilts 2003). Following BLL monitoring (Table 17) showing higher than average BLL in Trail and later despite a decline in overall BLLs, there were 39% of the Trail children tested in 1989 above the US EPA's level of no concern of 15µg/dL. This resulted in the formation of the Trail Community Lead Task Force in 1990.

The apportionment of childhood lead exposure to current and historical sources is an important factor in remedial decision making for sites with active sources of lead dust (Hilts, 2003). These findings suggest that increased attention should be paid to the importance of emission reductions at other sites with operating lead smelters. The IEUBK model over-predicted with measured BLLs in Trail children when the new smelter started. The only parameter change that brought the predicted BLLs in line was a reduction in soil/dust bioavailability from 30% to 10%. This research emphasises the importance of 'active sources' of lead vs soil concentrations.

"*The IEUBK* (USEPA, 2007)*, with its emphasis on soil concentrations, would not have predicted the dramatic decline in children's blood lead levels seen in Trail following the reductions in air lead levels but may have been due to inputting less accurate measured data for lead emissions. The Trail experience suggests that increased attention should be paid to the importance of active sources of highly bioavailable and mobile lead bearing dusts.*" (Hilts, 2003). Figure 16 shows the trends at the time.

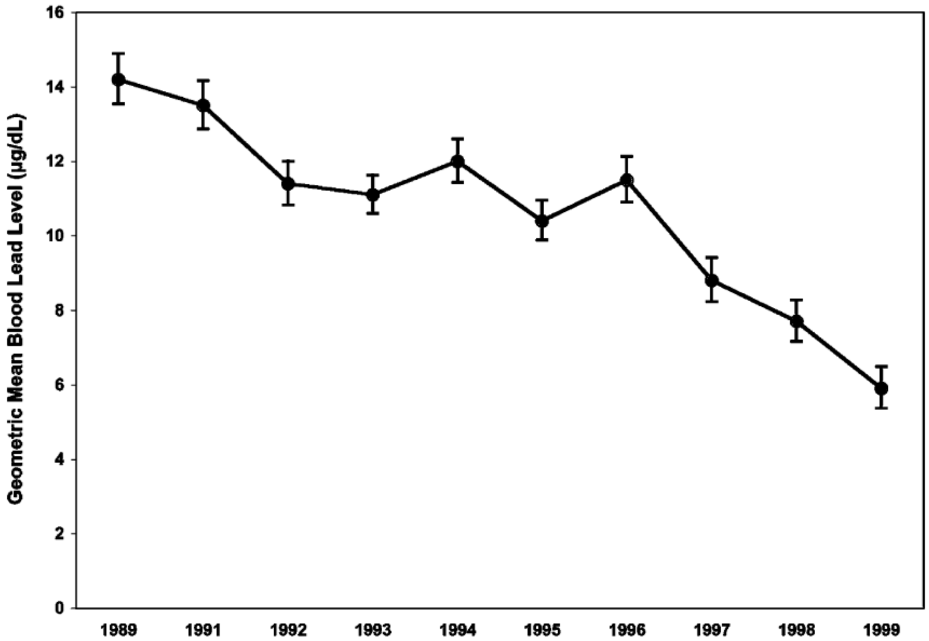


Figure 16 *Geometric mean BLLs in Trail children (error bars are 95% confidence limits on the geometric means) in Hilts (2003).*

More recently updated data from the Trail Area Health and Environment Program (TAHEP) (TAHEC, 2014) shows that the rate of change has reduced in the last few years (Figure 17).

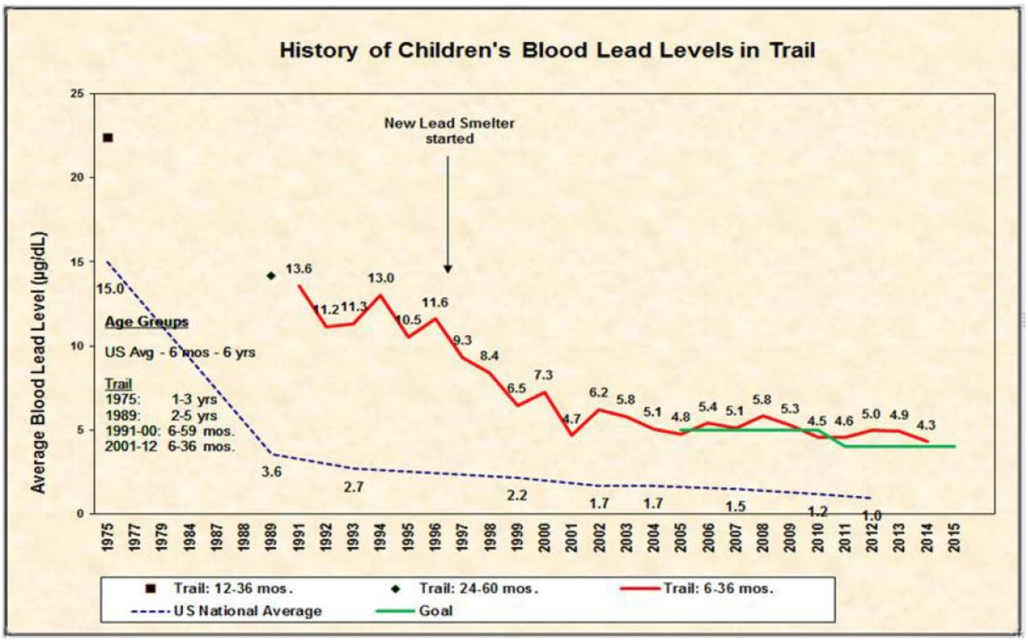


Figure 17 *History of children's BLL in Trail, 2014.*

Progress in reducing lead emissions is shown in Figure 18. The level of lead in community air has averaged around 0.35µg/m^3 in more recent years (TAHEC, 2014.)

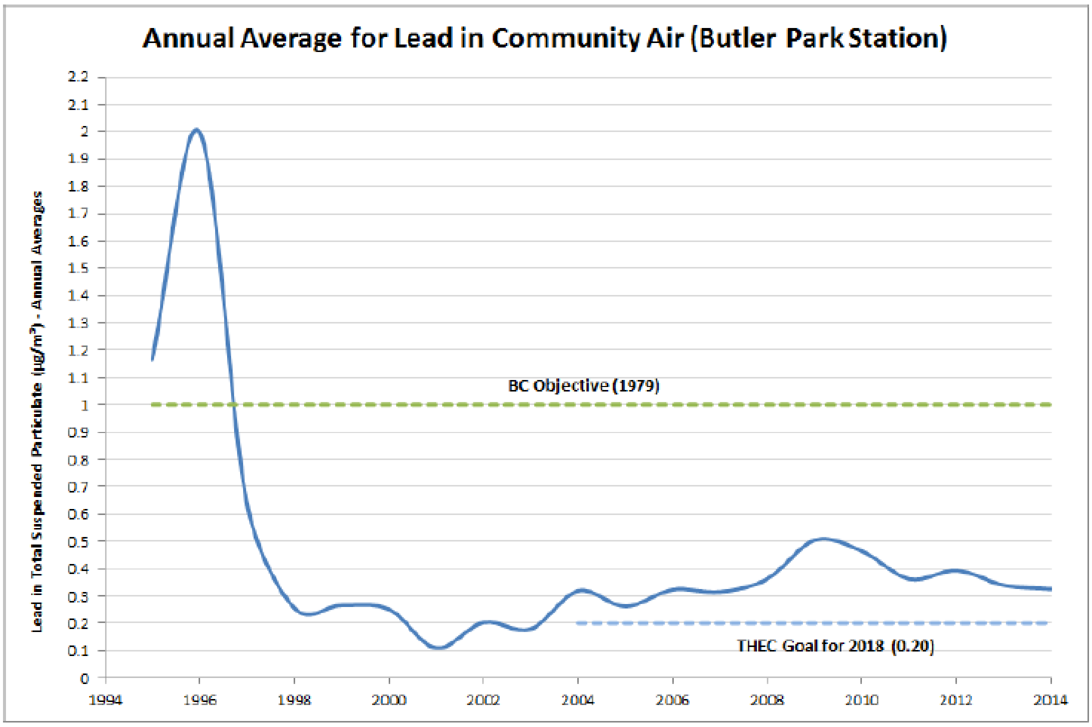


Figure 18 *Lead in community air (Butler Park Station) Trail (TAHEC, 2014).*

The finding that smelter lead emission reductions were associated with large and rapid declines in dust lead levels in Trail (TAHEC, 2014; p7) is consistent with the finding by van Alphen (1999) that metal deposition in dust fall containers in Port Pirie appeared to be derived more from current smelter emissions, than from historical dust lead sinks.

Yard clean-up near the Bunker Hill Superfund Site (BHSS) was found to be an effective tool for reducing house dust lead concentrations (and reduction in children's BLLs) (Sheldrake and Stifelman, 2003). It was noted that contiguous clean-up of residences has a three times greater reduction of children's BLLs versus cleaning neighbouring properties. This highlighted the importance of a community-wide preventative approach to controlling lead contamination in soil and lead dust.

Butte – Silver Bow, Montana, USA was a large scale mining and mineral processing activity which has experienced 25 years of ongoing remediation efforts and a residential metals abatement program (BSBHD, 2014). This program has included BLL monitoring of Butte children, examination of blood lead trends and assessment of the effectiveness of Butte's lead source and exposure reduction measures.

An evaluation study (Schoof et al., 2015) has examined the BLL trends in a total of 2,796 Butte children aged 1-5 years old from 2003 to 2010, as compared to a reference data set matched for similar demographic characteristics over the same period. Blood lead differences across Butte during the same period were interpreted with respect to effectiveness of remediation and other factors potentially contributing to ongoing exposure concerns.

The BLLs in Butte were higher when tested in summer/fall than in winter/spring for two neighbourhoods, and statistically higher BLLs were found for children in Uptown living in properties built before 1940, probably associated with lead in paint (Schoof et al., 2015). The persistence of greater percentage of high BLLs (45µg/dL) in certain areas of Butte, versus the reference data set, supported the continuation of the home lead abatement program. It was concluded that BLL declines in Butte arose from the cumulative effectiveness of screening efforts, community-wide remediation, and the ongoing metals abatement program. The Butte abatement programs, including home evaluations and assistance in addressing multiple sources of lead exposure, were considered to be important complements to community-wide soil remediation activities (Schoof et al., 2015). If investigates further, there may be a need to confirm that BLLs do not increase above the HIL in the future, for example in five years. The remediation of all properties surrounding the smelter site is not yet complete and further examination is needed to determine if historical contamination remains from lead and other metals.

The findings of the Coeur d'Alene symposium are presented as a review (Elias and Gulson, 2003). Whilst this review draws on the findings from a range other lead smelter remediation projects, the reviewers found that the most comprehensively documented programs from across the range of remediation case studies were primarily focussed on Coeur D'Alene River Basin, Idaho, USA (NRCNA, 2005), Trail, British Columbia, Canada (Hilts, 2003) and Butte – Silver Bow (BSBHD, 2014). Therefore, it is considered useful to examine the findings of these sites. The dispersion of lead throughout the surrounding community is dust from lead-contaminated soil that becomes mobilised by size-reduction processes. The study sites considered in this paper are closely aligned with those being considered in the current review and therefore it provides a reasonable basis for comparison of remediation issues with the current site.

5.2.2 Europe and elsewhere

Table 20 gives a summary of key items identified for lead smelter site remediation and abatement including Noyelles-Godault, Pas-de-Calais, France (Declercq et al., 2006; Douay et al., 2008), Rouyn-Noranda, Quebec, Canada ((Ettler 2016, Lorenzana et al. 2003), Flin Flon, Manitoba, Canada (Henderson at al., 1998; Pip, 1991), San Luis Potosi, Morales, Mexico (Carrizales, 2006; Di'az Barriga, 1993). These sites showed:

- extensive and repeated BLL surveys conducted prior to shut-down demonstrated the key role of soil and house dust;
- bioavailability and bioaccessibility measured in soils;
- persistence of soil pollution remained the key factor and highlighted the need for better knowledge of lead transfer from the smelter; and
- replacement of garden soil used as a remediation technique resulted in clear improvement for extensive contaminated garden soil.

***Table 20** Summary table of key items identified for lead smelter site remediation and abatement.*

Location of smelter	Significant aspects of abatement
Noyelles-Godault, Pas-de-Calais, France	• Extensive and repeated BLL surveys conducted prior to shut-down demonstrated the key role of soil and house dust. • Bioavailability and bioaccessibility measured in soils. • Persistence of soil pollution remained the key factor and pointed to need for better knowledge of lead transfer from the smelter. • Replacement of garden soil used as a remediation technique showed clear improvement for extensive contaminated garden soil.
Rouyn-Noranda, Quebec, Canada	• Largest copper smelter in the world with significant lead emissions. • Soil intervention was associated with reduced BLLs. • Seasonality did not contribute to reductions in BLLs.

Location of smelter	Significant aspects of abatement
Flin Flon, Manitoba, Canada	• Copper smelter with significant lead emissions. • Limited BLL survey data available. • Significant risks from exposure to arsenic, cadmium and lead emissions, and from eating fish from lakes contaminated with mercury. • Organic matter in soils retains lead and other metals. • Significant soil contamination and effects on terrestrial species. • Vegetable gardens show high leaf concentrations. In some cases existing soil was replaced with uncontaminated soil for garden cultivation.
San Luis Potosi, Morales, Mexico	• BLL survey data available. • Bioavailability and bioaccessibility measured in soils.
Trail, Canada	• Comprehensive remediation program. • Using specific air quality objectives. • Company reduction in emissions using improved smelter technology concurrent with community abatement program to give significant BLL reduction. • Publicly accessible project expenditure.
Bunker Hill, USA	• Comprehensive remediation program. • Included comprehensive fate of lead in the environment prediction and investigation due to lead dust deposition as well as tailings disposal in a riverine context. • Publicly accessible project expenditure.
Butte-Silver Bow, Montana USA	• Separation of storm water contamination. • Publicly accessible project expenditure. • Comprehensive spatial data on contaminant sources. • BLL declines achieved by community-wide abatement programs including home evaluations.

6. Outcomes of Review of Literature

6.1 Summary of Findings for Wollongong LGA

6.1.1 Soil

The soil samples from Port Kembla and surrounding locations in the Illawarra are listed in Table 9 and cover a time frame of 1972 until 2008 that corresponds to part of the operational of the copper smelter to beyond its decommissioning (Section 4.2.1). The largest and most comprehensive soil data set is in the study undertaken by Jafari (2009) collected following post-decommissioning. The soil data sets usually include lead with arsenic, cadmium, copper or zinc occasionally or individually. No data set is part of a routine monitoring program for heavy metals and arsenic in soil.

The data in Table 9, together with recalculation of the raw data from Jafari (2009) was compared against the respective NEPM Soil Investigation Levels for HIL A (Table 1) for arsenic, cadmium, copper, lead and zinc. The data set of Jafari (2009) included three slag samples (S33, S34 and S58) which were excluded from the comparison with the HIL A's, except for cadmium where the slag concentrations did not appear to exceed the maximum measure cadmium concentration in the remaining soil samples. Very high concentrations of lead in soil were also found to be due to lead in paint (Williams et al., 1995).

The data set of Jafari (2009) includes concentration data for 0.1M HCL extraction which provide an estimate of % bioaccessibility (gastro-intestinal simulation) for each heavy metal or arsenic (Section 4.2.1). The summaries for respective HIL A's are as follows:

- The highest arsenic total concentrations do not exceed HIL A when compared with Jafari (2009) data in Figure 4.6(c) plotted versus distance from the copper smelter.
- The 22 samples above detection limit for cadmium total concentration including the slag sample (Table 9) indicate that some of the samples exceeding the 75th percentile concentration (Table 10) would exceed HIL Level A. When the 'bioaccessibility-adjusted' concentration for cadmium is compared against HIL Level A there are no exceedances. It is possible that high cadmium concentrations for S89 (673 mg/kg), S90 (840 mg/kg) and S91 (626 mg/kg) are also for slag, but this origin is not confirmed.
- The highest copper total concentrations do not exceed HIL A when compared with Jafari (2009) data in Figure 4.4(b) plotted versus distance from the copper smelter.
- The highest lead total concentrations exceeded HIL A when taken from the Port Kembla area, close to the smelter (Table 9) that are assumed to be for 100% bioavailability. Comparison with Jafari (2009) data in Figure 4.6(b) plotted for lead concentration vs. distance from the copper smelter shows that total lead concentration does not exceed HIL A when < 1km from the smelter. When the 0.1M Hydrochloric acid extractable lead concentration equivalent to a site specific level of 1,071mg/kg (bioaccessibility-adjusted) comparison with Jafari (2009) data in Figure 4.6(b) was compared versus distance from the copper smelter there was no exceedances of HIL A excepting for the highest slag sample S58 (Table 9; 4,157mg/kg lead).
- The highest zinc total concentration do not exceed HIL A when compared with Jafari (2009) data in Figure 4.4(a) plotted vs. distance from the copper smelter.

These findings demonstrate the potential application of bioaccessibility measurement to more accurately define the health risk of heavy metal and arsenic concentrations in soil.

6.1.2 House dust

House dust samples were collected from houses between 1992 and 1997 primarily from Port Kembla and various other suburbs in Wollongong. Port Kembla received deposition from the copper smelter emissions.

Lead was the main metal measured in house dusts with occasional measurements of arsenic, cadmium, copper and zinc (Table 12). Highest concentrations of heavy metals and arsenic in house dusts were found between 0.3–1.0km from the copper smelter (Willison, 1993).

It has been known since 1992, from the Roof Dust Survey by IPHU (Willison, 1992), that there was accumulation of heavy metals in the roof dust of houses within 5km of the southern end of the Port Kembla industrial area, including the smelter. Sampling in concentric circles was found to give a good representation of the deposition of lead and other heavy metals in the area emanating from the smelter. The survey showed a clear pattern of diminishing deposition of lead and other heavy metals with increasing distance from the smelter. Houses within 1km of the smelter had high concentrations of lead, cadmium and arsenic in their ceiling dust (Table 11). It was observed that houses with building-paper lining under roof tiles had lower levels of the heavy metals. The average lead levels in the ceiling dust measured 3,500mg/kg at 200-300 metres from the smelter; 1,800mg/kg at 5km; 1,000 at 1km; and 500mg/kg at 5km (LMAP, 1994).

The 1994, NSW LMAP (LMAP, 1994) also identified that:

- lead in house dust is recognised as one of the best predictors of childhood exposure to lead poisoning, but is the least understood and has the greatest divergence of opinion on sampling protocols; and
- dust control, in general, is needed in construction and demolition sites.

No data set from Port Kembla is part of a routine monitoring program for heavy metals and arsenic in house dust. There was limited collection and measurement of heavy metals and arsenic in dust fallout and no measurement of indoor fallout or floor wipe concentrations. Surface soil at house blocks within 1km of the copper smelter may have levels of heavy metals and arsenic that are similar to dust in houses. Although lead dust loadings for various surfaces given in AS 4361.2-1998 could be followed, application of the clearance standards have not been used in Port Kembla houses, due to lack of floor surface and indoor air deposition data (Section 4.2.2). Concentration measurement of lead in house dust is able to identify if lead paint is present as it will contain 1% lead by weight. Using floor wipes (US EPA, 2001) for lead loading measurements (µg lead/m^2) more directly measures lead ingestion for a child and could better predict children's BLLs compared with house dust lead concentrations (mg/kg). However, house dust lead concentrations can be an input parameter for the IEUBK model prediction of blood lead.

The focus on managing contamination of houses at Port Kembla has therefore been based on identifying high or extreme levels of lead in house dusts and submitting adults and children for blood lead measurement, if notifiable.

6.1.3 Home grown fruit and vegetables

Section 4.2.3 identifies that lead levels in home grown food were in the Port Kembla area were generally low (ILMAP, 1997). The soil adhering to harvested root crops and leaves needed to be washed off before consuming. Lead in dust fall-out can also adhere to leaves and other above ground parts of plants, especially broad leafy vegetables. Sometimes cadmium uptake is observed with root vegetables (Kachenko and Balwant Singh, 2006).

In response to requests from residents near the copper smelter, the IPHU in 1996-97 collected 20 samples of home grown vegetables for analysis of lead and other heavy metals (carrot, onion, potatoes, capsicum, leek, zucchini, beans) and fruits (passionfruit, lemon, babaco, peach) (ILMAP, 1997). Although the sampling was limited, and two samples were above the maximum permissible concentration (MPC) for lead and one for cadmium, overall the results. Vegetables grown at Port Kembla showed exceedance for both cadmium and lead (Kachenko and Balwant Singh, 2006) and highlighted the risk of growing vegetables in the vicinity of smelters during and following operation.

6.1.4 Sediments

Studies conducted from 1997 to 2009 on heavy metals and arsenic at Lake Illawarra and associated waterbodies showed elevated levels against ANZECC/ARMCANZ (2000) sediment guidelines (Table 8) compared with background sites (Table 13). In particular Griffins Bay and Port Kembla Inner Harbour showed highest concentrations of copper, lead and zinc associated with wind dispersion from the copper smelter. Aquatic species such as fish and shell fish have the potential for uptake of heavy metals from sediment at the interface with water. People who catch fish and/or collect shellfish from these locations may be exposed to levels of heavy metals that are greater than food guidelines of the Australian and New Zealand Food Standards Code (FSANZ). There appears to be no data for heavy metals and arsenic intake from people catching and consuming fish and shellfish from Lake Illawarra and particularly Griffins Bay and Port Kembla Inner Harbour.

6.1.5 Airborne particulate data

Monitoring of lead in air particulates at Port Kembla has indicated the dispersion of fine particles from the copper smelter and showed there was a dramatic reduction 1974 to 1975 from 5 μg/m^3 down to 1.5 μg/m^3 coinciding with air pollution controls at the smelter (Section 4.3). Airborne lead particulate levels continued to decline with successive decreases in the NEPM guideline for lead to 1.5 μg/m^3 Following 2000, the highest annual average lead in air was 0.11 μg/m^3 and in 2004 monitoring of lead in air particulates at Port Kembla ceased. Recent measurements of lead in air at BlueScope Steel, Unanderra from 2016 to 2019 show lead was < 0.06μg/m^3.

Monitoring of lead in air particulates is of limited importance for health risk assessment as the fraction collected as PM_{10} (10μm diameter) that enter the bronchial tubes only constitutes 5% of dose (Section 3.6). The apparent importance of monitoring airborne PM_{10} for lead is outweighed by the need to have data which explains contribution to dose from all exposure pathways (Section 3.6.4).

6.1.6 Fall out data

Table 15 summarises the limited fall-out concentration data at Port Kembla and other Wollongong sites for lead and cadmium. This was undertaken by conversion of measured fall-out and lichen bag data in units of μg/cm^2.year or ng/cm^2.day to μg/m^2.day for lead and cadmium and enabled comparison with current dust and metal/metalloid deposition guidelines of TA LUFT (1990, 1991) (Table 3); there are no health based Australian guidelines for dust fall-out, only dust soiling (Table 3). The comparison of the limited data converted to units of μg/m^2.day in Table 15 shows that sites near smelters exceed the German lead TA LUFT 'Protection of human health and crop land integrity' and cadmium for all sites exceed TA LUFT 'Protection of human health' except when <5.5μg/m^2.day (Beavington 1977), and Port Kembla (Archibold and Crisp 1983; Crisp and Archibold, 1983) was 94μg/m^2.day for cadmium and exceeded the TA LUFT deposition guideline by 47 times.

Thus, retrospective exposure to heavy metals from dust deposition can be assessed (Table 15) and indicates that people were exposed to levels of lead and cadmium in fall-out that may be significant when close to the smelter locations. Deposited levels of heavy metals to ground has a specific connection with exposure via ingestion which for lead can by 95% of dose (Section 3.6.4).

The historical record of lead emissions from the Port Kembla copper smelter and steelworks (Section 4.3) indicates that the extent of dispersion of air particulates in fall-out that was deposited on houses was plausible based on residual concentrations in soil. Since the copper smelter operations have ceased it is unlikely that fallout dust deposition is likely to reach significant levels as occurred during the operational phase at Port Kembla. However, reconstitution and remobilisation of historical dust deposition in soil through undertaking earthworks or renovation of older houses may occur.

6.1.7 Blood lead

In 1982, BLL of children was GM 12.9µg/dL and in 1994 AM 6.4 µg/dL (Table 17). This decrease of BLL accompanied a reduction in smelter lead emissions airborne lead concentration. Since 1994, there has been no community BLL survey at Port Kembla.

Section 3.5.5 describes that in 2016 the NHMRC recommended that if a person has a BLL greater than 5µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman (NHMRC, 2016). This followed 22 years of have a BLL guide of less than 10µg/dL. Exposure to lead in Australia has dropped significantly over recent decades as a result of measures restricting the use of lead in paint, petrol and consumer goods (Gulson et al. 2014). As a result, the average BLL in Australia is estimated to be less than 5µg/dL. Investigating the source of exposure where BLLs are greater than 5µg/dL will reduce the risk to individuals, particularly children (NHMRC, 2016).

NSW Health set the blood lead notification level at 10 µg/dL from 1993, and in May 2015, the revised blood lead notification level of 5 µg/dL was adopted (NHMRC, 2015). Thus the only indication of an exceedance of BLL at Port Kembla above the guideline of 5 µg/dL (NHMRC, 2016) is from notifications of patients by doctors in NSW.

Specifically for lead, a risk assessment technique has been developed to assess the uptake of lead into the blood via soil intake, which effectively applies an a priori uptake factor to an estimated dose to estimate blood lead concentration (NEPC, 2013 Schedule B4). The US EPA IEUBK model for lead in children is widely known and used in this respect (USEPA, 2004). This approach, with the appropriate justifications, is considered suitable at Tier 2 for assessing risks from lead and can be applied for predicting blood lead on children who are exposed to lead from soil and house dust (Section 3.6.4; NEPC 2013, Schedule B4).

6.2 Summary of Findings for Other Sites

6.2.1 Observations from other studies

Table 21 summarises observations from both Australian and overseas study sites that show the link between soil and dust concentrations with BLL. The Australian and overseas studies emphasise the benefit of having long term site specific studies. It is in the context of experience and outcomes from the studies cited above that enables the observations summarised in Table 21 to be compared with the situation at Port Kembla. Although there was a copper smelter in Port Kembla, lead emissions were produced from the ore processed It is not uncommon to find lead associated with copper ore from sulfidic mineralisation. There many other copper smelters in Australia and elsewhere in the world that have measurable lead emissions.

Table 21 *Summary table of key items identified for lead smelter site remediation and abatement.*

Location of smelter	Significant features of lead reduction during abatement
Boolaroo, NSW	• Reduction of lead in air and BLL was basis for closure on site. Concept of lead budget to estimate total lead in the environment to map its fate. NEPM soil contamination guideline not used. • Vegetables grown in house garden exceed ML for lead. • High levels of lead in fish and shellfishes in Cockle Creek from slag eroded from off-site fill material.
Broken Hill, NSW	• 1994 Broken Hill Environmental Lead Centre used 5 element approach to promote remediation of home environment. And contaminated public land. BLL 1991 18 µg/dL down to 1996 10.8 µg/dL. • 2018 <5 µg/dL. Mean child 1 to <5 yr below the notifiable level of 5 µg/dL. 49% of population was above this level. Non aboriginal population mean 4.0 µg/dL 39%≥5 µg/dL GM 2.7 µg/dL children <12 months had 15% notifiable Seeking ≥80% children 2-<5 yr BLL<5 µg/dL at 150 mg/kg in soil Application of lead flux and passive wipe methods in houses very effective. • Knowledge gap on sources affecting children. Child blood lead mainly from orebody via soil but paint not fully controlled.
Port Pirie, SA	• Attention to emission reductions since 1984 gave reduced BLL. • Focused soil lead sampling program assessed three risk areas to categorise most significant exposure source linked to ingestion. Highest surface soil within 2km of smelter and highest BLLs. Child BLL associated with soil, initially thought to be paint. Footpath remediation reduced contamination.

Location of smelter	Significant features of lead reduction during abatement
Mt Isa,QLD	• Top soil surface 0-2 cm decreased exponentially from smelters NW down wind >100 km from Mt Isa. • 1996 BLL survey 1-4 yr 92.7% <10 µg/dL, 7.3% ≥10 µg/dL, 0.25% ≥25 µg/dL. • 2008 460 children GM 5.0 µg/dL, min 1.3 µg/dL, max 31.5 µg/dL. 11.3%BLL≥10 µg/dL. • 2011 167 children BLL 8% ≥10 µg/dL, 1 child >20 µg/dL. But 52% exceeded 10 µg/dL. • Fish from Leichhhardt River d/s plant exceeded FSANZ lead guideline, but not from Lake Moondarra. • Lead isotopes show no difference in source as all lead is from orebody. Synchrotron X-ray analysis shows differences in samples indicating source by lead compound composition. House study using floor, window sill, window trough for lead exposure based on USEPA (2001) could be used for health risk assessment together with IEUBK model using soil and carpet dust levels.
Bunker Hill Couer d'Alene, Idaho USA	• Comprehensive remediation program. .1000 mg/kg soil gave >10 µg/dL Used IUEBK model but site specific bioavailability data improved comparison with BLL IUEBK should not be the sole criteria for BLL estimate. • Included comprehensive fate of lead in the environment prediction and investigation due to lead dust deposition as well as tailings disposal in a riverine context. • Publicly accessible project expenditure.
Butte-Silver Bow, Montana USA	• Separation of storm water contamination. • Publicly accessible project expenditure. • Comprehensive spatial data on contaminant sources. House evaluation assisted in addressing multiple sources of lead exposure. Lead was mobilised by size reduction processes. • BLL declines achieved by community-wide abatement programs including home evaluations. Study shows importance of long-term evaluation of BLL from 2796 children. BLL higher in summer/fall than in winter/spring.

Location of smelter	Significant features of lead reduction during abatement
Trail, BC Canada	• Comprehensive remediation program. . Predicted BLLs gave better agreement when bioavailability of dust was reduced from 30% to 10% by paying attention to active sources. • Using specific air quality objectives. • Company reduction in emissions using improved smelter technology concurrent with community abatement program to give significant BLL reduction. • Publicly accessible project expenditure
Rouyn-Noranda, Quebec, Canada	• Largest copper smelter in the world with significant lead emissions. • Soil intervention was associated with reduced BLLs. • Seasonality did not contribute to reductions in BLLs.
Flin Flon, Manitoba, Canada	• Copper smelter with significant lead emissions. • Limited BLL survey data available. • Significant risks from exposure to arsenic, cadmium and lead emissions, and from eating fish from lakes contaminated with mercury. • Organic matter in soils retains lead and other metals. • Significant soil contamination and effects on terrestrial species. • Vegetable gardens show high leaf concentrations. In some cases existing soil was replaced with uncontaminated soil for garden cultivation.
San Luis Potosi, Morales, Mexico	• BLL survey data available. • Bioavailability and bioaccessibility measured in soils.
Noyelles-Godault, Pas-de-Calais, France	• Extensive and repeated BLL surveys conducted prior to shut-down demonstrated the key role of soil and house dust. • Bioavailability and bioaccessibility measured in soils. • Persistence of soil pollution remained the key factor and pointed to need for better knowledge of lead transfer from the smelter. • Replacement of garden soil used as a remediation technique showed clear improvement for extensive contaminated garden soil..

6.2.2 Measures for Clean-up of Lead and Other Heavy Metal Residues in Wollongong

Key details of relevance to the Port Kembla case from Table 17 are as follows:

- Reduction of lead in air and BLL is a basis for closure on site. A lead budget gives an estimate of total lead in the environment to map the fate.
  – Remediation is based on removal of lead and/or prevent its dispersion and re-entrainment in air.

  - Assessing effects on people require guidelines that are based on human health risk assessment.
  - There is a common observation that highest surface soil within 2km of smelter and accompanies highest child BLL.
- Utilisation of appropriate techniques at houses including indoor lead flux and passive wipe methods in houses and measurement of bioaccessibility in soil and dust for hazard assessment including dose response, and BLL for exposure assessment, enables effective application of health risk assessment.
- Lack of capability to identify sources of lead is dependent on insufficient range of analytical techniques being used.
- House study for health risk assessment together with IEUBK model to predict BLL of children requires site specific soil and dust levels using.

Residues in the Wollongong LGA that were produced from the smelting and industrial activities, conducted for over 100 years, comprise a range of solid wastes covering fine dusts that were dispersed as fugitive emissions through a range of solid wastes dependent on the process involved. There is available detail regarding the lead and other heavy metals from smelter emissions (Section 4.3; Alperstein et al., 1994) in soil and house dust and sediment in Lake Illawarra but very little detail about slags and other solid wastes.

The estimated lead emissions from the copper smelter at Port Kembla were 25,000kg/year as stack emissions and 21,500kg/year as fugitive emissions (Alperstein et al., 1994). The estimated stack, and particularly fugitive, emissions from Southern Copper were considerably higher than those estimated for Pasminco Metals – Sulphide at Boolaroo (stack: 21,000kg/year; fugitive: 9,000kg/year). Section 4.3 also identifies that fall-out concentration data at Port Kembla and other Wollongong sites was significant, historically for deposition of lead, cadmium and other metals to housing areas within 1-2km of the smelter. Retrospective exposure (Table 15) indicate that people may have been exposure to elevated lead and cadmium in dust fall-out when within 1 km of the copper smelter at Port Kembla. Such emissions are no longer an issue in Wollongong for human health risk but remobilisation of surface dust and soil with cadmium and lead form paint in houses may still be an ingestion issue, particularly for children (Section 4.2).

Section 4.2.2 summarises the studies of dusts in houses and the report by the Community Lead Advisory Service (Mosman, 2015). The survey conducted in 1992 showed a clear pattern of diminishing deposition of lead and other heavy metals with increasing distance from the smelter. The average lead levels in the ceiling dust measured 3,500mg/kg at 200-300 metres from the smelter; 1,800mg/kg at 5km; 1,000 at 1km; and 500mg/kg at 5km. However, there is no indication of the properties of these dusts that show features of speciation and bioaccessibility for lead or cadmium.

An issue raised by Elias and Gulson (2003) at various lead mining and smelting sites was the contribution of emissions from current operations versus historical contamination. The supporting details were as follows:

1. The key sites will look at a summary of issues for the respective sites.
2. Trail emission reduction with improved smelter operation (Hilts, 2003).
3. At Port Pirie, the significance of recent lead fall-out from current operations compared with historic fall-out was identified (van Alphen, 1999).
4. Lake Macquarie, despite reductions in emissions, still had exceedance of air concentrations (Morrison, 2000).
5. Broken Hill and occurrence of widespread lead contamination in houses (Boreland and Lyle 2014; Jacobs, 1992).

Elias and Gulson (2003) also reviewed details of bioavailability of lead mine waste that were identified in the very detailed studies carried out by Casteel and co-workers. Casteel et al. (1997) showed that the bioavailability of lead as galena varied, because of differences in particle size, with higher bioavailability being observed for smaller particle sizes. This study points to the importance of having bioavailability measurement of lead in actual mine or smelting wastes.

Finally, Elias and Gulson (2003) considered the issue: ‘is contamination always a problem?’ This is not always the case. ‘Living with lead in Broken Hill’ (Jacobs, 1992) is a key example that has demonstrated that diligence is required in maintaining awareness within a community with historical lead contamination where BLLs remain high. The need for such diligence at Broken Hill is demonstrated by the finding in 2018 (Lead report, 2018).

NRCNA (2005) recommended long-term support of an Institutional Control Program (ICP) ‘to avoid undue human health risks from recontamination and to maintain the integrity of remedies intended to protect human health’ (Sheldrake and Stifelman, 2003). They also recommended that the ‘effectiveness of remedial actions for human health protection needs to be further evaluated. This evaluation should be supported by ongoing environmental and blood lead monitoring efforts’ (Sheldrake and Stifelman, 2003).

The ICP enforcement is linked to building departments and land use planning activities and include:

- contaminant management rules;
- barrier design and permitting criteria;
- ordinances requirements;
- building permit approvals;
- ordinance amendments to comprehensive plans;
- ordinance amendments to zoning regulations;
- model subdivision ordinances;
- storm water management requirements; and
- road standards and design criteria.

Sheldrake and Stifelman (2003) analysed the following in their review:

- Blood lead levels;
- house dust lead levels;
- barrier effectiveness;
- institutional controls program;
- fugitive dust;
- recontamination sources; and
- infrastructure and disposal.

Throughout the ICP there was an ongoing need for disposal of lead contaminated materials.

In summary they noted that:

- a clean soil barrier was an essential part of clean-up;
- house dust was the most significant proximate source of lead exposure for young children (note that at Trail emissions were continuing as distinct from the NLM situation); and
- community maintenance and scale present challenges at all stages: funding, planning, construction and maintenance into perpetuity.

Public outcry may also be a cost issue, particularly if contamination issues were not dealt with in earlier times. Community reaction is well understood but dealing with or preventing such situations requires an extension of the health risk assessment process. If the health risk assessment is followed (enHealth, 2012) and the risk assessment is defined, it is then possible to proceed to the following steps: (1) Risk Management; and (2) Risk Communication.

6.3 Critical Review of Sampling and Analytical Procedures for Health Risk to the Wollongong LGA Population

6.3.1 Appropriateness of guidelines and lack thereof

The Contaminated Land Management Act 1997 (CLM Act) deals with site contamination at Wollongong under the Act and following sites for managing contaminated land (Section 3.5.1). The NSW EPA's contaminated sites guidelines approves the Australian guidelines used in this review. It also includes aspects of sampling and reporting to deal with site contamination under the CLM Act and following sites for managing contaminated land. These guidelines are listed in Appendix C of the CLM Act and those used here are described in Section 3.

Definition of the current extent of lead and other heavy metal contamination and arsenic in the Wollongong LGA has been achieved by following the current NEPM practices for soil and air, the NHMRC, the enHealth Human Risk assessment methodology, ANZECC/ARMCANZ (2000)/ANZG (2018) for water and sediment and reference to FSANZ food guidelines (Sections 3.5.and 3.6). Some application of overseas guidelines may be appropriate in the absence of suitable Australian guidelines, including the USEPA house clearance standards (2001) and the German air pollution control regulation TA LUFT and New Zealand guidelines). The German fallout guidelines (TA LUFT, 1990, 1999; (Table 3) could be used to compare against measured metal fall-out data from the 1970s and 1980s by normalising data to the guideline units (Section 4.3). Thus, retrofitting historical data to current guidelines can indicate how good or bad conditions were at the time of sampling and measurement.

The success of programs to control human exposure to lead and other heavy metals is judged by assessing the available data for soil total heavy metal and arsenic concentrations and local population blood and/or urine data, if available) against appropriate guidelines using recognised frameworks (Section 3.5). Best practice will be achieved if the risk assessment approach of enHealth (2012) is followed with guidance of NEPM (NEPC 2013) and the NHMRC (2016) by using their standardised procedures, including those of Standards Australia. In the absence of Australian guidelines or standards, those from overseas may need to be used.

The quantification of risk from lead and other heavy metal and arsenic contamination in soil is made more accurate if the measured concentrations correspond to a toxicity effect (Section 3.6). Simply analysing the total concentration of lead, arsenic and cadmium in soils, dusts or other materials is usually not an accurate measure of the potential health effect of the contamination (Ng et al., 2015). The health effects depend, in part, on the body's ability to absorb the contaminating substance. The ability of the human body to absorb lead, arsenic or cadmium depends on its chemical form. The solubility of lead, arsenic or cadmium minerals and other compounds relate to their uptake or absorption in the human body and is described as bioaccessibility. The bioaccessibility of lead, arsenic or cadmium as free ionic species is higher than less soluble mineral forms (Ruby et al., 1999). The bioavailability of lead, arsenic or cadmium in soil is the fraction of the element ingested and/or inhaled that reaches the circulatory system in the body and can thus be measured in the blood or urine. Therefore, the quantification of risk from lead, arsenic or cadmium contamination in soil will be more accurate if the bioavailability, measured as bioaccessibility, are known and used for the risk assessment (Section 3.6.4).

House assessment for lead contamination can be undertaken according to US EPA (2001) but here are no equivalent standards for arsenic, cadmium, copper and zinc. There has been no application of floor wipe standards, or indoor deposition flux, for lead at houses in Port Kembla or elsewhere in the Illawarra, unlike Broken Hill.

Historically, health risk assessment of the population has been undertaken by measuring blood lead. Arsenic and cadmium can also be assessed by measuring in blood and/or urine but there are no contamination guidelines for houses. Because BLL is notifiable in NSW, its measurement at Wollongong is not possible for screening unless there is an exceedance of the current guideline (5 µg/dL). In the case of lead (Section 3.5.5), the US EPA IEUBK model for predicting blood lead in children is widely known and used to estimate uptake and circulation in blood (US EPA, 2004). There is no equivalent model for cadmium, arsenic or other heavy metals and therefore the significance of exposure to adults or children is assessed by using known thresholds established by the WHO, US EPA, or other bodies.

Whilst lead is identified as the key health risk at Wollongong, residual cadmium from smelting operations is potentially significant as a health risk at Wollongong LGA (Section 6.1). The potential pathways of cadmium will be similar to that for lead (Section 6.1) in the Wollongong LGA and have a similar fate from dispersion of former smelting and industrial activities. In most cases there are parallel guidelines of lead for arsenic and cadmium in soil [(Section 3.5.3; Table 1); air (Section 3.5.4; Table 2, Table 3, Table 4; water and food including aquatic species (Section 3.5.6 and tables therein)] that follow the first step of health risk assessment and identify if guidelines have been exceeded. However, there is no equivalent house dust and clearance standards of US EPA, 2001 nor IEUBK model for cadmium, arsenic or other toxic metals and therefore the significance of exposure to adults or children need to be assessed by using known thresholds established by the WHO, US EPA, or other bodies by undertaking ‘desktop calculations’. The calculated doses for respective metal or metalloid are compared against recognised ‘standard’ values (eNHealth, 2012; NEPC, 2013; Schedule B4; or an example from Broken Hill by Drew and Hagen, 2010) (Section 3.6.4).

The US EPA (2001) lead clearance standards for house floors, window sills and window troughs can be a useful screening tool for identifying if houses in Wollongong LGA have lead contamination (Section 3.5.4). Other surface wipe sampling criteria (Table 4) have been developed by Brookhaven National Laboratory (2014), in the absence of any other guidelines. Based on the US EPA lead clearance standard used (US EPA, 2001), the Brookhaven National Laboratory surface levels (µg/m^2) correspond to window sill contamination. In the absence of validated guidelines, estimates based on exposure will be required to identify if the surface wipe criteria are valid to assess the health risk from dust in houses.

Lead dust loadings for various surfaces are given in AS 4361.2-1998 *Guide to lead paint management Part 2: Residential and Commercial Buildings*. These were originally based on the 1995 US guidance for investigation of lead poisoning (Section 3.5.4). Lead paint (defined in Australia as 1% lead by weight of the dry film) is the most common source of lead poisoning in children, and identified by BLL exceeding the notifiable guideline of 5µg/dL in NSW. Lead paint with more than 1% lead was used in residences in Australia up to 1970 and there are 3.7 million pre-1970 homes in Australia (Lead Group, 2002). In 1992, the maximum lead content was reduced to 0.25% and in 1997 it was reduced again to the current maximum lead content of domestic paint - 0.1%. Hand to mouth activities result in the ingestion of dust from lead paint that is either flaking, chalking, or has been sanded. Ingestion of lead paint chips directly, either flaking from the walls or being chewed from painted pieces of furniture or toys (in particular, cots), is rarer but can cause very serious to lethal lead poisoning (Lead Group, 2002).

Thus, there are no Australian standards available to assess health risk from metals and metalloids in dust from houses in Wollongong (Section 3.6.4). The health risk from metals and metalloids in house dusts requires first principles calculation of dose for the inhalation, ingestion and dermal pathways following the methodology of eNHealth (2012) (Section 3.6.4). However, there is an extensive number of publications that provide guidance on managing clean-up of lead in houses and screening of lead in house dust (Lead Group, 2002).

Details are given in Section 3.6 on assessing the health effects of arsenic and cadmium, taking into account that both are carcinogens. Cadmium is identified as potentially significant in soil (Section 4.2) and can be measured in blood or urine as well as house dust.

6.3.2 Analytical methods

Section 4.5.3 identified that standardised methodologies with proper quality control procedures are needed to produce reliable analytical data for site contamination assessment. Currently, soil concentrations are compared against the NEPM criteria given in Table 1 (NEPC, 2013). However, several schedules are provided by NEPC (2013) to give guidance on all steps for the assessment of site contamination of soil, including site characterisation, sampling design, laboratory analysis, derivation of the guidelines and background details and assessment of the reporting for use of various levels in Schedule B1 (NEPC, 2013) (Section 4.5.3). It is unlikely that all aspects of site characterisation have been undertaken in the studies of soil contamination from the copper smelter at Port Kembla.

There are Australian standards such as AS4482.1 *Guide to the investigation and sampling of sites with potentially contaminated soil, Part 1: non-volatile and semi-volatile compounds* (Standards Australia, 2005) and NSW EPA soil sampling guidelines (DEC NSW, 2006) that provide guidance for collecting sufficient and reliable information for the assessment of a site potentially contaminated by lead and other heavy metals and arsenic. Standard chemical analysis provides a measure of 'total' lead or other heavy metal in soil, expressed as a concentration of the elemental form, although this is not particularly informative as a means of assessing how toxic the soil could be with human exposure (Section 4.5.3).

Standards Association of Australia has also produced various standard methods of analysis that are referred to throughout this report. Laboratories generally secure laboratory accreditation in Australia from NATA according to ISO 17025 that was originally developed in Australia (Standards Australia, 2018). A rule of thumb regarding reliability of environmental monitoring data is whether the laboratory in question was accredited against ISO 17025 by NATA. Historical data from laboratories that did not have accreditation according to ISO 17025 is best assessed by accompanying validation of results using external or certified reference materials and estimates of interferences with spiking techniques, or incorporating analytical steps known to reduce matrix interferences.

6.3.3 Limited data collection and routine monitoring

The summary of data generated from environmental and health studies conducted at the Wollongong LGA (Appendix A) was grouped as follows (Section 3.7):

- Studies prior to 1990 soil air plans and some blood lead measurement. Based on scientific curiosity about extent of contamination from understanding of similar situations elsewhere overseas.
- From 1990 to following the 1994 NSW LMAP to 1999 when guidelines emerged.
- Members of the public and a representative of IRATE.
- Sporadic production of new data since 2000 and the lack of blood lead survey data in Wollongong LGA.

Area wide distribution for lead and other heavy metals tends to be limited and is most extensive for lead in the Wollongong LGA. The collective of data from references and reports in Appendix A give a reasonable idea of the extent of contamination which probably still exists in the Wollongong LGA as the lead and other heavy metals do not degrade. The study by Jafari (2009) covers a detailed sampling of the soils and sediments in Port Kembla, including selective extraction of soil and sediment samples, but had limited usefulness for health risk assessment without further interpretation. It is demonstrated that using 0.1M hydrochloric acid extraction gives an approximate percentage of bioaccessibility for soil concentration data from Port Kembla but needs to be validated by performing a proper gastro-intestinal simulation test. The effectiveness of this approach is demonstrated by showing that all lead soil concentrations in soils collected by Jafari (2009) can be demonstrated as not being a health risk (Section 4.2).

There is a general data limitation for the environmental and health studies conducted at the Wollongong LGA in the 1990s or earlier as the current NEPM criteria and recommended practices were just being developed in the 1990s.

6.3.4 Insufficient selectivity of analytical techniques

Understanding the detailed relationship between speciation and bioavailability necessarily begins with a complete, accurate, and direct identification of lead species (or arsenic and cadmium species) in environmental media, such as soils, house dusts, natural mineralisation and processed mine waste. Lead chemical form in soils has traditionally been estimated by XRD. However, XRD has limited sensitivity and cannot detect forms of lead or other heavy metals below 0.01% or greater than 10,000mg/kg, which is far higher than the NEPM (2013) soil criteria for lead. Selective extraction techniques based on Tessier's and the BCR methods are commonly used to measure 'operationally-defined' lead forms but do not measure the actual chemical form (Ure and Davidson 2002). In addition, techniques based on SEM and SEM/EDS can be used to examine and compare mineralogical and morphological characteristics of smelter slag (Morrison et al. 2016). However, there are limitations with distinguishing lead and other heavy metal chemical forms when using X-ray techniques and how different lead species affect lead bioavailability with constant particle size.

Selective extraction techniques give operationally-defined forms in the sample. Importantly, selective extraction techniques do not measure bioavailability or bioaccessibility for health risk assessment purposes (Jafari, 2009) and do not measure lead or other heavy metal speciation. Importantly, selective extraction techniques do not measure bioavailability or bioaccessibility for health risk assessment purposes. The study by Jafari (2009) covers detailed sampling of the soils and sediments in Port Kembla, including selective extraction of soil and sediment samples but is of limited usefulness for health risk assessment work that is needed to follow the NEPM assessment process (NEPC, 2013).

At Broken Hill, lead isotope ratios show no difference in source as there is a mixture of lead from ore, petrol lead and lead in paint (Gulson et al., 1995) and the source of lead could not be resolved (Dong et al., 2019; Yang and Cattle, 2019). Lead isotopes also show no difference in source of lead at Mt Isa as all lead is derived from the same orebody (Noller et al., 2017). The extensive synchrotron X-ray absorption (XAS) analysis undertaken in the Lead Pathways Study at Mt Isa shows resolution of lead source at Mt Isa based on compound composition differences in environmental samples. This is a very sensitive technique performed at a synchrotron facility which can detect lead down to environmental concentrations of 0.001-0.002% (10-20mg/kg), including both crystalline and amorphous forms. This indicates that source identification based on lead compound composition is possible. House study using floor, window sill, window trough, soil and carpet dust for lead exposure based on US EPA (2001) could be used for health risk assessment together with IEUBK model in the Mt Isa study (Noller et al., 2017).

Thus, a convenient technique for determination of lead chemical form in soils and mine waste is synchrotron-induced XAS (Brown et al., 1999). Similar studies have been undertaken for arsenic chemical form in mine wastes and its relationship to bioaccessibility and bioavailability (Diacomanolis, 2016). Application of this approach enables a better understanding of the role that chemical forms have in lead or other heavy metal toxicology and bioavailability of site features including the occurrence of natural and historical residues from use of lead in petrol and paint.

Section 3.6 describes how utilisation of health risk assessment is undertaken for assessing the significance of lead and other heavy metal contamination. Therefore, when predicting environmental transport and fate of metals and metalloids, it's critical to have accurate and extensive chemical and physical characterisations of natural mineralisation, mining sources, mineral processing sources, and community environmental samples. This is also critical in understanding and minimising important human exposure pathways. The key step in predicting the significance of human exposure to lead and other heavy metals and their bioavailabilities is to know how widely the variation is among different minerals and compounds in various environmental settings. This feature is demonstrated for lead in Figure 2. If bioaccessibility is demonstrated to be <100% for lead or other heavy metals in soil, it is able to provide a reduction in the risk of a human health hazard.

7. Conclusions and Recommendations

The NSW EPA has sought the services of a consultant to undertake a literature review and prepare a report on the key legacy contamination issues in the Port Kembla area from lead, other heavy metals (cadmium, copper and zinc), and arsenic in soil and associated human exposure.

Information has been generated from the Working Group but no meeting has yet been held with the Port Kembla Pollution Meeting, Port Kembla Harbour Environment Group and other relevant stakeholders due to the unprecedented COVID-19 related events. All reports, papers and websites listed in Schedule A (Appendix A) were examined as were several papers and reports from more recent literature.

The comprehensive independent review and analysis of information was undertaken in relation to the Wollongong LGA on levels and distribution of heavy metals and arsenic in soils and roof dust, lead in air, BLLs and associated strategies/measures to manage human exposure and prevent/minimise human health risks.

The review has considered the available information for the Port Kembla area against relevant, contemporary national and international Australia guidelines. These include the NHMRC and NEPC from the NSW EPA's contaminated sites guidelines which approves the Australian guidelines used in this review as listed in Appendix C of the CLM Act, together with aspects of sampling and reporting to deal with site contamination for managing contaminated land.

The rationale for the guidelines used to interpret information has been achieved by following the current NEPM practices for soil and air, the NHMRC, the enHealth Human Risk assessment methodology, ANZECC/ARMCANZ (2000)/ANZG (2018) for water and sediment, and making reference to FSANZ food guidelines. Some application of overseas guidelines was appropriate in the absence of suitable Australian guidelines, including the US EPA house clearance standards (2001) and the German air pollution control regulation TA LUFT (TA LUFT, 1990, 1999) and New Zealand guidelines (2001). Best practice is achieved if the health risk assessment approach of enHealth (2012) is followed with guidance of NEPM (NEPC 2013) and the NHMRC (2016) by using their standardised procedures, including those of Standards Australia. In the absence of Australian guidelines or standards, those from overseas are used.

7.1 Conclusions

This independent review report makes the following conclusions.

7.1.1 Soil

The soil samples from Port Kembla and surrounding locations in the Illawarra cover a time frame of 1972 until 2008 corresponding to part of the operational of the copper smelter to beyond its decommissioning. Very high concentrations of lead in soil were also found to be due to lead in paint (Williams et al., 1995). The levels and distribution of heavy metals in soils from the largest and most comprehensive soil data set is collected by Jafari (2009) following post-decommissioning.

It is concluded that the highest arsenic copper and zinc total concentrations do not exceed HIL A when plotted versus distance from the copper smelter.

The highest lead total concentrations plotted for lead concentration versus distance from the copper smelter shows that total lead concentration exceeds HIL A when < 1km from the smelter and is assumed to be for 100% bioavailability. When the 0.1M Hydrochloric acid extractable lead concentration equivalent to a site specific level of 1071mg/kg (bioaccessibility-adjusted) comparison with Jafari (2009) data was compared versus distance from the copper smelter, there was no exceedances of HIL A excepting for the highest slag sample S58 (4157mg/kg lead).

It is concluded that total lead concentration exceeds HIL A when < 1km from the smelter but testing with a proper bioaccessibility (gastro-intestinal) assay is likely to confirm the finding that 0.1M Hydrochloric acid extractable lead concentration could show no exceedances of HIL A for all samples, excluding the highest slag sample S58.

Twenty two samples exceed HIL Level A for cadmium and correspond to samples above the detection limit for cadmium total concentration including the slag sample (S58). It is possible that high cadmium concentrations for S89 (673 mg/kg), S90 (840 mg/kg) and S91 (626 mg/kg) are also for slag, but this origin is not confirmed. When the 0.1M Hydrochloric acid extractable cadmium concentration was compared with Jafari (2009) total cadmium concentration data , there was no exceedances of HIL A.

It is concluded that based on some of 22 samples total cadmium concentration above detection limit exceeding HIL A, further investigation of cadmium in soil, as collected by Jafari (2009) is warranted and should include both total and bioaccessible cadmium to enable a complete health risk assessment to be undertaken.

7.1.2 House dust

House dust samples collected from houses between 1992 and 1997 as accumulated roof dust, ceiling, wall vent and crack dust, floor and carpet dust, shelves and window sills showed highest concentrations of lead and arsenic in house dusts between 0.3 and 1.0km from the copper smelter (Willison, 1993). Although lead in house dust is recognised as one of the best predictors of childhood exposure to lead poisoning, it remains least understood as no data set exists from Port Kembla. There is no data available measured via a health risk based guideline to identify if dust in houses within 1km of the former copper smelter at Port Kembla is a potential health risk, or from lead paint. There was limited collection and measurement of heavy metals and arsenic in dust fallout but no measurement of indoor fallout or floor wipe concentrations (LMAP, 1994). The focus on managing contamination of houses at Port Kembla has therefore been based on identifying high or extreme levels of lead in house dusts and submitting adults and children for blood lead measurement, if notifiable.

Concentration measurement of lead in house dust is able to identify if lead paint is present as it will contain 1% lead by weight. Using floor wipes (US EPA, 2001) for lead loading measurements (µg lead/m^2) more directly measures lead ingestion for a child and could better predict children's BLLs by IEUBK model compared with house dust lead concentrations (mg/kg). House dust and soil lead concentrations can be an input parameter for the IEUBK model for prediction of blood lead.

The lack of any blood lead survey since the introduction of the 5µg/dL level by NHMRM in 2016 means that notifiable exceedance of this level is the only health based criteria to detect child exposure in Port Kembla houses.

It is concluded that the houses within 1km of the former copper smelter need to be screened by using floor wipe concentrations together with soil and house dust for total and bioaccessible lead concentrations that can be inputted to the IEUBK model to predict blood lead of children.

7.1.3 Lead in air

Monitoring of lead in air particulates at Port Kembla showed there was a dramatic reduction from 1974 to 1975 (from 5 µg/m^3 down to 1.5 µg/m^3). Airborne lead levels continued to decline with successive decreases in the NEPM guideline for lead to 1.5 µg/m^3. Following 2000, the highest annual average lead in air was 0.11 µg/m^3. By 2004 monitoring of lead in air particulates at Port Kembla ceased. Recent measurements of lead in air at BlueScope Steel, Unanderra from 2016 to 2019 show lead was < 0.06 µg/m^3.

Monitoring of lead in air particulates is of limited importance for health risk assessment as the fraction collected as PM_{10} (10µm diameter) that enter the bronchial tubes only constitutes 5% of exposure dose. The apparent importance of monitoring airborne PM_{10} for lead is outweighed by the need to have data which explains contribution to dose from the ingestion exposure pathways.

7.1.4 Blood lead levels

The historical record of lead emissions from the Port Kembla copper smelter and steelworks (Section 4.3) indicates that the extent of dispersion of air particulates in fall-out that was deposited on houses was plausible based on residual concentrations in soil. Since the copper smelter operations have ceased it is unlikely that fall-out dust deposition is likely to reach significant levels as occurred during the operational phase at Port Kembla. However, reconstitution and remobilisation of historical dust deposition in soil through undertaking earthworks or renovation of older houses may occur.

The BLL of children decreased from GM 12.9µg/dL in 1982 to AM 6.4µg/dL in 1994. This decrease accompanied a reduction in smelter lead emissions airborne lead concentration. Since 1994 there has been no community BLL survey at Port Kembla. Since 2016, the NHMRC recommended that if BLLs are greater than 5µg/dL, the source of exposure should be investigated and reduced, particularly if the person is a child or pregnant woman. This followed 22 years of having a BLL guide of less than 10µg/dL. Exposure to lead in Australia has dropped significantly over recent decades as a result of measures restricting the use of lead in paint, petrol and consumer goods (Gulson et al., 2014). As a result, the average BLL in Australia is estimated to be less than 5µg/dL. Investigating the source of exposure where BLLs are greater than 5µg/dL will reduce the risk to individuals, particularly children (NHMRC, 2016).

Specifically for lead, a risk assessment technique has been developed to assess the uptake of lead into the blood via soil intake, which effectively applies an a priori uptake factor to an estimated dose to estimate blood lead concentration (NEPC, 2013; Schedule B4). The US EPA IEUBK model for lead in children is widely known and used in this respect (US EPA, 2004). This approach, with the appropriate justifications, is considered suitable at Tier 2 for assessing risks from lead and can be applied for predicting blood lead on children who are exposed to lead from soil and house dust (Section 3.6.4; NEPC, 2013; Schedule B4).

7.1.5 Any associated strategies/measures to manage human exposure and prevent/minimise human health risks.

Key details of relevance to the Port Kembla case were identified as follows:

- Reduction of lead in air and BLL is a basis for closure on site. A lead budget gives an estimate of total lead in the environment to map the fate.
  - Remediation is based on removal of lead and/or prevent its dispersion and re-entrainment in air.
  - Assessing effects on people require guidelines that are based on human health risk assessment.
  - There is a common observation that highest surface soil within 2km of smelter and accompanies highest child BLL.
- Utilisation of appropriate techniques at houses including indoor lead flux and passive wipe methods in houses and measurement of bioaccessibility in soil and dust for hazard assessment including dose response, and BLL for exposure assessment, enables effective application of health risk assessment.
- Lack of capability to identify sources of lead is dependent on insufficient range of analytical techniques being used.
- House study for health risk assessment together with IEUBK model to predict BLL of children requires site specific soil and dust levels using.

7.1.6 The extent and limitations of the data and information available.

Appropriateness of guidelines and lack thereof

It is concluded that house dust assessment lacks an appropriate health risk based method that can be applied routinely at locations like Port Kembla. In the case of lead, the US EPA IEUBK model for predicting blood lead in children is widely known and used to estimate uptake and circulation in blood (US EPA, 2004). However, there is no equivalent model for cadmium, arsenic or other heavy metals and therefore the significance of exposure to adults or children is assessed by using known thresholds established by the WHO, US EPA, or other bodies. In the absence of validated guidelines, estimates based on exposure are required to identify if the surface wipe criteria are valid to assess the health risk from dust in houses. Details are given in Section 3.6 on assessing the health effects of arsenic and cadmium, taking into account that both are carcinogens. Cadmium is identified as potentially significant in soil (Section 4.2) and can be measured in blood or urine as well as house dust.

Analytical methods

House dust health risk assessment stands out as an area requiring further development of methodology, particularly for arsenic and cadmium.

Limited data collection and routine monitoring

The data limitation for the environmental and health studies conducted at the Wollongong LGA in the 1990s or earlier reflects the importance of maintaining a level of monitoring that will enable health risk assessment to be performed.

Insufficient selectivity of analytical techniques

The issue at Broken Hill with lead isotope ratios showing no difference in source as there is a mixture of lead from ore, petrol lead and lead in paint and the source of lead could not be resolved, points to the need to investigate methodologies that will enable identification of source components. Synchrotron XAS analysis, in contrast to lead isotope ratios, shows resolution of lead source at Mt Isa based on compound composition differences in environmental samples This approach will assist in undertaking more accurate human health risk assessment.

7.2 Recommendations

The following recommendations from this independent review report are made:

1. Undertake measurement of both total and bioaccessible (gastro-intestinal- sieved at < 250µm) assay concentration of cadmium in soils < 1km from the former smelter location to establish site specific data for more accurate comparison with the HIL A criteria.
2. Develop a methodology that will enable performing a health risk assessment on houses within 1km of the former copper smelter by screening the use of floor wipe concentrations together with soil and house dust for total and bioaccessible (gastro-intestinal-sieved at < 250µm) assay for arsenic, cadmium and lead concentrations that can be inputted to the IEUBK model to predict blood lead of children and dose calculations for arsenic and cadmium.

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Young, A.R.M., Bryant, E.A. and Winchester H.P.M. (1992) The Wollongong Lead Study: an investigation of the blood lead levels of pre-school children and their relationship to soil lead levels. Australian Geographer 23 121-133.

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Appendix A RFQ Statement of Requirements

<u>RFQ Statement of Requirements (scope of works)</u>

PART B – RFQ Statement of Requirements

LITERATURE REVIEW OF THE LEVELS OF LEAD AND OTHER HEAVY METALS IN SOIL AND ROOF DUST IN WOLLONGONG AND MEASURES TO MANAGE ANY ASSOCIATED HEALTH RISKS.

1. Terms of reference

The New South Wales Environment Protection Authority (EPA) is seeking the services of a consultant to undertake a literature review and prepare a report on the presence of lead and other heavy metals in air, soil and roof dust in the Wollongong Local Government area and any associated measures to manage human health risks.

2. Purpose

The Literature Review is being prepared to inform the Lead & Other Heavy Metal Contamination Working Group comprising representatives from the EPA, Wollongong City Council and NSW Health. The purpose of this group is to understand what has been done in the past and to determine what if any future actions are required to further address heavy metal contamination in the Wollongong Local Government area, particularly where human health risks are identified. The proposed literature review will be one of the matters considered by the Working Group in developing strategies to address contamination issues, should the need be identified.

3. Background Information

The City of Wollongong is a local government area in the Illawarra region of New South Wales, Australia. Located 80 kilometres south of Sydney it covers 714 square kilometres and has a population of around 208,000 people. It occupies a narrow coastal strip bordered by the Royal National Park to the north, Lake Illawarra to the south, the Tasman Sea to the east and the Illawarra escarpment to the west. The LGA contains an industrial complex (one of the largest in Australia) centred on Port Kembla. Port Kembla is a coastal suburb located 8 km south of Wollongong. It covers an area of approximately 800 hectares and has a population of around 5000 people. It includes residential, commercial and industrial precincts and extensive recreational/parklands. There are two primary schools, one secondary school and one preschool in the suburb.

Industry has been a feature of Port Kembla for over 100 years. A copper smelter commenced operation around 1908 and ceased in 2003. During this period it has been operated by several companies and undergone various upgrades, expansions and shutdowns. A small coal fired power station operated nearby from 1913 to 1963. Historically other industries have included hard rock quarrying and the production of fertilisers/industrial refractories. Some industries that produce sulphuric acid and copper products (from pure billets and scrap) as well as shipping related activities are ongoing. Nearby there is a large integrated steelworks (coke ovens, sinter plant, iron and steel making, metal finishing) that started in the 1930s and continues to the present day.

A considerable body of literature exists on the nature, extent and distribution of heavy metals in soils, lake sediments and roof dust in the Wollongong LGA, in particular in and around Port Kembla. Lead has been a key parameter investigated, but other metals include cadmium, arsenic, zinc, copper and chromium. Attempts have been made to identify the source of this contamination. The higher levels of metals in topsoil suggest airborne and anthropogenic sources. Some studies (for example isotopic testing of lead) have identified contributions from gasoline, industrial emissions (smelting and coal burning) and the local geology. Some limited vegetable testing has also been conducted and reported. Uptake from active aerial sources at the time of the studies has been suggested as key source of contamination of leafy vegetables compared to soil uptake.

Several blood lead (PbB) screening programs were conducted in the LGA in the 1980s and 1990s. In some instances a small percentage of children tested had blood lead levels higher than the recommended level and populations at risk of lead exposure were identified. Some studies found lead in air did not correspond to increased blood lead, however there was correlation between soil lead levels and PbB. There was no clear correlation between location and distances of residences and schools from specific industrial sources, such as the smelter. Follow up of children with moderately elevated PbB, indicated that the usual cause was 'multifactorial', i.e. likely to have resulted from multiple small exposures to lead from a number of sources. The main pathway for lead exposure among children was considered to be ingestion. The probable main sources/ pathways contributing to elevated PbB in Port Kembla were as follows:

- lead-based paint in pre-1970 houses with deteriorating paint &/ or following unsafe renovations;
- soil lead: from paint & airborne lead (from industrial emissions & petrol); and household dust from lead-based paint, soil lead & air-borne lead (with a negligible contribution from roof dust where ceiling spaces are sealed & undisturbed).

In 1994 a Lead Management Action Plan for NSW was released. This Plan included recommendations of specific actions for point source communities. The recommended Interim Action Plan for Port Kembla, involved quantification of the lead issue, to be undertaken by a multidisciplinary team, including NSW Health, EPA, industry & local government. The development of an action plan for management of lead issues was recommended, dependent on the findings of the investigation program.

In 1995 an Illawarra Lead Taskforce was convened by the Illawarra Public Health Unit to quantify the lead issue in the Illawarra, & develop a plan for lead management. The taskforce included representatives from state and local government agencies, University of Wollongong, industry, non-government community organisations and the community. An Illawarra Lead Management Plan was developed in 1998. The Plan included the following aims:

- Monitor, investigate & regularly feedback information to the community about blood lead levels & environmental lead levels in the Illawarra, focussing on Port Kembla
- Increase the awareness, knowledge & skills of people in the community, in particular parents of young children, & people working in local health services, childcare/ education, local government & relevant trades, so as to minimise lead exposure & environmental lead contamination in the Illawarra, focussing on Port Kembla
- Minimise the potential for exposure to historical lead contamination, & reduce further environmental lead contamination, focussing on the Port Kembla area

Lead levels in air have been extensively monitored by industry and/or government in the LGA since the 1970s. There has been a significant reduction in the air lead over the decades. In the 1970's and 1990's Port Kembla had some of the highest air lead levels in NSW. The reduction in lead in the air has been attributed to various measures including the phasing out of leaded gasoline, industry emission reductions and/or closures. Annual emissions of lead (tonnes per annum) in the LGA are low compared to other parts of NSW and Australia. The main contributions relate to Basic Ferrous Metal Manufacturing and motor vehicles respectively.

In general the identification of high lead levels in soils and PbB from previous studies appears to have a lower incidence in the Wollongong LGA (and Port Kembla) compared to other parts of NSW with major point source lead emissions, such as Lake Macquarie North and Broken Hill, or the inner city areas of Sydney. For example 90% of soil lead levels in Port Kembla are less than 1,000ppm, with the vast majority below 300ppm. As a general guideline no action is required where typical soil lead levels are below 300ppm and grass cover is recommended where soil levels are 300-1,500ppm. These lead levels are also lower than that for which remediation has been undertaken at Port Pirie, South Australia. Various options for soil/dust management were explored as part of the above management plans in the 1990's. No major programs of remediation were considered warranted at the time, but some roof dust and soil removal did occur at individual properties in response to specific concerns (for example Old Port Kembla Primary School).

The literature relevant to this review should focus on the above legacy contamination issues in the Port Kembla area. Other information across the LGA and other areas of NSW (for example Broken Hill and Lake Macquarie) and Australia (for example Port Pirie, South Australia and Mount Isa, Qld) may also reviewed where relevant. Literature known by the Working Group on air quality, soils, roof dust, blood lead studies and measures to manage human exposure and prevent/minimise human health risks are listed in Schedule A and are to be considered by this review.

4. Scope of work

A suitable consultant will be engaged to undertake the review. This includes the following:

1. Seek information from the Port Kembla Pollution Meeting, Port Kembla Harbour Environment Group and other relevant stakeholders that may be available that should be considered under (2) below and has not already been identified in Schedule A.

2. Undertake a comprehensive independent review and analysis of information in relation to the Wollongong LGA and:
   - The levels and distribution of heavy metals in soils and roof dust.
   - Lead in air
   - Blood lead levels
   - Any associated strategies/measures to manage human exposure and prevent/minimise human health risks.

   This review should include a detailed commerntary and analysis of:
   - the information against relevant, contemporary national and international Australia guidelines. Australian guidelines include the National Health & Medical Research Council and National Environment Protection Council;
   - the rationale for the guidelines used to interpret information; and
   - The extent and limitations of the data and information available.

   This information should include the information listed in Schedule A and identified in (1) above

3. Provide an Independent Review Report with recommendations concerning the abovementioned tasks.

4. Resources and information EPA will supply

See Schedule A – List of documents.

5. Outputs

The EPA requires timely delivery of the following services (the following timeline is indicative and may be negotiated on appointment):

- A commencement meeting with the Working Group to discuss project scope, methodologies and timeline. The consultant will consider any feedback from this meeting and ongoing progress communications when developing the methodological approach to the study.
- A draft project plan in Microsoft Word/Excel format. The draft plan must address the scope of works and include indicative costings, hours and an engagement strategy.
- A final project plan.
- A mid contract meeting with the Working Group to discuss the progress and findings.
- A draft review report in Microsoft Word format in accordance with the scope of the review; including conclusions and recommendations.
- A completed report in PDF format incorporating comments from the Working Group. The final report must address all aspects of the scope of work.
- A summary of the report and recommendations given as a presentation to:
  - The Working Group.
  - Wollongong City Council councillors.
  - Port Kembla Pollution Meeting.

7. Timeframes and payment schedule

Milestones and progress payments are outlined in the following table**.** The study must be completed by 30 March 2019.

Milestone	**Deliverable**	**Progress Payment**	**Timing**
1	Agreement on scope of analysis and detailed project plan	30% progress payment of contract sum	Project commencement
2	Delivery of draft report addressing scope of work	30% progress payment of contract sum	Within 3 months of project commencement
3	Delivery of final report addressing scope of work. A summary of the report and recommendations given as a presentation to the Working Group;	40% final payment of contract sum.	Within 6 months of project commencement.

SCHEDULE A

LIST OF DOCUMENTS

NOT EXHAUSTIVE
Metals Content of Dust in the Roofs of Houses Around the Port Kembla Industrial Area, Illawarra Public Health Unit, 25 March 1993
Trace Metal contamination of soils and sediments in the Port Kembla area, NSW. Yasaman Jafari, University of Wollongong Thesis Collection, 2009
The Health Atlas of the Illawarra – Wollongong, Kiama & Shellharbour. Tracey T.A McDonald & Murray G.A Wilson. Sponsored by the Illawarra Healthy Cities Project & the University of Wollongong 1990/91.
Metal concentrations in soils around the copper smelter and surrounding industrial complex of Port Kembla, NSW Australia. E. Martley et al. Science of the Total Environment 325, (2004)
Metal Partitioning in soil profiles in the vicinity of an industrial complex, NSW Australia. Elizabeth Martley et. al. Geochemistry: Exploration, Environment, Analysis, 4, 171 – 179 (2004)
The regional extent of heavy metal contamination in soils due to atmospheric emissions and potential health hazards. Elizabeth Martley. Thesis (MSc (Hons)) – Macquarie University (Division of Environmental and Life Sciences, Graduate school of the Environment), 2002
The use of wind direction data to predict pollution dispersal around the Port Kembla industrial area, New South Wales. P.T. Crisp, O.W. Archibold and E.A. Crisp. Australian Geographical Studies 22, October 1984
The distribution of airborne metals in the Illawarra region of New South Wales, Australia. O.W. Archibold and P.T. Crisp. Applied Geography (1983), 3, 331-344
Contamination of soil with zinc, copper, lead, and cadmium in the Wollongong city area. F. Beavington. Australian Journal of Soil Research 11, 27-31 (1973).
Some aspects of contamination of herbage with copper, zinc and iron. F. Beavington. Environmental Pollution 9, 65 – 71 (1975a).
Heavy metal contamination of vegetables and soil in domestic gardens around a smelting complex. F. Beavington. Environmental Pollution 9, 211 – 217 (1975b).
Seasonal enrichment by trace elements of kikuyu grass around heavy metals industries. F. Beavington. Plant and Soil 45, 283 – 286 (1976)
Trace elements in rainwater and dry deposition around a smelting complex. F. Beavington. Environmental Pollution 13, 127 – 131 (1977).

EPA Website Lead publications: http://www.epa.nsw.gov.au/pesticides/lead-safety.htm
NSW Workcover Lead Work http://www.workcover.nsw.gov.au/
The Lead Group Inc website publications: http://www.lead.org.au/index.html
National Pollutant Inventory – Search data for Wollongong LGA /Port Kembla: http://www.npi.gov.au/
Heavy metals contamination in vegetables grown in urban and metal smelter contaminated sites in Australia. Anthony George Kachenko and Balwant Singh. Water, Air, and Soil Pollution (2006) 169: 101-123
Identification of historical lead sources in roof dusts and recent lake sediments from an industrialised area: indications from lead isotopes. M. Chiaradia et. al. The science of the Total Environment 205 (1997) 107-128.
National Environment Protection Council – National Environment (Assessment of Site Contamination) Protection Measure http://www.nepc.gov.au/home
Evaluation of Possible Environmental Sources of Lead in Children in Port Kembla, Kemblawarra, Warrawong and Cringila. C. Williams et. al. Illawarra Environmental Health Unit. 1995
Blood lead levels in school children in the Port Kembla area. Ignatius Gan et. al. The Medical Journal of Australia. October 16 1982
Illawarra Child Blood Lead Study 1994 - Preliminary Report. I. A. Kreis et. al. Illawarra Environmental Health Unit 1994
EPA website - Lake Macquarie community and expert committees to review lead exposure management http://www.epa.nsw.gov.au/MediaInformation/lake-macquarie.htm
Draft Discussion Paper – Options related to the management of lead-contaminated dust in Port Kembla – 25 March 1998. Illawarra Public Health Unit (FOR DISCUSSION)
Reusing Potentially Contaminated Landscapes: Growing Gardens in Urban Soils. U.S. Environmental Protection Agency EPA/542/F-10/011 (2011). https://clu-in.org/ecotools/urbangardens.cfm
Managing Lead Contamination in Home Maintenance, Renovation and Demolition Practices. A Guide for Councils (EPA/Planning NSW, 2003). http://www.environment.nsw.gov.au/resources/pesticides/03004managinglead.pdf
Illawarra Lead Management Action Plan: Background Information for the Illawarra Lead Taskforce. Draft 24 November 1997. DOC15/294173

Illawarra Lead Management Plan 1998-2001. Illawarra Public Health Unit, Illawarra Area Health Service, October 1998. DOC15/294173
Background information – Technical documents – Australian Institute of Environmental Health – Lead in Children report DOC15/294146
Case study: The Port Kembla Community's Dilemma with Toxic Dust. By Robin Mosman, NSW Community Lead Advisory Service - Lead Action news Vol 5 No. 1 1997. DOC15/294140
Environmental Lead Assessment. Port Kembla Public School. Prepared for NSW Department of School Education by Graeme Waller & Associates PO Box 369 Charlestown NSW 2290 (1996).
Report prepared by Illawarra Public Health Unit for Port Kembla Pollution Meeting (April, 1997)
NSW EPA website - Managing Contaminated Land *http://www.epa.nsw.gov.au/clm/management.htm*
NSW Health website – Health Topics from A to Z - Lead & Lead Exposure in Children *http://www.health.nsw.gov.au/pages/a2z.aspx*
Current Air Quality in NSW: A technical paper supporting the Clean Air Forum (NSW Department of Environment, Climate Change and Water NSW, 2010) *http://www.environment.nsw.gov.au/air/cpairqual.htm*
NSW State of the Environment Reports *http://www.epa.nsw.gov.au/publications/index.htm*
Air Quality Trends in the Illawarra - Current knowledge based on emission, monitoring and modelling studies, and areas of ongoing research (OEH, 2015). *http://www.epa.nsw.gov.au/esdsmoky/illawarra-air-quality.htm*
The relationship between atmospheric lead emissions and aggressive crime: an ecological study. Taylor et al. Environmental Health (2016) 15:23
ANSTO Fine particle pollution monitoring - coastal NSW *http://www.ansto.gov.au/Resources/Localenvironment/Atmosphericmonitoring/Fineparticlepollution/index.htm*
Ambient Air Quality Monitoring Data – Bluescope Steel Ltd – Environment Protection Licence Number 6092
Ambient Air Quality Monitoring Data – Port Kembla Copper Ltd – Environment Protection Licence Number 1753

Appendix B **Experience of Consultant**

Associate Professor Noller has a PhD (1978) in Environmental Chemistry from the University of Tasmania. He worked as a Research Fellow at the Australian National University (1978-1980), Senior Research Scientist at the newly created Alligator Rivers Region Research Institute, Jabiru, Northern Territory (1980-1990) and then as Principal Environmental Chemist for the Department of Mines and Energy, Darwin Northern Territory (1990-1998). From 1998-2006 Professor Noller has been Deputy Director of the National Research Centre for Environmental Toxicology (ENTOX) – The University of Queensland, Coopers Plains, Qld. ENTOX has a strong involvement with the utilisation of the risk assessment process to deal with toxicological hazards, including in environmental systems. Since November 2006 Professor Noller has been appointed as Honorary Consultant and Associate Professor at the Centre of Mined Land Rehabilitation (CMLR) a centre of the University of Queensland based at St Lucia. The CMLR is part of the Sustainable Minerals Institute. Professor Noller has been working and publishing in the field of environmental chemistry and industrial toxicology for the past 40 years and has presented 430 conference papers and published 220 papers. His professional activities undertaken at 4 different centres have covered processes and fates of trace substances in the environment, particularly in tropical environmental systems with special reference to risk management associated with their application and studies of the bioavailability of toxic elements in mine wastes, including waters. He has undertaken a number of consulting activities in Queensland, Tasmania, New South Wales, Western Australia and the Northern Territory and has undertaken a number of investigations at the Metropolitan Colliery since 2007. He was appointed in 2007 as Lead Author of the Australian Government Leading Practice Sustainable Development Program for the Mining Industry Handbook on Cyanide Management and was Project Leader for the Lead Pathways Study conducted at Mount Isa on behalf of Glencore Xstrata 2007-2013.

Centre for Mined Land Rehabilitation (CMLR) (www.cmlr.uq.edu.au)

At the forefront of research, education and technical expertise, the Centre for Mined Land Rehabilitation (CMLR) is leading the way we think about mining environmental management. CMLR is involved in a broad range of research and training projects with mining companies, industry bodies and government departments from across Australia and the world. As a part of one of the largest universities in the world, the CMLR has a team of highly skilled professionals focusing on the key issues facing modern mining and minerals processing industries.

A member of the Sustainable Minerals Institute (previously the Sir James Foots Institute of Mineral Resources), the Centre was established at The University of Queensland in 1993 and has built on more than twenty years involvement with the mining and minerals industries.

CMLR and the Sustainable Minerals Institute (www.smi.uq.edu.au)

The Sustainable Minerals Institute (SMI) was established in 2001 as a joint initiative between the Queensland Government, The University of Queensland and the Minerals Industry. The proposed development was to build upon the existing expertise within the various centres and departments and provide and over-arching framework for progressing Minerals Industry Research, Education and Training activities.

The CMLR is the sole provider of environmental mining management within the University and has established for itself and the SMI a reputation of national and international significance.

Our Location. The CMLR is situated on the 5th floor of the Sir James Foots Building (No 47A) at the University of Queensland, St Lucia campus (www.uq.edu.au).

Appendix C **NSW EPA Websites**

- EPA website: Lead safety information and factsheets
  http://www.epa.nsw.gov.au/your-environment/household-building-and-renovation/lead-safety
- EPA website: Lake Macquarie community and expert committees to review lead exposure management http://www.epa.nsw.gov.au/working-together/community-engagement/community-news/lmc-review-lead-exposure-management
- EPA website: NSW State of the Environment Reports
  http://www.epa.nsw.gov.au/about-us/publications-and-reports/state-of-the-environment
- EPA website: Contaminated Land
  http://www.epa.nsw.gov.au/your-environment/contaminated-land
- Broken Hill Environmental Lead Program - Lead Smart website
  http://leadsmart.nsw.gov.au/
  http://www.environment.nsw.gov.au/topics/air/research/current-research/broken-hill-environmental-lead-study
- The Lead Education and Abatement Design (LEAD) Group
  http://www.lead.org.au/
- LEAD Group factsheets
  http://www.lead.org.au/fs-index.html
  - Lead aware housekeeping
  - Ceiling dust & lead poisoning
  - Lead in ceiling dust
  - Lead paint & ceiling dust management - how to do it lead-safely
    - ➢ Lead, Your Health & the Environment
    - ➢ Lead Safe Housekeeping
    - ➢ Old Lead Paint
    - ➢ Working safely with lead
    - ➢ A Renovator's Guide To The Dangers Of Lead (Brochure 30 pages)
    - ➢ A Guide For Health Care Professionals (Brochure 34 pages)
    - ➢ A Guide To Keeping Your Family Safe From Lead (Brochure 20 pages)
    - ➢ Lead Hazard Management In Children's Services (Brochure 15 pages)
    - ➢ A Guide To Dealing With Soil That Might Be Lead-Contaminated
    - ➢ Lead and Home Renovations (Brochure 2 pages)
- Department of the Environment and Energy – Lead
  http://www.environment.gov.au/protection/chemicals-management/lead
- National Pollutant Inventory – Data search for Wollongong/Port Kembla LGA
  http://www.npi.gov.au/npidata/action/load/advance-search
- SafeWork NSW – Lead Work
  http://www.safework.nsw.gov.au/health-and-safety/safety-topics-a-z/hazardous-chemical/lead-work

- NSW Health – Health Topics from A-Z – Lead
  http://www.environment.gov.au/protection/chemicals-management/lead
- NSW Health – Health Topics from A-Z – Lead exposure in children
  http://www.health.nsw.gov.au/environment/factsheets/Pages/lead-exposure-children.aspx
- National Environment Protection Council – NEPM (Assessment of Site Contamination)
  http://www.nepc.gov.au/nepms/assessment-site-contamination
- ANSTO Fine Particle pollution monitoring – Coastal NSW
  http://www.ansto.gov.au/Resources/Localenvironment/Atmosphericmonitoring/Fineparticlepollution/
- BlueScope Steel Illawarra – Monitoring data
  https://www.bluescopeillawarra.com.au/environment/reporting-on-performance/2017-nsw-monitoring-data/

A number of guidelines are listed to deal with particular kinds of contaminated sites and aspects of sampling and reporting deal with site contamination under the Act and the following sites for managing contaminated land. These guidelines are listed in Appendix C.

- Guidelines for the vertical mixing of soil on former broad-acre agricultural land (PDF 148KB) (reprinted June 2003)
- Sampling design guidelines (PDF 2MB) (September 1995)
- Guidelines for assessing banana plantation sites (PDF 586KB) (reprinted August 2003)
- Guidelines for consultants reporting on contaminated sites (PDF 428KB) (reprinted August 2011)
- Guidelines for assessing former orchards and market gardens (PDF 172KB) (June 2005)
- Guidelines for the NSW Site Auditor Scheme, 3rd edition (PDF 999KB) (October 2017)
- Guidelines for the assessment and management of groundwater contamination (PDF 604KB) (March 2007)
- Guidelines on the duty to report contamination under the Contaminated Land Management Act 1997 (PDF 412KB) (September 2015)

The EPA's contaminated sites guidelines refer to:

- the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC, October 2000), are replaced as of 29 August 2018 by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, August 2018), subject to the same terms with the exception of the Water quality for primary industries component which still refer to the ANZECC 2000 guidelines
- the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC 1999) are replaced as of 16 May 2013 by the National Environment Protection (Assessment of Site Contamination) Measure 1999 (April 2013), subject to the same terms.
- Guidelines approved by the EPA

Australian and New Zealand Government (ANZG):

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality, published by ANZG (August 2018)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality - Water Quality for primary industries (ANZECC 2000)

EnHealth publications (formerly National Environmental Health Forum monographs):

- Composite sampling, Lock, W. H., National Environmental Health Forum Monographs, Soil Series No.3, 1996, SA Health Commission, Adelaide. Email enHealth.Secretariat@health.gov.au for an electronic copy of this publication.
- Environmental health risk assessment: Guidelines for assessing human health risks from environmental hazards, Department of Health and Ageing and EnHealth Council, Commonwealth of Australia (2012)

National Environment Protection Council publications:

- National Environment Protection (Assessment of Site Contamination) Measure 1999 (April 2013)

The NEPM consists of a policy framework for the assessment of site contamination: Schedule A (Recommended General Process for the Assessment of Site Contamination) and Schedule B (Guidelines).

Schedule B guidelines include:

- Guideline on investigation levels for soil and groundwater
- Guideline on site characterisation
- Guideline on laboratory analysis of potentially contaminated soils
- Guideline on site-specific health risk assessment methodology
- Guideline on ecological risk assessment
- Guideline on methodology to derive ecological investigation levels in contaminated soils
- Guideline on ecological investigation levels for arsenic, chromium(iii), copper, DDT, lead, naphthalene, nickel and zinc
- Guideline on the framework for risk-based assessment of groundwater contamination
- Guideline on derivation of health-based investigation levels
- Guideline on community engagement and risk communication
- Guideline on competencies and acceptance of environmental auditors and related professionals

The ASC NEPM was amended on 16 May 2013.

Other:

- Guidelines for the Assessment and Clean Up of Cattle Tick Dip Sites for Residential Purposes, NSW Agriculture and CMPS&F Environmental (February 1996)
- Australian Drinking Water Guidelines, NHMRC and Natural Resource Management Ministerial Council of Australia and New Zealand (2011)

Appendix D NEPM Ecological Soil Ecological Investigation Levels

Ecological Investigation Levels for soil

The NEPM Ecological Investigation Levels (EILs) have been expanded and cover a range of soil types and constituents that apply for fresh and aged contamination in soil (NEPC, 2013). The former Interim Urban EILs (NEPC, 1996) were intended to give an indication of potential phytotoxicity at urban locations only. Thus, the current NEPM requires that both the potential effects to human health and the environment (ecology) of metals and metalloids associated with the Eastern Precinct be fully evaluated.

The NEPM (2013) now defines the EIL as the concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values will be required. The EILs are calculated using EC30 or lowest observed effect concentrations (LOEC) toxicity data. EILs are the sum of the added contaminant limit (ACL) and the ambient background concentration (ABC) and the limit is expressed in terms of total concentration. EILs depend on specific soil physicochemical properties and land use scenarios, and generally apply to the top two metres of soil.

The derivation and methodology for EILs used within the ecological risk assessment (ERA) framework is described in Schedules B5b and B5c (NEPC, 2013). It provides:

(i) protection of introduced and native animals, plants, microorganisms and microbial processes (including nutrient cycling);

(ii) setting levels of protection based on land use;

(iii) accounting for background concentration of contaminants;

(iv) accounting for changes in bioavailability of contaminants over time and in different soils; and

(v) accounting for contaminants that biomagnify.

Table A1 *Soil Ecological Investigation Levels for fresh and aged contamination in soil with various land uses (NEPM, 2013).*

Metal or Metalloida	Age of contaminant	Added contaminant limits (mg added/kg soil) or EIL (mg/kg) for various land uses		
		1. Area of ecological significance[3]	2. Urban residential/ public open space[4]	3. Commercial and industrial[5]
Arsenic[2] (As)	fresh	20	50	80
	aged	40	100	160
Copper[1] (Cu)	fresh	15-60	30-120	45-200
	aged	20-80	60-230	85-340
Lead[1] (Pb)	fresh	110	270	440
	aged	470	1100	1,800
Nickel[1] (Ni)	fresh	1-25	10-170	20-350
	aged	5-95	30-560	55-960
Zinc[1] (Zn)	fresh	7-130	25-500	45-800
	aged	15-280	70-1300	100-2000

Notes:

1 = the values presented for zinc, chromium (III), copper and lead are added contaminant limits (ACLs) based on added concentrations. The EIL is calculated from summing the ACL and the ambient background concentration (ABC).

2 = the values presented for arsenic are generic EILs based on total concentrations. Insufficient information was available to calculate ACLs for these contaminants.

3 = the standard protection level is 99%

4 = the standard protection level is 80%

5 = the standard protection level is 60%.

Because the toxicity of some contaminants is affected by physicochemical properties of the soils in which the contaminant is located, empirical relationships are used to model the effect of soil properties on toxicity as established so that soil-specific EILs can be developed (NEPC, 2013). An EIL calculation spreadsheet provides step-by-step guidance to enable deriving EILs specific to the site, with consideration of certain physicochemical properties of soils.

The EILs take into account the biological availability of the metal or metalloid in different soils and separate naturally occurring concentrations of a contaminant and the added contaminant in deriving EILs which are based on the 'added risk approach' (Struijs et al. 1997; Crommentuijn et al. 1997). This approach assumes that the availability of the ABC of a contaminant is zero or sufficiently close that it makes no practical difference and assumes that the background '*has resulted in the biodiversity of ecosystems or serves to fulfil the needs for micronutrients for the organisms in the environment*' (Traas, 2001). Therefore, the approach views only the effect of added contaminants to the environment as adverse (Section 2.4, Schedule B5b). Rather than having a single numerical limit for a contaminant, different soils will have different limits. The EIL derivation methodology seeks to generate soil-specific EILs wherever possible. However, it was not possible to derive soil-specific EILs for all contaminants (NEPC, 2013) and therefore the EILs for some contaminants are soil-specific while for others they are generic. Where sufficient data permitted, EILs were derived for sites with fresh (<2 years) and aged (≥2 years) contamination (NEPC, 2013). Those contaminants with generic EILs have a single value for each combination of land use and age of the contamination (arsenic and lead), whereas contaminants with soil-specific EILs have a suite of values derived (based on the soil physicochemical properties that control the toxicity) for each combination of land use and age of contamination (copper, nickel and zinc).

A summary of the EILs for arsenic, copper, lead, nickel and zinc is given in Table A1 (NEPC, 2013). There is no current EIL for cadmium. Importantly, EILs only apply to soil down to a depth of two metres below the current soil surface, which corresponds to the root zone and habitation zone of many species. The tiered ERA approach used in this guideline (NEPC, 2013) permits:

(i) identification of the ecological receptors of concern;

(ii) estimation of the concentration of a contaminant of concern to which the ecological receptors are exposed;

(iii) consideration of the toxicity-modifying or toxicity-enhancing capacity of the receiving environment (whether that be soil, sediment or water);

(iv) determination of whether the ecological receptors and ecological values may be at risk; and

(v) application of a multiple-lines-of-evidence approach to assess risks.

This tiered approach focuses resources on those sites that pose the greatest potential risk and provides a means of assessing the significance of ecological effects from soil contamination.

Relationship to animal health effects

PM is not normally assessed for domesticated terrestrial animals. However animals breathe air and may ingest deposited particles on soil surface or via ingestion of grass or other plants (Arslan and Aybek, 2012; Serita, 1999; Zhang, 2005). Wild animals may also be exposed when air particulates drift over natural open land or forest (Isaksson, 2010).

The wellbeing of domestic animals can be assessed by comparing contaminant levels with guidelines or establishing levels of toxicity. Contributions to human diet can be assessed by comparing contaminant levels with food guidelines (FSANZ, 2010). Wild (game) animals that are consumed as food can also be compared in a similar fashion. However, species that are part of the ecosystem have no guidelines for estimating exposure to specific contaminants. Blood or urine monitoring of wild terrestrial species may be appropriate to assess exposed and control animals.

Deposition to soil is assessed by collecting fall-out and by measuring specified constituents in soil that can be compared against guidelines. Soil cumulative contaminant loading limits (CCL) trigger values for heavy metals and metalloids (kg/ha) were developed (NWQMS, 2000) for long-term application of irrigation water to soil (Table 6). Table 6 gives a summary data for various livestock's body weight, peak water intake and peak food intake (ANZECC/ARMCANZ, 2000 p 9.3-16). Peak food intake assumes importance with cattle and sheep from grazing and involuntary ingestion because (Thornton and Abrahams, 1983): (i) cattle ingest up to 20% as soil (2kg); and (ii) sheep ingest up to 30% as soil (0.7kg). Thus, spraying deposition over open farmlands used for grazing may be significant if contamination from metals and metalloids in surface soil builds up. Salinity from spraying may also be important with crop cultivation as well as pasture. Table 6 gives various soil guidelines that may be linked to a build-up of salinity in soil and affect cultivated crops. The tolerances of pasture and other plant species to various forms of salinity can be quite low. Salinity build-up is most likely to be a problem when existing soil levels are high. Each of these sources may only contribute a small amount of lead, however the cumulative result may be elevated lead or arsenic, cadmium and copper levels in animals. It is also noted that birds are highly sensitive to zinc. Thus, zinc toxicity in birds results from chronic and/or repeated exposure (Richardson, 2006).

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