Interior Health

Medical Health Officer Recommendation Under Contaminated Site Regulations Sections 18 and 18.1 – Risk-based standards for lead (Pb) for the environmental management area surrounding Teck Trail Operations

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Executive Brief

The lead (Pb) contamination in the proposed Trail environmental management area, primarily resulting from historical and ongoing emissions by the Teck Trail smelter operation, poses a significant public health challenge. This contamination has led to higher-than-average blood Pb levels in children living in the area. As a Medical Health Officer (MHO) for Interior Health (IH), my task was to recommend a risk-based remediation standard that is protective of the health of people living in this area.

This report outlines the primary recommendation of reducing the gap in blood Pb levels between Trail children and a comparable age-matched Canadian cohort by 25% over the next five years. Using a blood Pb concentration as a risk-based remediation standard best enables interventions to focus on all sources of Pb contamination related to smelter emissions, inclusive of Pb in soil and Pb in airborne dust and dustfall. Additional recommendations to support achieving this blood lead target are discussed in the report.

Table of Contents

Land Acknowledgement

Interior Health would like to recognize and acknowledge the traditional, ancestral, and unceded territories of the Dãkelh Dené, Ktunaxa, Nlaka'pamux, Secwépemc, St'át'imc, Syilx, and Tŝilhqot'in Nations where we live, learn, collaborate and work together.
I personally would also like to recognize the Sinixt peoples and their connection with the Columbia River.

Introduction

This report fulfils the responsibility of the local Medical Health Officer as outlined in Sections 18 and/or 18.1 of the *Contaminated Sites Regulation* (CSR; CSR, 1996).

I was asked to make a recommendation, as a Medical Health Officer (MHO) within Interior Health (IH), in response to a request under the Contaminated Sites Regulation (CSR) enacted under the B.C. Environmental Management Act (EMA; Government of BC, 2024). The request was to have an MHO recommend a risk-based standard for the remediation of contamination due to the heavy metal, lead (Pb), in the proposed Trail Environmental Management (EM) Area related to historical aerial emissions from Teck Metals Ltd in Trail (hereby Teck Trail). An MHO recommendation may be requested, as outlined within the Contaminated Sites Regulation (CSR) sections 18 and 18.1, when alternative risk-based standards are proposed in lieu of default standards (i.e. in lieu of the standardized soil concentration of Pb).

MHOs derive their powers and duties from the Public Health Act and have legislated responsibilities under several Acts and regulations, including those described in CSR Part 6 – Remediation Standards (section 18 and 18.1). Work toward a Wide Area Remediation plan has been underway for several decades. My involvement in developing a proposed recommendation began in 2022 and builds on previous work completed by other IH MHOs. In preparing this recommendation, I have reviewed relevant documents written by Dr. Nelson Ames (Ames, 2021) and Dr. Kamran Golmohammadi (Internal communication) regarding their previous analyses and recommendations.

The chemical I have been asked to make a recommendation for is the heavy metal lead (Pb). Current sources of Pb in the environment are varied, but the primary sources are secondary to human actions (e.g. adding Pb to gasoline, industrial sources of Pb, Pb in pipes and solder, paint containing Pb, and Pb found in other products such as toys, jewelry, home remedies, cosmetics, ceramics, and leaded crystal). This recommendation will focus on the impacts of the local smelter, acknowledging the other sources of Pb in the local Trail environment.

This recommendation is made with consideration of information gathered from analyses of the health risks related to Pb in the environment, with the focus on understanding the health effects that are due to historical and ongoing emissions from the Teck Trail smelter operations. Two foundational analyses supporting this recommendation included (1) a Human Health Risk Assessment (HHRA) for Pb, completed on behalf of Teck Trail (AtkinsRéalis, 2024b), and (2) the Analysis of Variables Influencing Children's Blood Lead levels in Trail BC, completed on behalf of IH (IH, 2024), referred to in this document as the blood Pb analysis. The HHRA is a standardized approach to predict the potential risks to human health based on exposure to contaminants (in this case Pb) in environmental soil, air, and dust. It uses actual concentrations of Pb measured in environmental media in the Trail area to estimate children's exposure to Pb. The blood Pb analysis, on the other hand, uses quantitative data from both the environmental samples and from children's blood Pb samples to examine the association between blood Pb values from children living in the area and how they relate to various potential sources of Pb in the environment, focusing on soil and airborne dust.

Abiding by my statutory responsibilities as an MHO, the recommendations provided are made in the best interests of the health of the population living in the EM Area. As such, I considered evidence of the health effects of Pb within the context of the broader determinants of health, facilitated a public consultation, and considered all submissions received from affected persons and the responsible party (Teck Trail).

My recommendation also considers the contributions and information provided by many experts. I would like to highlight that I was fortunate to rely on the nationally recognized expertise of Dr. Ray Copes, consultant for IH, who has expertise in epidemiology, environmental health, human health risk assessment, and was previously a physician lead for Environmental Health at the BC Centre for Disease Control (BCCDC). I would also like to recognize the significant work in the previous decades – noting the collaborative work and the previous MHO report completed by Dr. Nelson Ames. I am fortunate to have Dr. Ames as both a mentor and an amazing "bank of knowledge" on the history and work completed previously on Pb contamination and human health.

Dr. Karin Goodison

Medical Health Officer, Interior Health

Medical Health Officer Recommendations

Primary Recommendation: Blood Lead Maximum Value Recommendation

Decrease the gap in children's blood lead between Trail children and an age-matched Canadian cohort by 25% over the next five years.

The expectation is to continue to **decrease the gap** between blood Pb levels in Trail children and blood Pb levels (BLL) elsewhere for age-matched children in Canada (and/or the United States of America as appropriate). The use of comparison to an age-matched Canadian blood Pb geomean is critical to enable us to measure and demonstrate improvements to blood Pb in Trail beyond the general exposure decrease observed in same aged Canadian children. The recommended blood Pb value will be determined over 5-year cycles.

Decreasing the gap by a proportion of the difference between Canadian and Trail blood Pb geomeans for children aged 1-3 is an effective and relevant approach to reducing children's exposure to Pb in the environment in the Trail area. Using the goal of a **25% reduction in the gap**, while a challenging goal for the community, will motivate best actions to protect health.

This equation demonstrates how this would be calculated:

$$BLL_{Trail} - 0.25\ x\ (BLL_{Trail} - BLL_{Canada})$$

Figure 1. Equation to calculate the 25-percentage reduction in the difference between Canadian and Trail blood Pb geomeans. BLL= Blood Lead Level.

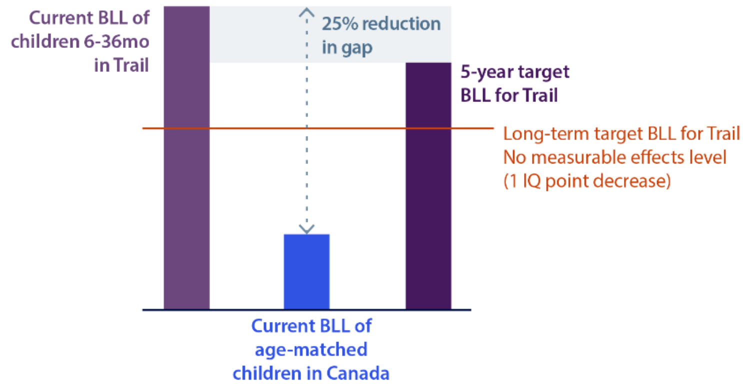

Figure 2. Graphic of the concepts used in the MHO Blood Lead Recommendation.

The recommendation aims to reduce the gap in blood Pb values between Trail children and age-matched Canadian children by 25 % in the next 5 years, with longer term goal of a blood Pb level for Trail children that demonstrates no measurable health effects from Pb exposure.

An example of the calculation of BLL to achieve 25% reduction in the geomean difference between Trail and Canadian children's BLL is shown below:

2.0 µg/dL - 0.25(2.0 µg/dL - 0.50 µg/dL) = 1.63 µg/dL

This equation uses the 2023 Trail blood Pb geomean (6-36 months old included in current blood Pb testing; Goodison, 2023) of 2.0 µg/dL and the most recent Canadian geomean (for 3–5-year-olds as closest age match available) of 0.50 µg/dL.

Thus, the target blood Pb achievement for children in Trail for the first example 5-year cycle (ending 2028, as 2023 values are used in this example) would be **1.63 µg/dL,** a **decrease of 0.38 µg/dL**.

Note that the geomean values would be updated with the latest Trail and Canadian geomeans, enabling a continuous improvement model. We also anticipate being able to use more comparably age-matched children in the future as Canada moves to include 1-3-year-olds in upcoming Canadian Health Measures Surveys. Using the above approach could lead us to expect an approximate geomean blood Pb of about 1.6 µg/dL in 5 years and 1.3 or 1.4 µg/dL in 10 years for 6-36-month-old children living in Trail.

The blood Pb recommendation is in line with current understanding of Pb impacts on human health. In 2024, the current understanding is that there is no level of exposure to Pb that has been demonstrated to be without effects on health in epidemiologic studies (i.e., Pb is treated as a non-threshold substance). The literature recognizes that the current knowledge of health effects of Pb is somewhat limited at lower levels of blood Pb (e.g. 1-2 µg/dL). The European Food Safety Authority and Health Canada currently use a blood Pb of 1.2 µg/dL as a benchmark measure associated with a decrease in intelligence quotient (IQ) by about 1 IQ point (HC, 2013). This benchmark may change as our knowledge increases.

The goal is to decrease blood Pb geomean as low as **reasonably possible**, and to levels that are protective of human health. I would like to recognize that this community may not reach a geomean as low as an age-matched Canadian population (most recent Canadian Health Measures Survey for 3-5-year-old children reported a geomean blood Pb of 0.5 µg/dL). It is not my expectation (nor is it likely feasible) that geomean blood Pb levels in Trail would reach that of Canadian geomean, but we must continue to decrease the gap. This will require ongoing evaluation and review, especially based on the rapidly changing research on Pb levels that are protective of human health.

Blood Pb levels are a measure of exposure to all sources of Pb including food, water, air, dust, and soil. The use of blood Pb for this recommendation is thus influenced by factors outside of the historical contamination within the EM Area, some of which are outside of the control of Teck Trail operations. The CSR focuses on historical emissions (primarily soil Pb levels). In addition, current emissions from the smelter site, while lower than in the past, continue to represent an important source of exposure. As is the case in other Canadian communities, multiple sources of Pb are not associated with the smelter such as Pb in paint, water and purchased foods and supplements. Although this recommendation is intended to support the CSR, it is also intended to encourage actions to reduce all sources of Pb in the environment and it will provide a "gold standard" monitoring mechanism (i.e., blood Pb) to measure the effects of remediation and other interventions on overall exposure of children to Pb.

It is not my intent to have the blood Pb recommendation used out of context. I am thus recommending a risk-based soil Pb standard and the related hazard index (HI) to enable a measurable "end point" for soil remediation. A risk-based soil standard is recommended to support achieving the blood Pb recommendation. Specific to the Teck Trail site, and to enable easier application in the WARP, I recommend that soil is remediated to a soil Pb concentration of ≤ 400 µg/g. Since soil is not the only source of Pb exposure in the community, I hope this recommendation serves to enhance actions on other smelter associated sources of Pb (e.g. air borne dust), and to consider other factors that influence children's blood Pb. This must also be considered within the context of overall health for people living in the EM Area.

Additional Recommendations

To achieve a reduction in the gap between Trail children and age-matched Canadian children's blood Pb values, I recommend the following objectives and resources be in place:

1. Continue ongoing blood lead testing and continue to encourage participation of children/families to ensure adequate representation of the population.

- Recognition and reciprocation of parents and children's time and contribution to blood testing could be enabled by offering additional resources to support children, such as food vouchers (e.g. for dairy products and iron fortified pablum, and other healthy foods).
- Further consideration for periodic testing at other ages should be reviewed. This year, maternal blood Pb testing was added to assess that age group.

2. Have a goal of continuous improvement in blood Pb levels, to get children's blood Pb levels as low as reasonably possible.

- To be clear, the term "reasonable" above indicates reasonable within a community with historical and ongoing smelter activities. Using best practices and best available science, a reduction in children's blood Pb will reflect reduced environmental exposure. We will also need to continue and ensure we have appropriate measures of environmental sources of Pb, sources, including Pb in Total Suspended Particulate (TSP) and/or dustfall to ensure we have data that is representative of the exposed population.
- We should support continuation of an adaptive management approach agreed upon by the working group (all relevant parties). This leads to an iterative improvement process.

3. Enhance the current primary and secondary prevention programs with additional elements to promote evidence-based programs and services that support children's development, while ensuring culturally accessible and appropriate supports for Indigenous families.

- The current program is helpful in connecting families to supports and other programs which will continue to improve health outcomes for children.
- Additional resources to support the Healthy Families Healthy Homes program and associated services will improve the health of children living in Trail. Evidence-based examples include reading programs, learning opportunities, affordable childcare, appropriate and relevant nutritional supports (particularly for children with low ferritin or anemia), Head Start program and others. These primary and secondary prevention program should consider the impacts of other determinants of health, such as poverty, and take an equity approach to supporting families. An example of this might be offering grocery cards for families having difficulty covering food costs (supporting impacts of diet and nutritional state on children's health as it relates to Pb). Many of the children with elevated Pb levels also have other factors in their lives that may impact their development. Equitable support (those who need more, get more) will support the health of the entire community.
- Continue the enhanced supports and services for families of children with blood Pb over British Columbia's Exposure Investigation Level (or lower as able). Ongoing support of the residential lead inspection and Pb-based paint screening program and the lead-safe renovation program will continue to support children to have reduced overall Pb exposure.

- The Trail Area Health & Environment Program is key to coordinating these programs and services and should continue.
- The THEP website should continue to be a source of information for the community.
- Carry-home Pb from parents/others in the home who work at sites where Pb exposure occurs was identified as a significant contributor to children's blood Pb levels in the analysis. This should inform additional education and improvement in work safe practices in all work sites where Pb exposure occurs.
- Continue, and enhance as appropriate, interventions to reduce children's exposure to lead-containing dust in the community (e.g., street sweeping and dust suppression activities in the City of Trail). Review, and consider applicability, of evidence-based interventions undertaken in other smelter communities.

4. Prioritize interventions to reduce the movement of Pb offsite from the Teck Trail smelter property (inclusive of fugitive dust and any other emissions).

- It is important to recognize the contribution of recent efforts to reduce current Pb exposures from the smelter site (e.g., fugitive dust and other emissions) to the reduction of children's blood Pb values. Fugitive and ongoing emissions from the smelter site continue to contribute to children's Pb exposure, so it will be important to determine additional measures and controls for fugitive dust and other identified ongoing emissions. We need to reduce the contributions of Pb in airborne dust/Total Suspended Particulate (TSP) to children's Pb exposure.

5. Guide interventions based on ongoing evaluation including (a) an annual review and analysis of health and environment data with, (b) an in-depth analysis, alongside a review of current state of knowledge of Pb impacts on health, completed every five years.

- An adaptive management approach will enable regular evaluation of the effectiveness of interventions and guide changes as needed. Every five years, an in-depth review should occur that includes a review of the state of the science and application of this knowledge to the recommendations and interventions.
- Assessment of remediated soil should be performed over time to determine the potential for recontamination from ongoing smelter emissions.
- Assessment of representative data for Pb in dust/TSP to support the evaluation of the influence of TSP and/or dustfall on health of people living in the EM area, particularly those living close to the smelter.
- Evaluating the effectiveness of controlling operational emissions and remediation actions and better understanding the factors that contribute to elevated blood leads are crucial due to the costs associated with cleanup activities and the significant public health concern posed by elevated blood

leads. This would be best achieved with an ongoing collaborative working group (Human Health Risk assessment working group with relevant ENV, health (IH) and Teck participants). There would be a need for ongoing data sharing to accomplish this, from a public health perspective.

6. Develop a plan that considers climate change impacts on the potential for Pb exposure and evaluate these potential effects within the adaptive management process.

- Hotter, dryer summers may contribute to increased dust movement in the community, and decreased ability to maintain lawns as one barrier to exposure to Pb in soil.

Public Consultation – Summary and Acknowledgement

We would like to extend our sincere appreciation to all participants who attended the recent public consultation. Your engagement and thoughtful contributions are invaluable to the ongoing work of the Trail Health & Environment Program (THEP).

The consultation summary report has been finalized and will be published on the THEP website (Kirk and Co. Consulting Ltd, 2025.)

Feedback on the Medical Health Officer's (MHO) Recommendation was largely supportive. The majority of respondents expressed general agreement, with no additional considerations noted. There was strong endorsement for continued efforts to reduce blood lead levels and support for existing initiatives aimed at minimizing lead exposure in children.

Additional questions raised during the consultation are addressed within the MHO Recommendation report. Comments specific to remediation methods have been referred to Teck for further review.

We thank all participants for their continued interest and commitment to improving community health.

Legislative Requirements

Background on Relevant Legislation

Contaminated site remediation falls under part 4 of the Environmental Management Act (Government of BC, 2024). A contaminated site means an area of the land in which the soil or any groundwater lying beneath it, or the water or the underlying sediment, contains a prescribed substance in quantities or concentrations exceeding prescribed risk based or numerical criteria, standards, or conditions.

For Pb, in terms of human health protection (via direct exposure pathway), a generic numerical soil standard is 120 µg/g for wildlands, agricultural, urban parks, and residential properties (150 µg/g for commercial lands and 4000 µg/g for industrial lands; Contaminated Sites Regulation, 1996).

The Teck Trail operation's associated contaminated site is a proposed environmental management area (CSR Section 14; CSR, 1996), due to its extensive area comprising many individual properties, sites, or parcels. The proposed Trail EM area's boundaries were established based on concentration limits (above CSR standards) for Pb, arsenic, cadmium, and zinc in surficial soils, attributed to historical smelter emissions. It covers a large area approximately 28 km from its most northern point in South Castlegar to the southern end at the US border and at its widest spans from Rossland to east of Montrose (approximately 16 km), in an irregular shape. The total area is approximately 250 km squared and is outlined in the map below (see Figure 3).

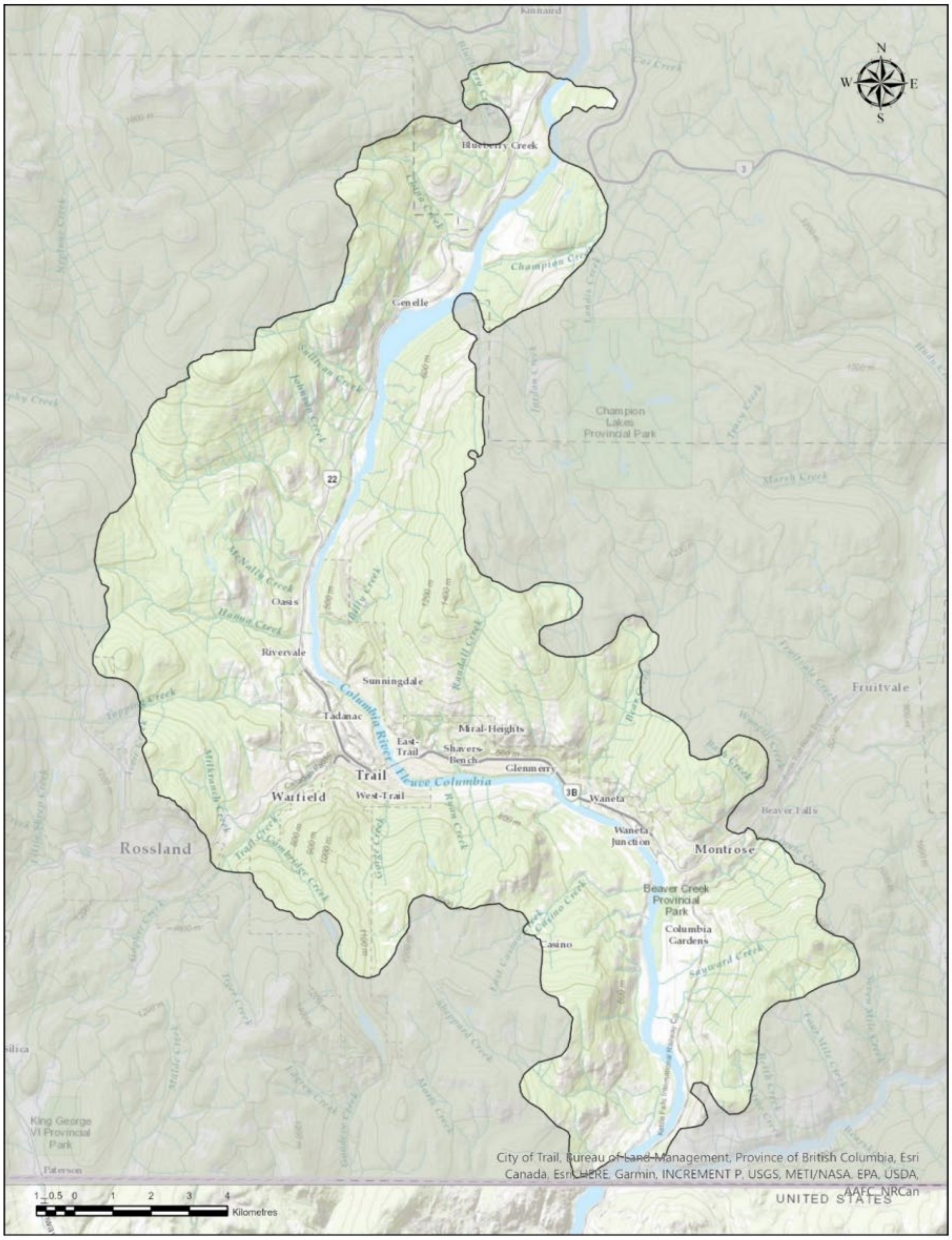

Figure 3. The Environmental Management Area Boundary (taken directly from Teck's DRAFT WARP document, AtkinsRéalis, 2024b*)*

Soil removal and replacement, coverage of the soil with grass, concrete or other material, or limiting access to an area is the current approach to reducing human exposure to Pb in soil. This is not feasible to do for the entire EM area to meet generic numerical standards, so a risk-based standard is requested. I would also note that the current soil Pb standard in BC is based on a "background" concentration and does not necessarily reflect health risk.

The CSR allows for the medical and public health expertise of the MHO to be utilized for the application of risk-based standards for determining what remediation is required to protect human health within this large, contaminated area. The MHO was requested to provide a site-specific and holistic recommendation for a risk-based standard, within the context of all the duties and responsibilities that the MHO has, to adequately protect public health.

The MHO may recommend a Hazard Index (HI) greater than one under CSR section 18 (1)(b). A hazard index is a calculation that provides an estimate of the potential for health effects due to exposure to a toxic substance – if the HI is below one, no adverse effects are expected; if it is above one, adverse health effects are possible. Alternatively, the MHO may recommend an **alternate risk-based standard**, which is one that takes a form other than that of a hazard index, which then requires review and endorsement by the Provincial Health Officer [section 18.1 (1)]. A blood Pb concentration is an example of an alternate risk-based standard. In either form, the MHO is recommending a maximum value that is determined to be protective of human health. This value would be reviewed in five years to ensure consideration of advances in scientific knowledge.

Selection of Legislative Option (18 or 18.1)

Section 18.1 of the Contaminated Sites Regulation enables application of risk-based standards for remediation specific to EM Areas. This regulation allows the maximum value recommended by a medical health officer to take a form other than that of a hazard index. Thus, to ensure all sources and pathways of exposure are considered, blood Pb concentration was selected.

I considered the two sections within the CSR that allow for an MHO to make recommendations on a risk-based standard for remediation of contaminated sites. Section 18 enables the MHO to recommend a risk-based standard allowing for a Hazard Index greater than one due to exposure to Pb at the site. The Hazard index is based on calculations, and importantly, the assumptions about Pb exposure sources and routes used within these calculations focus on soil Pb being the most relevant exposure pathway. If we were to use a soil Pb concentration or a hazard index (based on calculations that incorporate only limited risk from exposure to Pb in TSP), we would primarily address a single source (i.e. soil) of Pb exposure. Pb that is carried in the air as dust particles (Pb in airborne dust) is not as well accounted for (it is "lost" within the soil component of the calculation and cannot be separated out). The blood Pb analysis demonstrates that Pb in airborne dust is an important source of exposure to Pb in Trail that is needed in our consideration to protect the health of those living in the EM Area (the blood lead analysis identified a moderate to strong correlation of blood lead levels with Pb in airborne dust).

A hazard index of 1.6 could be considered as a risk-based remediation standard applicable to soil. This corresponds to 400 µg/g of Pb in soil. However, **soil remediation alone is not sufficient to reduce exposure to Pb in the Trail area**. Pb exposure from fugitive dust and contemporary Pb emissions from the Teck Trail smelter should be highlighted and needs to continue to be prioritized.

Pb exposures from fugitive dust and ongoing stack emissions must be further evaluated and continue to be prioritized as key Pb exposures potentially impacting child health in the Trail area.

Section 18.1 of the Contaminated Sites Regulation enables application of risk-based standards for remediation specific to EM Areas. This regulation allows the maximum value recommended by a Medical Health Officer to take a form other than that of a hazard index. Thus, to ensure all pathways of exposure are considered, blood lead concentration (units are µg/dL, and commonly reported as µmol/L) is the form I have selected.

The primary MHO recommendation is therefore based on CSR section 18.1 and takes the form of a blood lead concentration, as it more appropriately accounts for all exposures inclusive of soil Pb, stack emissions, and fugitive dust in addition to the "baseline" exposures common to all people in non-smelter communities. This will allow for continued focus on all sources and routes of exposure without being limited by insufficient environmental data or differential risk management and hygiene. Contemporary fugitive dust emissions are a key source of Pb that is likely responsible for significant influence on blood lead levels in the community, so this recommendation is aimed at reducing all Pb exposures inclusive of Pb in soil and Pb in dust/airborne dust.

The focus of the WARP is to achieve a standard for remediation activities. The blood lead recommendation enables protection of health using actual biological outcomes specific to the EM area but doesn't provide a specific soil Pb concentration remediation target. The Ministry of Environment and Parks and Teck Trail have supported the value of a recommendation for a soil concentration or a hazard index. Thus, to offer practical guidance that encourages addressing all sources of Pb, I will make a recommendation specifically for the WARP. Based on current knowledge, and to enable achievement of the MHO blood lead recommendation, **I also recommend that a soil Pb concentration of ≤ 400 µg/g be the soil Pb standard over the next 5 years.** As with all the recommendations, this will need to be reviewed in 5 years to determine if additional information is available to further our knowledge of what soil Pb levels will be protective of health in the Trail area.

> A value of 400 mg/kg was the outcome recommendation of the HHRA. When 400 mg/kg is used as an exposure point concentration in the HHRA model to estimate risks for young children, the resulting hazard quotient for the CT exposure scenario is 1.6. This translates directly to a **Hazard Index of 1.6.**

Importantly, no particular soil Pb concentration will provide a solution on its own. We must look at other sources of Pb that continue to come from the smelter site. More broadly, we should also consider other non-smelter sources of Pb in the environment to best protect children from Pb exposure.

All lead (Pb) exposures are cumulative via different sources and pathways, and they all matter to the health of individuals and populations.

Background and Evidence Base

Brief Introduction to History of Track Trail Smelter

Teck Trail operations is one of the largest integrated zinc and lead smelting and refining complexes in the world. It first opened in 1896 and is located within the municipal boundaries of the City of Trail. In the early years of operation, few protective measures were in place which led to historical contamination of a broad area over the past century. Sources, exposures, and health risks associated with lead in the Trail area have been assessed over many years. The Trail Lead Task Force was formed in 1990 with a collaborative membership inclusive of the City of Trail (chaired by the mayor), Teck Trail, the Ministry of Environment and Climate Change Strategy (ENV, now the Ministry of Environment and Parks), Health (Interior Health, with Ministry of Health as appropriate), and the community of Trail. It has now become the Trail Health and Environment Committee (THEC) with the Program supporting its work. Further details can be found in the HHRA document (AtkinsRéalis, 2024a).

Health Effect of Lead Exposure

Lead (Pb) is a naturally occurring metal that is found in the environment through both natural sources (geogenic Pb in bedrock, sediment, etc.) and anthropogenic contributions (including the addition of Pb to gasoline and paint, mining, smelting etc.). Pb has been noted to be associated with health effects over centuries, but more recently, much has been learned about the more subtle health effects of exposure to ever lower levels of lead. Health effects associated with blood lead levels below 10 µg/dL are reported to include neurodevelopmental, neurodegenerative, cardiovascular, renal, and reproductive effects. Evidence of health effects related to blood lead levels in the 2-8 µg/dL range during early childhood (age 4 or younger) include cognitive effects, such as reduction of IQ score (HC, 2013; USEPA, 2024; ATSDR, 2020). These early life exposures are associated with persistent cognitive effects into adolescence and adulthood.

The US Integrated Science Assessments (USEPA, 2013; USEPA, 2024) note that while Pb affects nearly every organ system in the body, the nervous system appears to be the most sensitive target. Pb effects include reduced cognitive function, attention difficulties, impulsivity and conduct disorders. There is evidence indicating that Pb exposure is likely to be causally related to aggression, criminal behaviour, anxiety, depression, and motor function.

There is population level evidence of developmental neurotoxicity at blood lead levels in the range of 1-2 µg/dL; however, there is some uncertainty associated with the effects observed at these levels due to several factors, including the reliability of lab values at these lower concentrations, controlling for confounding, and reduced sensitivity to detect the effect(s) (HC, 2013; USISA, 2024). There is no currently demonstrated threshold for developmental neurotoxicity due to lead.

Health Canada and other national health agencies set guidance values for exposure to many substances that can cause harm to humans. Health Canada has a provisional guidance value (called a toxicity reference value, TRV) for Pb that is based on our current understanding of the health impacts of Pb on children (who are the most sensitive population to Pb exposure). The guidance value for lead (Pb) is an oral tolerable daily intake of 0.0005 mg/kg of body weight per day – this is based on a target blood Pb value of 1.2 µg/dL. A 1.2 µg/dL increase in blood Pb lead has been associated with a decrease in one intelligence quotient (IQ) point in large scale research studies (HC, 2013; HC 2021a).

Infants and children are a susceptible population for health effects related to Pb as they are more likely to absorb lead from the environment through hand to mouth activities (putting fingers and objects into their mouths). They also have greater gastrointestinal absorption of Pb and less effective renal excretion than do adults (HC, 2013). Blood Pb levels tend to rise after infancy, peak between 1 and 3 years of age, then decline during childhood and adolescence. Pb uptake and management by the human body (the Pb kinetics) are influenced by calcium, iron, and zinc levels in the body. For example, iron deficiency can increase Pb uptake into the body and elevated Pb levels can cause iron deficiency anemia. Variables such as sex, disease state, nutritional state, genetics, and ethnicity can influence Pb absorption and health effects. Diet and nutritional state are factors that we can influence, while others are biologically determined.

> "Selection of infants and children as the susceptible population, and selection of neurodevelopmental effects as the critical health effect is considered protective for other adverse health effects of lead across the entire population."

Potential Health Effects for Children in the Trail EM Area

The effects we would expect to see in children at blood lead levels less than 10 µg/dL are neurodevelopmental effects including decrements in IQ and decreased ability to pay attention. While the literature outlines the specific neurodevelopmental health impacts that are found in children, these health outcomes are difficult to measure in a small population where we see about 80-100 children (Meghan Morris, IH Kootenay Boundary Public Health Nurse, personal communication, May 2024) born per year across the EM Area. There are no administrative data that have IQ measurements for these children, and attention deficit hyperactivity disorder (ADHD) diagnoses will be imperfect for many reasons (increasing recognition of diagnosis, variability in methodology/diagnostic criteria, and moderating factors; Espinet et al., 2022). The influence of other factors that affect neurodevelopmental indicators, such as IQ, will be significant (e.g. socioeconomic situation, genetics, etc.). For these reasons, it is challenging to assess "measurable health impacts" for children in the Trail EM Area related to lead in the environment.

One child health assessment tool that may be helpful is the Early Development Instrument (EDI). It is a measure of children's physical, emotional, social, and cognitive development at kindergarten age and data is available for the past two decades. We are currently working with the Human Early Learning Partnership at UBC to review that data.

Context and Considerations for Analysis and Recommendations

There are many environmental factors that influence the health, and more specifically the neurodevelopment, of children: poverty, nutrition, social environment, emotional support, education, etc. It is important to contextualize health risks related to Pb with other factors that may influence health of people, especially children, living in Trail. It is essential in this work to step back and consider the health risks related to ongoing environmental contamination, the cost effectiveness of various interventions, and the economic (and social) benefits the community experiences from having this business active within the city.

The economic benefits of a large employer in the area directly influence the health and well being of children living in Trail. Poverty can have a significant impact on a child's IQ. Several studies have investigated this association and report that children from low-income households scored 4-7 points lower on standardized tests. As the above information demonstrates, we are aiming to reduce the exposure to Pb with the goal of protecting children from population-based impacts of Pb equivalent to an IQ deficit of one point. In doing so, we don't wish to increase risks from other factors.

Blood Lead Geomean Expectation

What is a reasonable expectation for blood lead geomean in a city the same age as Trail, but without the smelter?

The Canadian geomean for blood Pb is currently 0.50 μg/dL for children 3-5 years of age (Canadian Health Measures Survey (CHMS); HC, 2021b; HC, 2021d). Pb is one of many substances that is measured regularly for a randomly selected group of children to create a national database on the extent of health concerns. The geomean referenced was data collected during cycle 6 of the survey (2018-2019). Note that the blood lead measurements for children in Trail are taken from children aged 6-36 months, so we don't have a direct age-matched comparison in either the Canadian data or in US published data. It is also important to note that blood Pb testing for children in Trail is done in the fall months, and thus generally represents the highest environmental exposure after the dry, hot weather of summer and right after the time of year when children spend more time outside. This timing, to measure the highest blood lead levels, does not apply to most other blood Pb comparisons, including CMHS and most published literature.

Blood lead levels peak between 1 and 3 years of age (HC, 2013), so we expect that the mean for children aged 6-36 months in Trail should be higher than that measured from CHMS ages 3-5 years. Age-matched blood lead data was analyzed from NHANES by Dr. Rosalind Schoof (R. Schoof, personal communication, April, 2023).

This demonstrated higher geomean lead levels in the subset of children aged 12-36 months (2015-16 data), a more similar comparator than the published data for 1-5-year-olds. The geomean for children 12-36 months (or 1-3 years) was 0.84 µg/dL, while the geomean for 1-5-year-olds was 0.76 µg/dL for the same period. We thus anticipate that in future CHMS data that children aged 1-3 years old may have slightly higher blood lead geomeans than those aged 3-5 years.

Dr. Schoof's team also analyzed the US data by income to poverty ratios and found significant differences. Again, looking at the most recent year this data is available (2015/16), the "poorest" children (income to poverty ratio <1) have higher blood lead levels (geomean of 1.12), while the "richest" (income to poverty ratio of >4) have much lower blood lead geomeans of 0.62.

Many factors influence blood lead values, including age of home, family income, diet, health status, and environmental sources that children may eat, handle, or get exposed to in the home environment (e.g. lead in paint, imported spices, traditional medicine, pottery, hobbies, etc.). Some of these factors are more prevalent in Trail, including older homes (average age of home in our blood lead analysis was 75 years old), thus one would expect this to influence the blood lead "baseline" geomean in this population. The geomean blood lead for children living in a similar city as Trail, but without a smelter, would thus be expected to be slightly higher than the Canadian geomean.

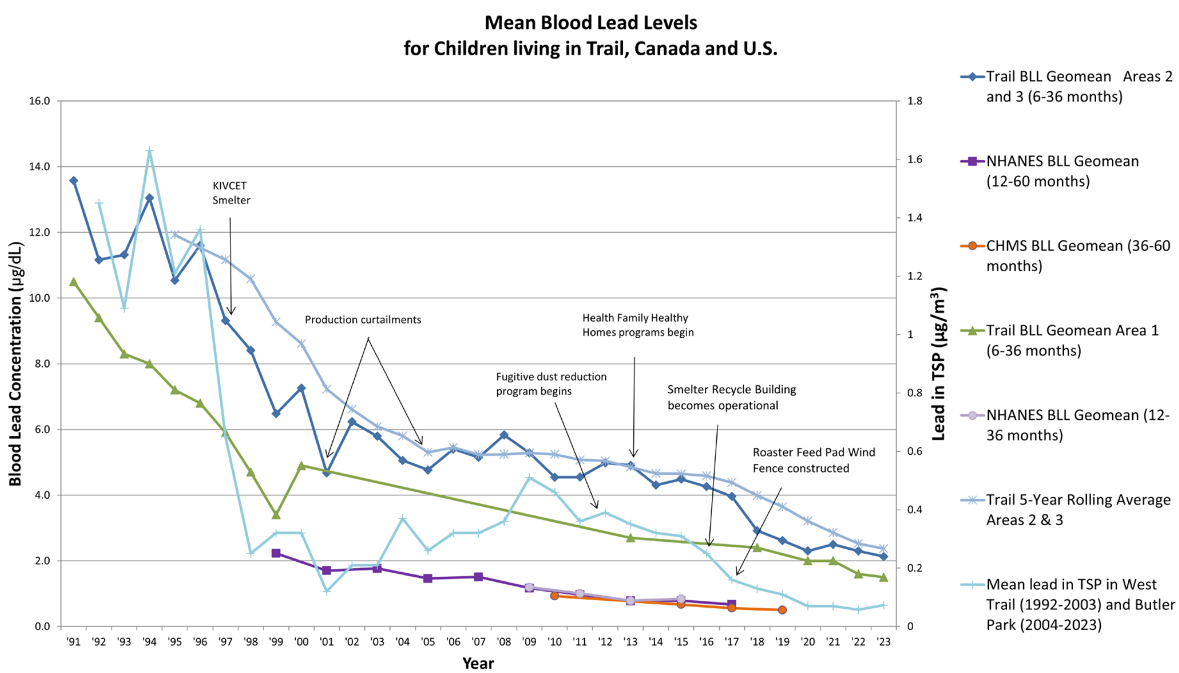

Figure 4. Yearly geometric mean blood lead levels for Trail, CHMS and NHANES.

In summary, the Canadian geomean is going to underestimate a “non smelter comparator” for children tested in Trail. The current age group included in CHMS is older (aged 3-5 years versus 6 months to 3 years of age when higher blood lead levels are expected) and children are more likely to live in older homes with higher prevalence of home-related lead exposures (e.g. paint, plumbing, solder, etc.). Using the Canadian geomean for children aged 3-5 will provide a very conservative comparator.

Considerations from the Analyses

Human Health Risk Assessment

Teck Trail completed a Human Health Risk Assessment. Key components of the HHRA are listed here and the full document is available for review (AtkinsRéalis, 2024a).

1) The toxicological Reference Value (TRV, Health Canada's provisional TRV) used in the HHRA is based on an estimated blood Pb level of 1.2 µg/dL – this is intended to represent a one-point IQ decrement at a population level. An exposure dose of 0.5 µg/kg bw/day is estimated to result in a 1.2 µg/dl blood lead level, which has been associated with a one IQ point decrement. This value is the best measure we currently have for lead levels that are deemed to not cause measurable human health effects. Lead is considered a non-threshold substance, meaning it has not been determined at what level of exposure there are no negative health effects. Note here that the measurable health effect is one IQ point decrement, and it is only measurable at a population level. Individuals could have this variation from one IQ test to the next, and different individuals have different IQ scores across a range of values.

2) Both reasonable maximum (a scenario using the highest expected concentrations of lead that the child could be exposed to), and central tendency scenarios (scenarios using average/expected lead exposures) were used to predict potential blood lead levels based on results of HHRA calculations across soil Pb concentrations resulting in the following:
    a. Reasonable Maximum Scenario: for every 100 mg/kg increase in Pb in soil, there is a 1.6 µg/dL increase in Blood lead level; and
    b. Central Tendency Scenario: for every 100 mg/kg increase in Pb in soil, there is a 0.5 µg/dL increase in Blood lead level.

   Inclusion of results from IH blood lead analysis determined that the line of best fit estimated an increase of 0.10 µg/dL Blood lead level for every 100 mg/kg increase in soil Pb.
   See the graph below for a visual of this.

   In general, ENV requires that reasonable maximum approach is taken, especially when there is limited data. In this case, both were used, but the central tendency is more "realistic" (less conservative) for comparison with BLL to inform development of an MHO risk-based standard.
   This was recommended by our HHRA working group (with representation from IH and ENV). ENV acknowledged the rationale makes sense for the

intended use. This HHRA working group recommendation was then incorporated in the IH BLL analysis.

3) The HHRA concluded that a soil Pb concentration is the most appropriate measure to achieve the requirements of the CSR and the WARP. Using the blood lead analysis correlation, it has been estimated that for young children, exposure to 400 mg/kg Pb in soil is estimated to contribute approximately 0.4 µg/dL to blood lead.

4) Measured (IH blood lead data) and predicted (by HHRA) blood lead levels were assessed, and the results reflected below. The blood lead analysis indicates that for every 100 mg/kg increase in Pb in soil, there is a 0.10 µg/dl increase in blood lead. This is lower than the blood lead levels predicted by the HHRA which predicts much larger increases in blood lead per 100 mg/kg increase in soil Pb concentrations (1.6 and 0.5 µg/dl increase in blood lead for the reasonable maximum and central tendency scenarios respectively).

Figure 5. Measured and Predicted Soil Lead and Blood Lead Levels in Trail. The blue dots represent actual values from Trail children.

This graphic demonstrates that the HHRA modelling is underpredicting actual blood Pb values at the lower soil Pb concentrations and overpredicting blood Pb values at the higher soil Pb concentrations. The predicted values from the HHRA do not appropriately account for sources of Pb other than those found in soil (hence the intersection with zero when the soil lead concentration is zero). Limitations of the

HHRA is that it uses overly conservative assumptions and has limitations accounting for Pb in airborne dust. The HHRA predicted BLL shown in this graphic also do not account for “background” lead sources, so the green and blue prediction lines should not intersect with zero blood lead, but with the intersect of background BLL (e.g. around a Canadian background of 0.5 μg/dL for children aged 3-5 years old). This does not change the observation that the HHRA is over-predicting the blood lead levels expected to be seen in Trail children who have contaminated soil. This is more pronounced at the higher soil lead concentrations.

Measured BLLs provide a more realistic insight into actual uptake of Pb based on exposure to all sources specific to Trail population, and without conservative assumptions. The correlations from the blood lead analysis are relied upon for developing the MHO recommended risk-based standard.

Analysis of Variables Influencing Children’s Blood Lead levels in Trail BC

IH completed an analysis of the association of key sources (Pb in soil, Pb in TSP for subset of children) of environmental Pb in the Trail area and blood Pb data from Trail area children for the years 2007-2023. Blood Pb levels have been collected from children aged 6 months to 36 months in the Trail area since the early 1990s. 2007-2023 data was used for the analysis as it allowed for assessment of multiple additional variables. All the blood lead samples (n=918) were used in the first group of models, while the second group of models, looking at the variable of Pb in TSP, were only able to analyze a subset of the samples (n=155). The analysis evaluated the impact of various environmental exposure media and socioeconomic variables on children blood lead levels in the community of Trail. The analysis aimed to answer the following questions:

1) What is the association between soil lead concentrations and child blood lead levels?
2) What is the association between lead in airborne dust (total suspended particulate/TSP) and child blood lead levels? (This was completed for East Trail and Shavers Bench areas only)
3) What is the association between pre- and post-remediation soil lead concentrations and pre- and post-remediation child blood lead levels?
4) What is the comparison between rate of change of blood lead levels in Trail and rate of change from Canadian and US population blood lead levels?
5) What is the association between indoor and outdoor dust lead levels and child blood lead levels in 2016 study?

What is the association between soil lead concentrations with child blood Pb levels? Additionally, what other variables were analyzed and interact with this association between soil and blood lead?

Both a univariate and a multivariate analysis were done for soil Pb and blood lead.

The univariate analysis of Pb in soil and blood lead (n=918 samples) found the following:

1) Pb in soil – a model of the association between only Pb in soil and blood Pb in the children tested in Trail (n=918) demonstrates a correlation coefficient between blood lead levels and soil lead levels is 0.29 (univariate model) indicating a weak to moderate positive linear relationship between these variables.

   Interpretation: Higher concentrations of lead in the yard soil increases the likelihood that children will have a higher blood lead level. This relationship was found to be weak to moderate.

Variables are analyzed using both univariate and multivariate analyses. While we can look at individual factors and detect possible associations with blood Pb (univariate), looking at many variables together (multivariate) helps identify the most significant ones, as many variables can interact with each other. We analyzed the variables in multiple different ways to limit confounding (when a variable causes a spurious association due to its interaction with blood lead and another variable). Further details can be found in the full report (IH, 2024).

The multivariate analysis for the first model of 918 samples demonstrated that other factors are influencing blood lead levels. House age did not appear to be a significant predictor in this model, but median income is a significant predictor. As house age, median income and year are added into the model, the association of Pb in soil and blood Pb decreases in magnitude.

The second model reports on the associations between Pb in TSP (airborne dust) and blood Pb. The TSP (airborne dust) monitoring data was considered representative for only a subset of the samples (n=155).

2) Pb in soil (additional variables included) – the correlation coefficient between blood lead levels and soil lead levels is **0.08,** in a multivariate model that included Pb in TSP, indicating a weak positive linear relationship between these variables.

   Interpretation: Higher concentrations of lead in the yard soil increases the likelihood that children will have a higher blood Pb level. This relationship was found to be weak in the multivariate analysis.

It is important to note that the correlation coefficient is different in the univariate versus multivariate analysis, suggesting the importance of other variables in affecting the association between soil and blood Pb. Pb in TSP and other variables are discussed here as they are influencing exposure and uptake of Pb from the environment. As the model is built out with additional predictors, the estimate for soil Pb levels decreases. This is in line with the “strength” of the correlations discussed here.

3) Lead in TSP – Pb in TSP demonstrates a correlation coefficient of **0.41** for blood lead levels and Pb in TSP. This is the sub-analysis (n=155), which demonstrates a stronger correlation of Pb in TSP with blood Pb than the correlation of Pb in Soil with blood Pb.

   Interpretation: Higher amounts of Pb in TSP increase the likelihood that children will have a higher blood Pb level. This relationship was found to be moderately strong. Pb in TSP shows a stronger association with blood Pb compared to the association of Pb in soil with blood Pb.

4) Age of Home – a positive linear relationship between house age and blood lead levels was demonstrated.

   Interpretation: As the age of the home increased, children were more likely to have higher blood Pb values. Older homes have more lead sources (lead in paint, especially prior to 1960; lead in solder in pipes). Older homes in Trail are also generally closer to the smelter, so would have higher amounts of lead in the dust in the home.

5) Income – a negative linear relationship between median income and blood Pb levels was seen.

   Interpretation: children living in homes with higher incomes were found to have lower blood Pb levels. This is a finding borne out in the literature (Nguyen et al., 2024) and may relate to a number of risk factors that change in relation to income. Examples include the control of the home environment that a home renter versus owner may have, which may influence their ability to make significant changes to the home, such as cover or remove leaded paint. Food affordability may impact the child’s diet. Parents may be juggling several jobs, so have less time for deep cleaning the home. In Trail, less expensive rental properties and smaller homes are more likely to be proximal to the smelter.

6) Household variables – addition of household variables including having pets, recent renovations, smoking, and a parent working in a lead-based industry was analyzed for the years these variables were available (2019-2023; a subset of 289 samples). A positive correlation was found between blood Pb levels and the variables of smoking and working in a lead-based industry. Of the household variables, only working in a lead-based industry was found to be significantly associated with blood lead in the modelling.

What is the association between lead in airborne dust [total suspended particulate (TSP)] and child blood lead levels?

> **Pb in TSP** analysis was analyzed in the multivariate sub-analysis of the area for which TSP data was deemed applicable. It demonstrates a correlation coefficient of **0.41** for the blood lead levels and Pb in TSP. This was notably higher than the correlation coefficient for soil Pb and blood Pb calculated in the same sub-analysis (**0.08** in this multivariate sub analysis).
> **Interpretation**: Higher concentrations of lead in dust particles near children's homes increased the likelihood that they would have higher blood lead levels. This relationship was found to be moderate, and notably stronger than the relationship of concentrations of Pb in soil and blood Pb.

There is a **stronger correlation of blood Pb with Pb in TSP than Pb in soil**. Neither age of home nor median income are significant in the sub-analysis (significance will of course be impacted by the number of data available for analysis), while Pb in TSP is very significant.

What is the association between pre- and post-remediation soil lead concentrations and pre- and post-remediation child blood lead levels?

Comparisons were made for children pre- and post-remediation, but due to the small number of children with both pre- and post-remediation samples, we are unable to draw conclusions about the association of soil lead concentrations with blood Pb levels.

We do see a decline in children's blood Pbs over time, regardless of remediation status. This mirrors the decline seen in the Canadian population but is occurring at a greater rate of change as discussed in the next section.

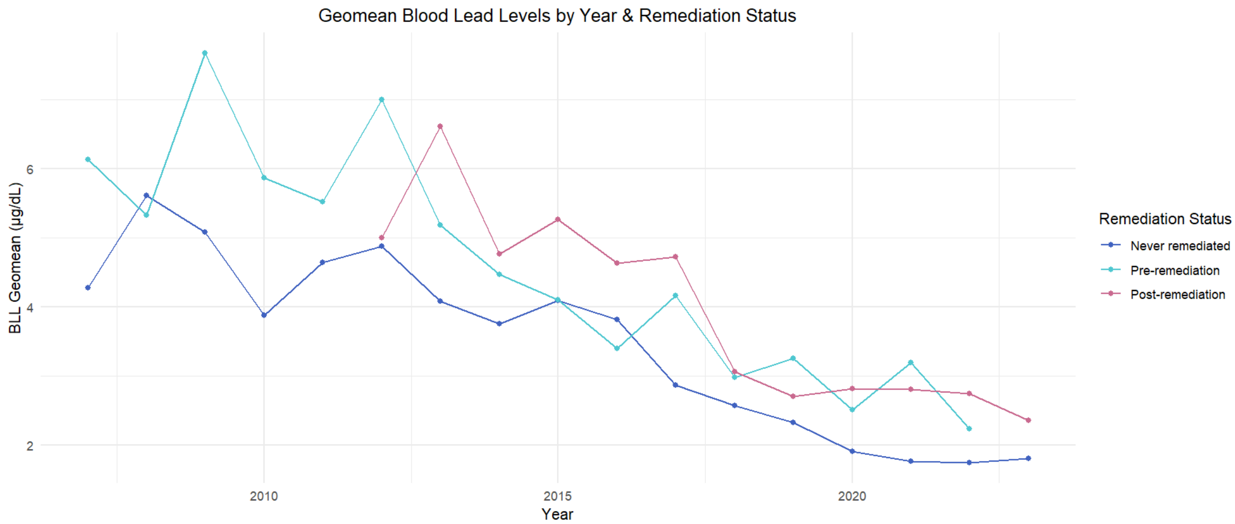

Figure 6. Yearly geometric mean blood lead levels by property remediation status.

What is the comparison between rate of change of blood Pb levels in Trail to rate of change from Canadian and US population blood lead levels?

The blood Pb analysis reviewed the rate of change of blood lead levels in Trail compared to Canadian and US populations using Canadian data from the Canadian Health Measures Survey (CHMS) and United States data from the National Health and Nutrition Examination Survey (NHANES). Overall, the Trail, CHMS, and NHANES data show that blood Pb levels have been decreasing over time. The blood Pb levels in Trail demonstrate higher absolute differences between years compared to the national data.

This observation, alongside the association of significant blood lead decreases in children with interventions such as the KIVCET smelter and fugitive dust reduction program, indicate that these interventions are having an impact that is greater than the “expected” change due to other environmental changes that have occurred across Canada (removal of Pb from gasoline, removal of lead from paint, and new housing stock).

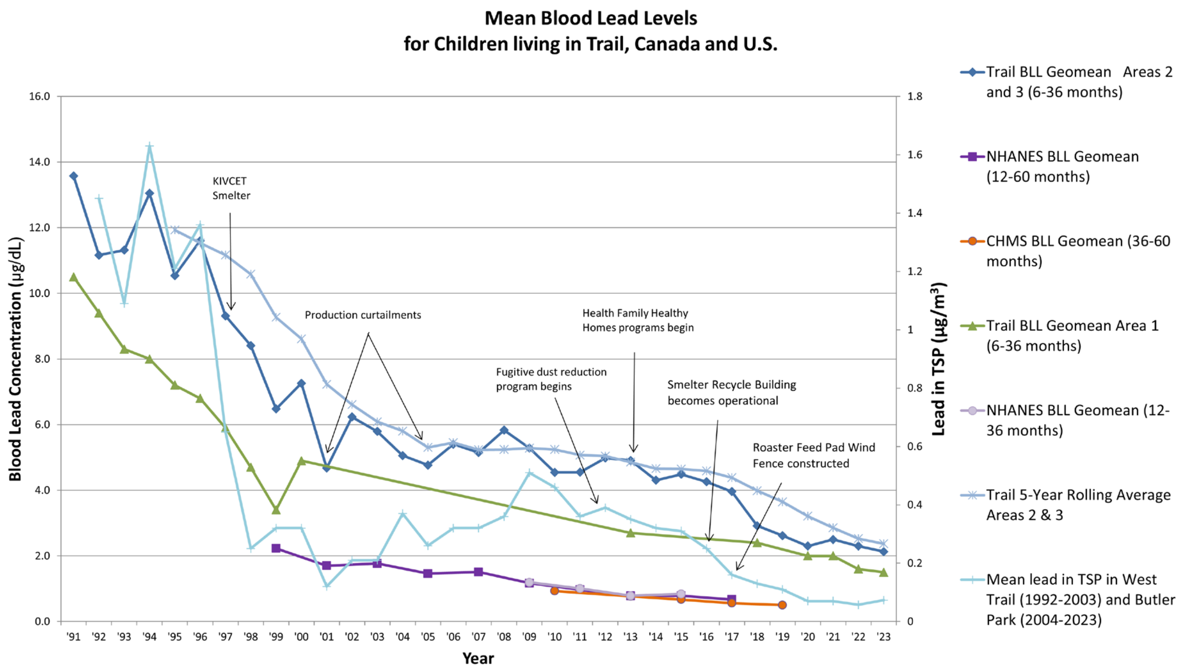

Figure 7. Yearly geometric mean blood lead levels for Trail, CHMS and NHANES.

The Canadian geomean for 3-5-year-olds provides a low estimate as a "non smelter comparator" for children tested in Trail. The current age group included in CHMS is older (aged 3-5 years versus 6 months to 3 years of age when higher blood Pb levels are expected) and Trail has a high proportion of older homes, so children are more likely to live in older homes with higher prevalence of home-related lead exposures (e.g. paint, plumbing, solder, etc.). Using the Canadian geomean for children aged 3-5 years-old will provide a very conservative comparator. We look forward to the data for 1-3 years-old children in Canada expected from the next CHMS.

What is the association between indoor and outdoor dust lead levels and child blood lead levels from the 2016 study?

A 2016 study looked at indoor and outdoor dust Pb levels collected from 60 properties, of which 20 had blood lead level data for children living in the home that year. Interestingly, the correlation matrix indicates is a **weak to moderate negative** relationship between blood lead levels with indoor dust fall lead loading. Modelling of the association of blood Pb with soil Pb, and both indoor and outdoor dust Pb demonstrates no significant association between indoor dust fall Pb loading and blood lead levels. There is a **moderate to strong positive** relationship between blood lead levels with **outdoor dust fall lead loading** and this does reach significance in the same model.

Outdoor, but not indoor, dust fall lead loading is positively associated with blood Pb levels in this small study. Adding in household income and house age as predictors into the model demonstrates no significant associations. Due to the limited sample size, no interpretation can be made.

Key points for MHO recommendation:

The Blood Pb Analysis used available data to determine the strength of association of key sources of environmental Pb with children's BLL in the Trail area. The strongest association was found to be between blood Pb and Pb in TSP, with a weaker association between blood Pb and Pb in soil. The analysis also indicates that other factors influence BLL including household income, age of home, and having a parent working in lead-based industry.

Limitations of the Blood Lead Analysis

The data used for the analysis (TSP, soil and BLL) was not collected for the express purpose of this analysis, so we are using what is available in the best way our expert team (and other consulted experts) was able. The data analysis has the inherent limitation of using linear models which assumes there is a linear relationship between the dependent and independent variables.

All environmental data (soil Pb concentrations and Pb in TSP) was provided by Teck Trail Operations to IH for use in the blood lead data analysis. This report thus relies on the data provided by Teck, and/or the working group's input regarding the:

- Selection of the type of data used for the TSP/airborne dust data (there is also dustfall data that could be useful to analyze).
- Representativeness of the sample locations for TSP data (this limited the population size that could be included in that part of the analysis).
- Method and locations of soil sampling.

The reliability and representativeness of the data will impact our understanding of children's exposure (e.g. selection and availability of sampling stations and their position(s) relative to child's potential and actual exposures). The existing dataset was reviewed in this context, with the understanding that data collection will be on-going and used to revisit the finding of this analysis as appropriate.

The data was assumed to be complete and accurate, and the assumptions used in the blood lead data analysis were developed with input from the working group. The working group agreed that the approach taken for the analysis was the most appropriate and defensible given the dataset's limitations.

The sample size for the TSP analysis was limited by the location of the sampling station. A scientifically informed decision was made to assign the TSP Pb concentrations measured at the Butler Park monitoring station to only specific neighbourhoods located proximate to the station. In future analyses, we hope to obtain additional TSP data to allow for analysis of all BLL tested children.

The pre and post remediation analysis was also limited due to a limited number of paired samples of the same child before and after a remediation. We don't anticipate improvement in this data set, as properties are being remediated when women are pregnant and expecting their child, or very early in the child's life, both scenarios limiting the possibility of collecting a pre-remediation blood sample.

The analysis of correlations between measured BLLs and various risk factors was conducted for specific years based on the data that was available for the risk factor variables of interest (e.g., questionnaire responses regarding home factors).

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Appendices

Recognition of Collaborative Work

I would like to thank the many people involved in the Human Health Risk Assessment and the blood lead analysis which informed the MHO recommendations:

Dr. Ray Copes, consultant for Interior Health (physician with expertise in epidemiology, environmental health, and human health risk assessment), Leanne Cusack (public health epidemiologist, Epidemiology and Surveillance Unit, Interior Health), Jenna Le Noble (Surveillance analyst, epidemiology and surveillance unit, Interior Health), Christina Yamada (Manager, Environmental assessment, Interior Health), Anders Erickson (Senior human health risk assessment specialist, health protection branch, Ministry of Health), Tara Kennedy (Senior Risk Assessor and Toxicologist/ National Risk Assessment Practice Lead; AtkinsRéalis, 2024a), Clare North (Superintendent of Environmental Remediation, Teck Trail Operations), Dave Bell (Senior Environmental specialist, Teck Metals Ltd), Andrea McCormick (Director, Site Assessment & Remediation West 2, Environment; AtkinsRéalis, 2024b), Natalia Kukleva (Manager Investigation and Remediation, Land Remediation Section, Ministry of Environment and Climate Change Strategy), Jasen Nelson (Senior Risk Assessment Officer, Land Remediation Section, BC Ministry of Environment and Climate Change Strategy), Lavinia Zanini (Senior Contaminated Sites Officer, Ministry of Environment and climate Change Strategy), Rosalind Schoof (Toxicologist, Principal, Risk Assessment and Community Health, Ramboll), Alma Feldpausch (toxicologist, Principal, Health Sciences, Ramboll), Julie Tu and Cynthia Van Landingham (Ramboll group), Steven Hilts (Trail Health and Environment Committee member, past Director of environmental legacies with Teck, and author of multiple studies on smelter emissions and children's blood lead). We also consulted with experts at the BC Centre for Disease Control and would like to thank Max Xie (Biostatistician and Data Linkage Lead) and Felicity Clemens (Senior Data Scientist) for their guidance on the blood lead analysis.

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