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# Estimates of potential childhood lead exposure from contaminated soil using the US EPA IEUBK Model in Sydney, Australia

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ABSTRACT

Surface soils in portions of the Sydney (New South Wales, Australia) urban area are contaminated with lead (Pb) primarily from past use of Pb in gasoline, the deterioration of exterior lead-based paints, and industrial activities. Surface soil samples (n = 341) were collected from a depth of 0–2.5 cm at a density of approximately one sample per square kilometre within the Sydney estuary catchment and analysed for lead. The bioaccessibility of soil Pb was analysed in 18 samples. The blood lead level (BLL) of a hypothetical 24 month old child was predicted at soil sampling sites in residential and open land use using the United States Environmental Protection Agency (US EPA) Integrated Exposure Uptake and Biokinetic (IEUBK) model. Other environmental exposures used the Australian National Environmental Protection Measure (NEPM) default values. The IEUBK model predicted a geometric mean BLL of 2.0 ± 2.1 μg/dL using measured soil lead bioavailability measurements (bioavailability = 34%) and 2.4 ± 2.8 μg/dL using the Australian NEPM default assumption (bioavailability = 50%). Assuming children were present and residing at the sampling locations, the IEUBK model incorporating soil Pb bioavailability predicted that 5.6% of the children at the sampling locations could potentially have BLLs exceeding 5 μg/dL and 2.1% potentially could have BLLs exceeding 10 μg/dL. These estimations are consistent with BLLs previously measured in children in Sydney.

## 1. Introduction

### 1.1. Soil investigations in the Sydney area

Environmental contamination of air, dust and soils in Australia is derived from a range of industrial sources, which peaked in the 1970s and declined thereafter (Kristensen et al., 2017). The largest anthropogenic source of Pb emissions was Australian motor vehicles using petrol containing tetramethyl and tetraethyl Pb additives from 1932 to 2002 (Kristensen, 2015). Atmospheric emissions of Pb to the entire Australian continent from leaded petrol were calculated to total 240,510 t over seven decades of use, attaining a maximum of 7869 t in 1974 (Kristensen, 2015). Kristensen (2015) calculated that approximately 68,000 t of lead were emitted into the atmosphere from leaded petrol in the state of New South Wales (NSW) between 1958 and 2002. From 1980 to 2001 leaded gasoline contributed approximately 90% to Pb in Sydney air (Chiaradia et al., 1997). Other sources of environmental lead include Australian paint, which were up to 50% Pb by volume before the 1950s, thereafter several mandated reductions reduced the allowable concentration to 0.1% (by weight) in 1997 (AGFOEE, 2017). Rouillon et al. (2017) showed that soil around houses in Sydney with painted exteriors built before 1970 were markedly more contaminated than non-painted houses and houses that were built from the 1970s onwards. The Pb from past petrol lead emissions, industrial sources and the deterioration of exterior lead-based paints have been deposited and concentrated in surface soils and urban areas of Australia (Gulson et al., 1995a; Olszowy et al., 1995; Laidlaw and Taylor, 2011; Harvey et al., 2017; Rouillon et al., 2017; Kristensen et al., 2017).

Birch et al. (2011) systematically sampled soil Pb concentrations in surface soils (0–2.5 cm) at 491 locations across the Sydney estuary catchment (480 $km^2$; Fig. 1). One soil sample was collected in each 1 $km^2$ grid and sampling sites (one per grid square) were selected

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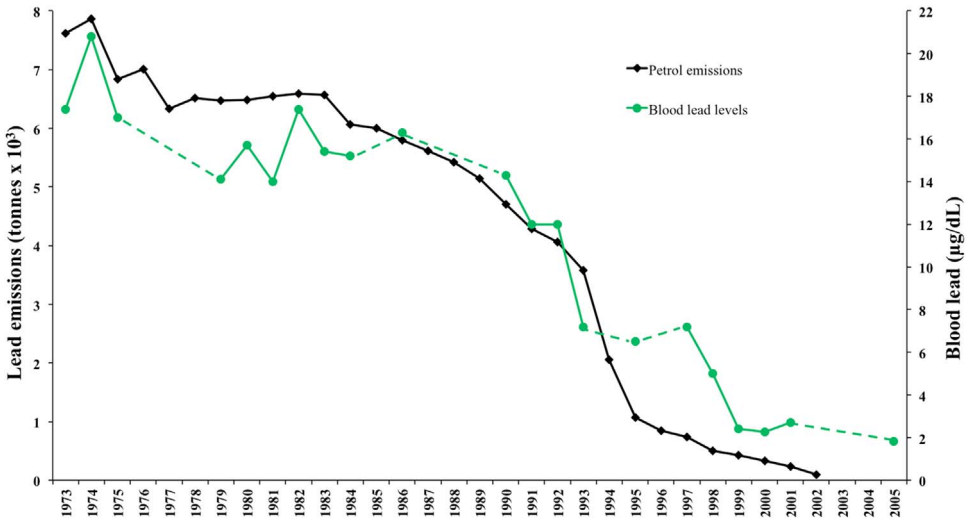


**Fig. 1.** Temporal blood lead levels for Sydney children (data from Table 1) plotted against NSW petrol lead emissions data (figure from Kristensen et al., 2017).

randomly for the dominant land use type in each square. The results indicated that soil concentrations in the < 2 mm grain size fraction had an arithmetic mean and median Pb concentration of 194 mg/kg and 60 mg/kg, respectively. Spatial patterns indicated that the inner city suburbs were most contaminated with concentrations decreasing with distance from the city centre (see also Rouillon et al., 2017).

In addition to the systematic investigation of Sydney soil Pb concentrations by Birch et al. (2011) there have been several more localised soil Pb studies in the Sydney region. In Balmain, an inner Sydney suburb located 2.5 km north-west of the Sydney central business district (CBD), a soil Pb survey of 41 samples found 68% of residential housing samples exceeded the National Environmental Protection Council (NEPM, 2013a) 300 mg/kg residential soil Pb guideline (Royal Prince Alfred Hospital and Central and Southern Sydney Area Health Service, 1988). At 24 inner Sydney suburban homes, Fett et al. (1992) observed a median and mean 'play' area soil Pb concentration of 380 mg/kg and 627 mg/kg, respectively with 54% of the soil samples exceeding the NEPM 300 mg/kg residential soil Pb guideline (NEPM, 2013a). In 18 of the same inner Sydney homes, Fett et al. (1992) observed median and mean 'sink' (garden) soil Pb concentrations of 1237 mg/kg and 1944 mg/kg (range 123 to 5407 mg/kg), respectively. Skinner et al. (1993) collected seven soil samples at a depth of 0–5 cm from Bradfield Park (beneath the Harbour Bridge) and three samples at distances up to 350 m from the park. Four sites were sampled farther north at distances of 50–300 m from the major arterial Warringah Freeway in North Sydney. The median values for the two areas were 708 mg/kg (range 19 to 1451 mg/kg) and 637 mg/kg (range 216 to 1269 mg/kg), respectively. Olszowy et al. (1995) analysed 80 surface soil samples from residential properties in Sydney and found that about 40% of soil samples exceeded the NEPM residential 300 mg/kg soil Pb guideline. Lead concentrations ranged from 37 to 2660 mg/kg in bulk soil samples from 8 houses in the same inner Sydney suburbs investigated by Fett et al. (1992) and up to 3130 mg/kg (Gulson et al., 1995a). Gulson and Ray (1997) measured Pb in surface soil from playground areas, sandpits and along the eaves line in six day care centres from inner Sydney suburbs and compared these data with vacuum cleaner dust, long-term dust accumulation using petri dishes and paint lead. They found Pb levels below the Australian NEPM guidelines of 300 mg/kg in five of the six soil samples, although in one case the sandpit soil had been recently replaced. Most recently, the Rouillon et al. (2017) study of Sydney gardens (as opposed to public spaces) showed that 40% of the 203 homes sampled contained soil that exceeded the NEPM 300 mg/kg soil lead guideline for residential homes and 15% of homes contained soil lead > 1000 mg/kg. Furthermore, the majority of high soil Pb concentrations were located within three local government areas: City of Sydney (containing the central business district (CBD)), Leichhardt Municipal Council (located between 0.5 and 2 km west of the CBD) and Marrickville Council (located approximately 3.75 km southwest of the CBD), which exhibited mean soil Pb concentrations of 883 mg/kg, 960 mg/kg and 689 mg/kg, respectively.

Markus and McBrantney (1996) analysed 219 surface soil samples for Pb and other heavy metal concentrations in Glebe, a suburb located approximately 1 km west of Sydney CBD, and found that more than 50% of Pb concentrations exceeded the 300 mg/kg residential soil Pb guideline. Cattle et al. (2002) reported that 41% of 807 surface soil samples in Glebe and Camperdown (located immediately west of Glebe) exceeded the NEPM 300 mg/kg residential soil Pb guideline. Cattle et al. (2002) tested four geostatistical techniques to determine which was best able to delineate soil Pb concentrations in the 807 soil samples above and below the 300 mg/kg guideline—they concluded that multiple indicator kriging was the best predictor of 'clean' versus 'contaminated' soil. Markus and McBrantney (2001) compiled a brief review of Australian soil Pb studies prior to 2001.

### 1.2. Previous BLL studies in the Sydney area

Most of the available BLL data collected from children in the Sydney area are from years of high petrol lead emissions, when exposures were considerably higher than in more recent times, and methods of sample collection and analysis were more variable. Assessment of historic petrol lead emissions and opportunistic studies of BLLs in Sydney show that BLLs in Sydney have declined substantially following the gradual phasing out of Pb in petrol between the 1970s and 2002 (Kristensen, 2015; Table 1 and Fig. 1).

Until about 1998, blood lead surveys of Sydney's children indicated that average BLLs were above the current 5 µg/dL reference level (NHMRC, 2015). The sample sizes of the opportunistic blood lead studies of children in Sydney and other localities in Australia have been small compared with those undertaken in the United States where universal screening is implemented in some communities (CEH, 1998). The US Centres for Disease Control and Prevention (CDC) recommends that children at high risk of exposure be sampled at the ages of 12 and 24 months or at ages between 36 and 72 months if they have not previously been screened (CDC, 2000). For example, in the city of Detroit (USA) between 2001 and 2009, the Michigan Department of Community Health (MDCH) measured BLLs in 367,839 children (Zahran et al., 2013b). The only Australia-wide investigation into sources of lead and childhood BLLs was carried out in 1995 (Donovan, 1996). The geometric mean BLL of children sampled in the