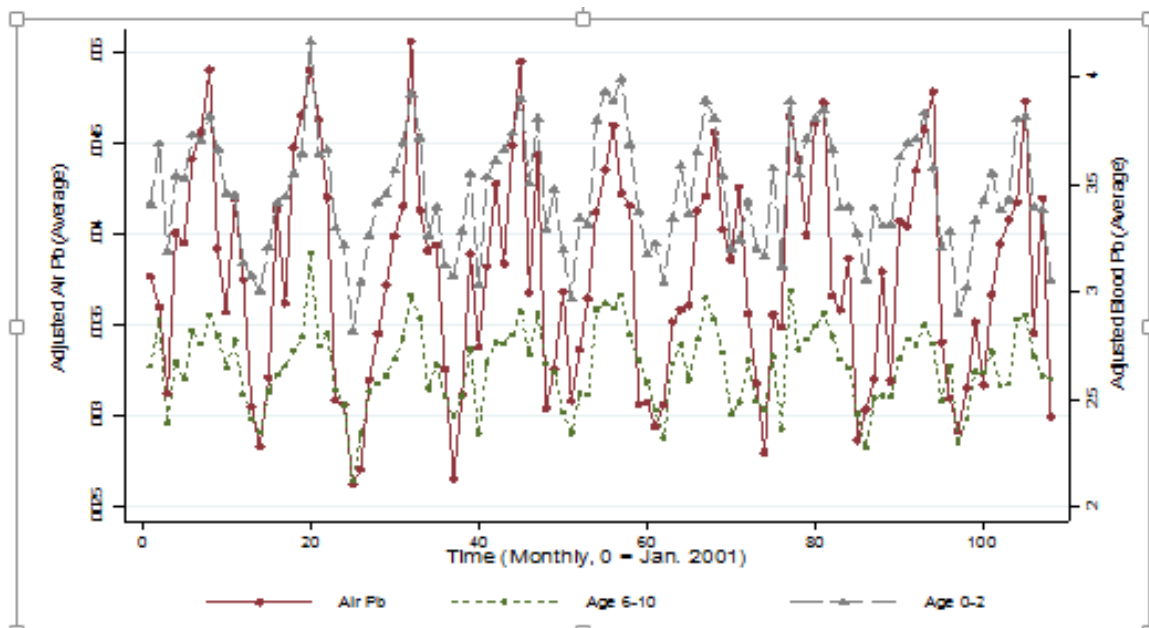


Soil lead and human health exposure risks: Studies from Australia and the United States of America



Weather-adjusted air lead (Pb) ($\mu\text{g}/\text{m}^3$) and Blood Pb (PbB) ($\mu\text{g}/\text{dL}$) by age group in Detroit, Michigan. Average monthly child PbB levels adjusted by local weather conditions, child gender, method of blood draw, and census tract fixed effects. (Source = Zahran et al., 2013a)

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This thesis is presented for the award of Doctor of Philosophy (Environmental Science)

Date: 1 April, 2014

ABSTRACT

Urban surface soils have been contaminated with lead (Pb) primarily from the former use of Pb additives in petrol and Pb paint, and in some instances from Pb smelters. These exposures continue to pose an ongoing risk to human health globally. Lead is a neurotoxin. When it is absorbed, inhaled or ingested, it can affect the development of the child's nervous system causing lower intelligence quotient measures, Attention Deficit Hyperactivity Disorder (ADHD) and delinquent behaviors.

In a series of 8 published peer-reviewed papers (and one response to comments paper), this thesis assesses soil Pb contributions to blood Pb (PbB) in Australia and the USA. In addition, the study assesses the role of Pb additives in petrol (gasoline) as a potential source of blood PbB in children. In evaluating the potential role of petrol Pb additives for elevating children's PbB levels and urban soil Pb levels, the spatial and temporal variation of Pb in atmospheric and household dusts were evaluated.

The results from the thesis studies demonstrate that the historical use of leaded gasoline and Pb in exterior paints has contaminated urban soils to levels that pose a potential risk of harm to children. Leaded gasoline is a major source of Pb urban soils and house dust. Children's PbB levels are associated spatially with soil Pb concentrations and temporally with atmospheric soil and Pb concentrations. Roadside soils contaminated with Pb are subject to re-suspension by vehicle movement, which causes dispersal into the urban environment.

This thesis indicates that the paradigm that Pb paint is *the* sole primary source of Pb exposure in urban children is incorrect. Ongoing exposure from legacy deposition of Pb from petrol is also a major source of exposure in children and still poses a significant risk of harm.

ACKNOWLEDGEMENTS

Several people and organizations have helped me with this project and I would like to take this opportunity to thank them.

My highest appreciation goes to my wife Lisa Hayden and daughter Isobella Laidlaw who came to Australia to allow me to pursue a PhD and stayed with me in Australia for eight more years. Lisa's assistance was crucial as she encouraged me to keep going when I was about to quit. My Father (deceased) and Mother greatly contributed by supporting my move to Australia to pursue a PhD and gave abundant support while I was in Australia. My sisters Kari Laidlaw and Heather Schneider also supported me emotionally when I was isolated in a foreign land. Professor Mark Taylor was very flexible and very inspirational and gave me the freedom to pursue my own study design and encouraged my collaboration with other colleagues. He has been a great mentor. I greatly appreciate Macquarie University's support for funding me. A very special thank you goes to the 5 Sydney Residents who gave me a great deal of their time and put up with monthly inconveniences for 15 months – this study would not have been possible without them. I gratefully acknowledge Emeritus Professor Brian Gulson and Karen Mizon for their assistance at the start of my thesis in introducing me to two Sydney residents involved in the Sydney study. I also thank Associate Professor Damian Gore, Macquarie University for his useful occasional advice on technical aspects of my PhD. Russell Field was very helpful and assisted with my laboratory studies. Glyn Devlin and the Australian Synchrotron deserve special thanks for providing funding and access to the Synchrotron. I thank ALS Laboratories for their metal analysis and the National Measurement Institute for their analysis work on Pb isotopes. These high quality analyses were critical to my 5 home Sydney study. I am indebted to Professor Gabriel Filippelli who continued to collaborate with me when I was no longer enrolled at IUPUI and who has put up

with my obsession with soil and lead poisoning for a long time. I am also extremely grateful to Professor Howard Mielke who agreed to collaborate with an unknown and unpublished student (me) after we met in Scotland in 2003. He deserves the Nobel Prize for his pioneering work in this field. I have been very fortunate to meet the super skilled Assistant Professor Sammy Zahran who has contributed greatly to our papers. I have also been very lucky to work with Professor Nicholas Pingitore and Dr. Juan Clague of the University of Texas at El Paso who have graciously assisted with the interpretation of the synchrotron data. I am very thankful that Assistant Professor Shawn P. McElmurry was willing to collaborate and play a crucial role by obtaining the Detroit child PbB database. Dr. Charles Ritter deserves a special recognition for stimulating my interest in heavy metals in soils and the atmosphere while I was an undergraduate at the University of Dayton, way back in 1993. Without his influence, this thesis would not have been pursued. Professor Don Pair and Mr. George Springer (and others) were also very inspirational at the University of Dayton geology department. Linda Patrick's editing assistance was also invaluable.

This dissertation is dedicated to my father Duncan M. Laidlaw (deceased) who was very kind throughout the years and contributed to my interest in science through his passion for plants and flower gardens.

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STATEMENT OF CANDIDATE

I certify that the work in this thesis entitled “*Soil lead and human health exposure risks: Studies from Australia and the United States of America*” has not been submitted previously, in whole or in part, for a degree at this or any other university. The thesis does not contain, to the best of my knowledge and belief, any material published or written by another person, except where acknowledged. I certify that this thesis is an original piece of research that is comprised of solely my own work.



Mark Andrew Scott Laidlaw, 1 April, 2014

NOTES REGARDING THESIS FORMATTING AND STATEMENT OF CONTRIBUTION

This thesis is structured into six chapters and two appendices. The first chapter consists of a broad-scale introduction to the research principles and study area. The underlying research aims and objectives are addressed over eight published papers (and one response to comments paper) that make up Chapters 2 to 4, introduced below. The thesis chapters are comprised of individual journal articles or groups of individual journal articles that contribute towards answering the research questions and aims of the thesis. Chapter 5 consists of the Discussion and Chapter 6 the Conclusions.

Chapter 2: Petrol derived lead (Pb) in urban surface soils is a major source of Pb in house dust and has the potential to poison children in the inner cities of Australia.

- 1) **Laidlaw MAS** (75%), Taylor MP (25%). 2011. Potential for childhood Pb poisoning in the inner cities of Australia due to exposure to Pb in soil dust. *Environmental Pollution* 159(1), 1-9.

This paper was largely my own conception, development and execution with direction from Mark Taylor.

- 2) **Laidlaw M.A.S.** (60%), Zahran S. (10%), Pingitore N. (2%), Clague J. (2%), Devlin G. (1%), Taylor M.P. (25%). 2014a. Identification of lead sources in residential environments: Sydney, Australia. *Environmental Pollution*. (Accepted).

This original idea for this paper was my own and I directed its development, the text and its execution. I performed the field-work. Taylor assisted with some

aspects of the study design, fieldwork, mentoring, development of text, reviewing and final drafting of the manuscript. Zahran performed advanced statistical analysis and wrote some of the results section, Clague extracted the synchrotron data and plotted the data into charts, Pingitore wrote the results section for the synchrotron samples and Devlin assisted with the synchrotron sample analysis and wrote the synchrotron methods section.

- 3) **Laidlaw M.A.S.** (60%), Zahran S. (5%), Pingitore N. (5%), Clague J. (0%), Devlin G. (0%), Taylor M.P. (30%). 2014b. Response to comments on: Identification of lead sources in residential environments: Sydney Australia. By Laidlaw, M.A.S., Zahran, S., Pingitore, N., Clague, J., Devlin, G., Taylor, M.P., 2014. Environmental Pollution 184, 238-246

The Laidlaw et al. (2014b) paper contains Laidlaw et al.'s response to comments made by Brian Gulson (Gulson, 2014) about the Laidlaw et al. (2014a) paper.

Chapter 3: Calculation of historical vehicle traffic Pb emissions in US and California urbanized areas and its legacy in urban soils and continued effect on children's health.

- 1) Mielke H.W. (55%), Laidlaw M.A.S. (40%), Gonzales C.R. (5%). 2011. Estimation of leaded gasoline's continuing material and health impacts on 90 US urbanized areas. Environment International 37(1), 248-57.

While this paper was largely Howard Mielke's conception, development and execution, I developed approximately 40% of the text and compiled and analysed the USA literature on soil Pb studies.

- 2) Mielke H.W. (55%), **Laidlaw M.A.S.** (30%), Gonzales C.R. (5%). 2010. Lead (Pb) legacy from vehicle traffic in eight California urbanized areas: continuing influence of Pb dust on children's health. *Science of the Total Environment* 408(19), 3965-75.

Although this paper was largely Howard Mielke's conception, development and execution, I developed around 30% of the text, including the section on analysis and discussion.

Chapter 4: Soil Pb and children's blood Pb (PbB) levels are associated spatially and temporally in urban areas.

- 1) **Laidlaw M.A.S.** (65%), Zahran S. (20%), Mielke H.W. (5%), Taylor M.P. (5%), Filippelli G.M. (5%). 2012. Re-suspension of Pb contaminated urban soil as a dominant source of atmospheric Pb in Birmingham, Chicago, Detroit and Pittsburgh, USA. *Atmospheric Environment* 49, 302-310.

I had the original idea for this manuscript in 2009 when I published the following conference paper: *Laidlaw, M.A.S. 2009. Correlation of Atmospheric Soil and Atmospheric Pb in Three North American Cities: Can Re-suspension of Urban Pb Contaminated Soil be a Major Source of Urban Atmospheric Pb and Cause Seasonal Variations in Children's PbB Levels? 24th International Applied Geochemistry Symposium. New Brunswick, Canada.* I further developed this pilot study by adding a fourth city. Sammy Zahran took the natural logs of the soil and atmospheric data and discovered the significant difference in the weekly versus weekend values. We hypothesised this was due to changes in traffic volumes and

its effect on contaminated dust re-suspension. Mielke, Filippelli and Taylor assisted with editing.

- 2) Zahran S. (40%), **Laidlaw M.A.S.** (30%), McElmurry, S. (20%), Taylor M. (5%), Filippelli G.M. (5%). 2013a. Linking Source and Effect: Re-suspended Soil Pb, Air Pb, and Children's PbB Levels in Detroit, Michigan. *Environmental Science and Technology* 47(6), 2839-45.

The original idea for this manuscript was mine. I identified seasonal PbB curves for Detroit from web published data (Shawn McElmurry) for the period 2001 to 2009. I then extracted seasonal atmospheric soil and Pb data for one of the Detroit IMPROVE stations located on the IMPROVE database (IMPROVE, 2013) and compared the datasets where I observed clearly that the PbB and Child PbB peaks coincided in the summer and autumn time. I then contacted Shawn McElmurry and asked if he could obtain the Detroit child PbB database for comparison to the IMPROVE air Pb data. I asked Sammy Zahran to assist with the complex statistical analysis of the data relationships. Gabriel Filippelli assisted with editing. Mark Taylor assisted with the formulation of the argument, data interpretation, manuscript editing and writing.

- 3) Zahran S. (50%), Mielke H.W. (20%), Filippelli G.M. (7.5%), McElmurry S. P. (7.5%), **Laidlaw M.A.S.** (7.5%), Taylor M.P. (7.5%). 2013b. Determining the relative importance of soil sample locations to predict risk of children's lead (Pb) exposure. *Environment International* 60, 7-14

The concept for this study was developed by Sammy Zahran, Howard Mielke and myself while much of the development and execution were performed by Zahran and Mielke. My main contribution was to identify and argue that the best contribution of this paper was its potential future use by other researchers to select soil sample locations in an urban area in a manner which limits the number of samples required to assess spatial patterns of children's PbB levels. This assisted with the overall arrangement of the paper. I also performed editing and writing of some sections of the work. Taylor, McElmurry and Filippelli performed writing and editing.

- 4) Filippelli, G.M. (90%) and **Laidlaw**, M.A.S. (10%). 2010. The Elephant in the Playground: Confronting Pb-contaminated soils as an important source of Pb burdens to urban populations. *Perspectives in Biology and Medicine* 53, 31-45.

This paper was largely Gabriel Filippelli's conception, development and execution. I developed approximately 20% of the text and performed editing and proofing.