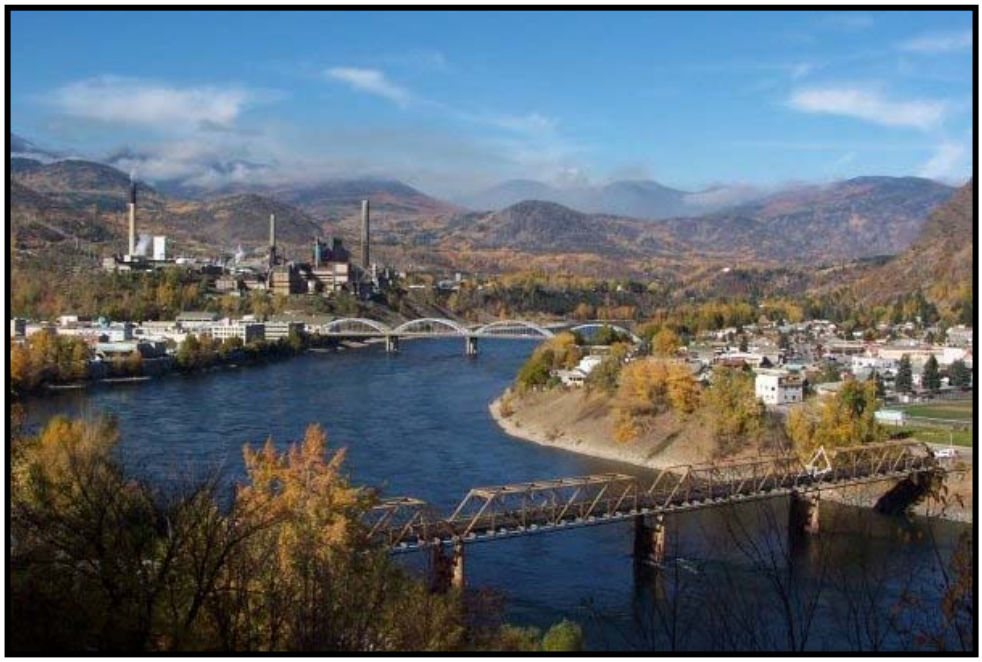
Teck

SUMMARY REPORT

TECK COMINCO METALS LTD.
PHASE 4 HUMAN HEALTH RISK ASSESSMENT



Issue Date: March 2009

integral consulting inc.

Welcome to the City of Trail

Glenmerry in fall

Trail wildlife

Tadanac in winter

FIGURES

TABLES

INTRODUCTION

The Teck Cominco Metals Ltd. Smelter, Trail, B.C.

This Summary Report presents the final results of the Teck Cominco Metals Ltd. (Teck) Phase 4 update to the quantitative human health risk assessment (HHRA) for offsite exposures to metals, other than lead, released from the smelter in Trail, British Columbia (B.C.). The Phase 4 HHRA refines and augments site-specific risk estimates generated in prior HHRA phases, selectively employing probabilistic risk assessment techniques where appropriate. The results of the Phase 4 HHRA support development of a Wide Area Remediation Plan that will satisfy Trail's community-based goals and the B.C. Contaminated Sites Regulation (BC CSR). The Phase 4 HHRA was conducted in accordance with guidance from the B.C. Ministry of Environment (BCMoE), Health Canada, and the U.S. Environmental Protection Agency (EPA).

The Phase 4 report, along with all the other lead and nonlead HHRA reports generated for Trail, may be found in the libraries at Selkirk College in Castlegar, at the Trail facility, and at the District Public Library in Trail.

Background to the Risk Assessment

Meeting of the Trail Health and Environment Committee

Trail, B.C. has been the site of a major lead and zinc smelting facility operated by Teck for more than 100 years. These operations have resulted in releases of lead and other metals found in the lead and zinc ores to the air from both stack and fugitive emissions, with resultant deposition of metals-containing dust onto the surrounding area. Prior to the development of modern pollution control technology, deposition of metals-containing dust led to increased metal concentrations in soil. During the past several decades, operational changes, including transition to a new smelter in 1997 with significant improvements in emission controls, have resulted in marked reductions of releases and stabilization of soil metal concentrations. Emissions from the smelter have also included releases to the Columbia River via permitted discharge of treated effluent and historical discharge of slag.

Reductions in smelter releases combined with community outreach efforts have resulted in substantial reductions in blood lead levels of children residing in Trail. Lead exposures continue to be addressed in Trail, both by ongoing blood lead monitoring of preschool aged children and remediation efforts by Teck and the City of Trail (Trail Lead Program 2001).

Trail has a history of more than 15 years of HHRAs related to both lead and other metals in the environment. A series of more than 12 detailed

reports and four peer-reviewed journal articles published by the staff and consultants of the Trail Community Lead Task Force culminated in the final report in early 2001 (Trail Lead Program 2001). Later in 2001, the Medical Health Officer for the Kootenay Boundary Community Health Services Society endorsed the remedial recommendations of the Trail Lead Task Force (Trail Lead Program 2001), indicating that he believes the top priority should be further reduction of smelter emissions and the second priority should be control of secondary movement of metals in surface dust (Ames 2001).

Specific occupational exposures at the smelter were not evaluated as part of the Trail HHRAs. Workplace exposures are regulated separately by Worksafe B.C. and monitored, as required, by Teck.

Included among the Task Force documents is a series of three reports (Phases 1 through 3) on the estimated health risks to Trail residents from smelter releases other than lead (Exponent 1997; 1998a,b,c; 2000a,b).

- **Phase 1**—Included a review and evaluation of existing data, exposure pathway screening, the creation of a conceptual diagram or picture of site-related impacts to potential exposure media for the Trail population (i.e., the "conceptual site model"), and refinement of the list of potential contaminants of concern (PCOCs).
- **Phase 2**—Consisted of bioaccessibility testing, screening of new data, refining the list of PCOCs, and a screening level risk assessment focusing on exposure to arsenic, antimony, and cadmium for selected residential and agricultural scenarios.
- **Phase 3**—Incorporated measured produce and house dust data into the existing risk assessment.

HHRA Phases 1 through 3 for the Trail site resulted in a risk characterization focusing on risks associated with exposure to arsenic, antimony, and cadmium that was presented to the Task Force and the community in 2000 (Exponent 1997; 1998a; 2000a). At that time, the Task Force acknowledged that incorporation of additional or new data and the addition of an analysis using probabilistic methods to refine exposure and risk estimates for PCOCs could be completed in a subsequent Phase 4 HHRA.

According to Health Canada (2007) guidance on complex site-specific human health risk assessment of chemicals:

> *The primary reason for undertaking a probabilistic analysis is to determine the possible range and distribution of the estimated risk, in cases where a single point estimate of risk is insufficient. Other reasons for a probabilistic analysis may include: quantifying the influence of uncertainty and communicating the resulting confidence in the risk estimate; quantifying the selection of a risk estimate in terms of the portion of the population potentially receiving greater exposure; decision-making regarding the value of information and additional data collection; cost-benefit analysis and allocation of resources for remediation or risk management strategies.*

Based on the recommendations resulting from prior phases, the Phase 4 HHRA (Integral 2008):

- Incorporates additional site-specific data for air, sediment, soil, outdoor dust, surface water, groundwater, fish, and homegrown produce that was collected since completion of Phase 3
- Addresses data and information gaps identified in BCMoE reviews of Phases 1 through 3 (Fox 2004) and the Phase 4 Work Plan (Fox 2007)
- Identifies and addresses changes from prior risk assessment phases in analytical methods used to measure metals in soil and other media, regulatory standards, and toxicity reference values utilized characterize potential metal toxicity at various levels of exposure
- For key exposure pathways, uses probabilistic risk calculations to more clearly identify the range of potential risks at the site
- Reviews and summarizes results of the urinary thallium survey conducted in Trail in 2002 to characterize exposures to thallium in the community
- Develops recommendations regarding the potential utility of characterizing local exposures to arsenic and/or cadmium by "biomonitoring"—analyzing biological samples (e.g., blood and urine) collected from a population of interest for markers of exposure to these metals
- Develops recommendations regarding possible methods for deciding where contaminated soil cannot be safely managed in place.

In addition, because the remediation plan for the Trail site is evolving and will likely take a site-wide approach, the Phase 4 HHRA evaluates risks on a site-wide basis as well as those neighborhoods that are expected to have the highest exposures to PCOCs.

Study Area Description

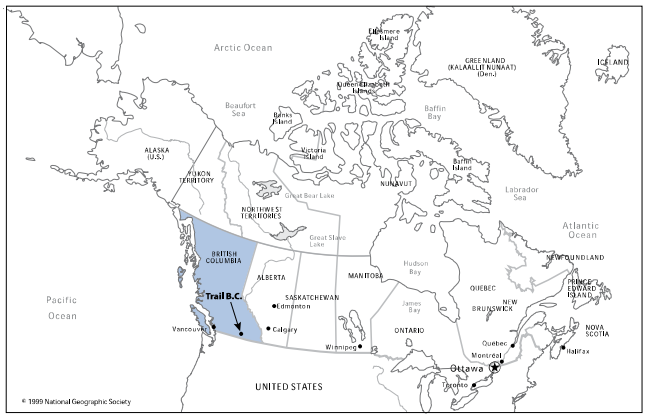


Figure S-1. Teck Cominco Smelter Site, Trail, British Columbia

The Teck smelter is located in the City of Trail, which is situated in the West Kootenay region of southeastern B.C. The smelter facility is in the Columbia River valley, approximately 15 km north of the boundary with Washington State (Figure S-1).

The risk characterization for Phase 4 focuses on site wide risks for all Trail communities, but also presents neighborhood-specific risks for East Trail, Rivervale, Tadanac, Waneta, and West Trail. These neighborhoods were also evaluated in the Phase 3 HHRA. The Phase 4 HHRA also characterizes risks for consumption of locally caught fish from the Columbia River in the vicinity of the Trail facility and incidental ingestion of soil during recreational use of all terrain vehicles and dirt bikes in off-road areas adjacent to the river downstream of the facility.

RISK ASSESSMENT APPROACH

The use of probabilistic techniques for risk assessment has become more accepted over the last 15 years. Probabilistic approaches selectively use distributions or ranges of parameter values ("parameter distributions") for inputs to the risk assessment. Non-probabilistic approaches, such as those employed in the prior phases, used only single values ("point estimates") for each risk input.

The Phase 4 HHRA builds upon the prior phase HHRAs by incorporating reassessment of old data with new data and selectively employing probabilistic risk assessment techniques to better quantify potential risks to Trail residents. As with Phases 1 through 3, BCMoE's recommended framework for Quantitative Human Health Risk Assessment (Golder Associates 1993) provides the overarching process followed for the Phase 4 HHRA. As recommended by BCMoE (2006), this original framework is supplemented by additional Canadian and U.S. risk assessment methodologies and guidance that have continued to evolve or be developed since 1993. The original risk assessment framework, which "…is intended specifically to support the contaminated site remediation process, from project planning through monitoring" (Golder Associates 1993), consists of four primary components: Problem Formulation, Exposure Assessment, Toxicity Assessment, and Risk Characterization. Each of these components is discussed further in this Summary Report.

Problem Formulation: Refining the Conceptual Site Models

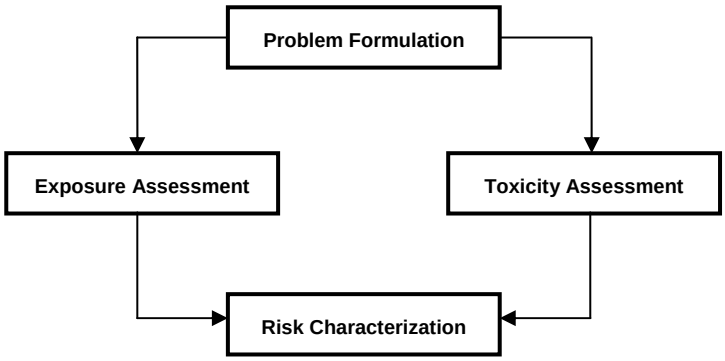


Figure S-2. Relationship between Each of the Four Risk Assessment Framework Components

The Phase 4 Problem Formulation step (see Figure S-2) includes preliminary characterization of the ways in which the contaminants are released from the facility and subsequently transported to and between exposure media (e.g., air, surface water, groundwater, soil, dust, sediment, and produce), as well as how people may then contact the chemicals in those media. Within the problem formulation, existing data on PCOCs in potential exposure media are also evaluated to determine if more data are needed to better describe this picture of contaminant release, transport, exposure, and people, which collectively comprise potential "exposure pathways" for the site.

Exposure pathway and contaminant screening evaluations during this component develop and refine the conceptual site model, which focuses the remainder of the risk assessment process on those contaminants and exposure scenarios that could represent risks to people in Trail.

Pathway Screening Analysis

Residential vegetable garden in Waneta

Exposure scenarios differ depending on anticipated land use at and around the site, and how the site is or will be used by people living, playing, or working at or near it. In the Phase 4 Problem Formulation, exposure scenarios identified as potentially complete are shown in the pathway screening conceptual site model for Phase 4 summarized below and depicted in Figure S-3:

- Residential exposures to contaminants in air, outdoor dust, indoor dust, soil, fish, homegrown produce, commercial crops, livestock, groundwater, and surface water by adults and children living in Trail communities
- Commercial exposures to contaminants in air, outdoor dust, indoor dust, soil, groundwater, and surface water by adults and children at commercial sites in Trail, such as at daycare centers
- Agricultural exposures to contaminants in air, outdoor dust, soil, groundwater, and surface water by workers at a dairy or winery in the Trail vicinity
- Recreational exposures to contaminants in sediments by people recreating at local beach areas along the Columbia River
- Recreational exposures to contaminants in air, outdoor dust, and surface soil along a limited stretch of the Columbia River where dirt bike and all-terrain vehicle (ATV) riding occurs.

The Phase 4 HHRA excludes two of these exposure pathways for further consideration, based on the pathway screening analysis conducted in Phase 1 (Exponent 1997) that remains applicable to Phase 4. Specifically, consumption of commercial crops represents an incomplete pathway based on information that suggests that crops (e.g., grains or commercially grown vegetables) are unlikely to be grown and consumed locally as a large part of an individual's diet. The other excluded pathway, consumption of local livestock, while potentially complete, is considered to be a minor pathway of exposure for the site-related contaminants, because these contaminants do not accumulate in livestock at levels of human health concern for the general population.

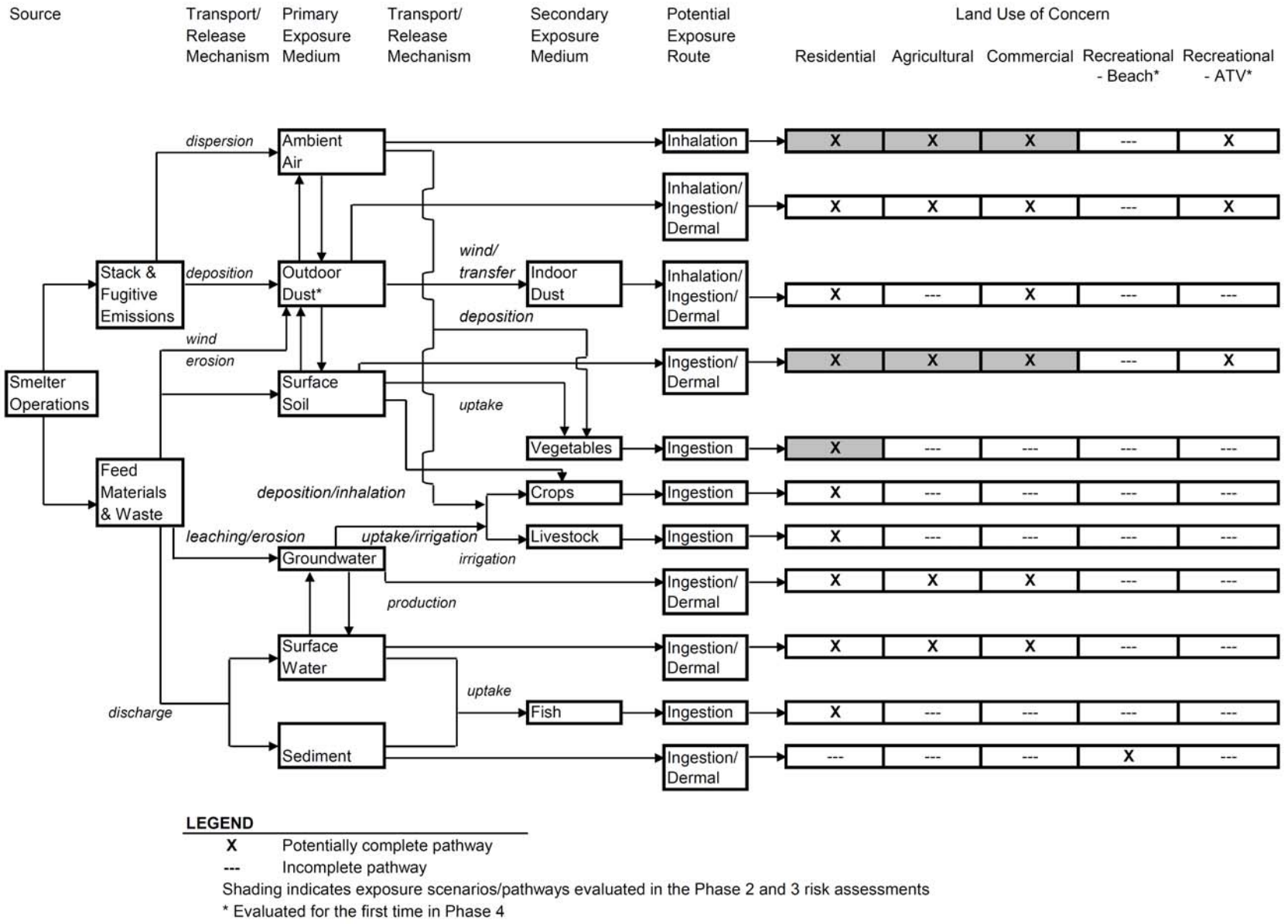


Figure S-3. Phase 4 HHRA Conceptual Site Model for Pathway Screening

Identification of Potential Chemicals of Concern

The following contaminants were screened to identify PCOCs:

- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Fluoride
- Mercury
- Molybdenum
- Nickel
- Selenium
- Silver
- Thallium
- Tin
- Vanadium
- Zinc

For each of the remaining scenarios, Phase 4 evaluates available data for each medium (e.g., soil, air, and fish) against current applicable regulatory criteria, site-specific background concentrations (as appropriate), and/or site-specific risk-based objectives. This "screening" process, recommended by BCMoE, is used to identify PCOCs for focused evaluation in the HHRA. Screening criteria are compared to the maximum concentration for each contaminant for each medium on a site-wide basis and in each of five Phase 4 neighborhoods. All contaminants with at least one result above the respective criterion for that medium are retained as PCOCs in this HHRA. For soil, outdoor dust, and indoor dust, PCOCs identified in any of these media are retained for all three media, regardless of the medium-specific screening result. All data of good quality collected between 1989 and 2007 are included in the Phase 4 HHRA. For air, only data collected since the new smelter was operational is included in this HHRA.

Phase 4 PCOCs identified for each exposure pathway within an exposure scenario are summarized below:

Residential Scenario

- Incidental ingestion of antimony, arsenic, cadmium, selenium, silver, thallium, tin, and zinc in soil, indoor dust, and outdoor dust
- Inhalation of arsenic and cadmium in ambient air
- Ingestion of antimony, arsenic, cadmium, and thallium in homegrown produce
- Ingestion of arsenic, chromium, mercury, selenium, thallium, and vanadium in locally caught fish.

Example of a residential soil sample location

Commercial Scenario

- Incidental ingestion of antimony and cadmium in soil/dust
- Inhalation of arsenic and cadmium in ambient air.

Example of a commercial soil sample location

Agricultural Scenario

- Incidental ingestion of antimony and cadmium in soil
- Inhalation of antimony and cadmium in particulates in air.

Recreational Scenario

- Incidental ingestion of antimony in soil
- Inhalation of antimony in particulates in air.

No PCOCs are included for beach sediment, groundwater, or surface water in Phase 4 because all contaminant concentrations in these media are below their respective criteria.

Fishing in the Columbia River

Exposure Assessment: Calculating Receptor Intakes

Intake or dose is estimated using each of these variables and the PCOC medium-specific concentration in the following equation:

$$\text{Intake/Dose (mg/kg-d)} = \frac{C \times CR \times F \times EF \times ED \times AF}{BW \times AT}$$

Where:

C = chemical-specific exposure concentration
CR = contact rate
F = intake fraction
EF = exposure frequency
ED = exposure duration
AF = absorption factor
BW = body weight
AT = averaging time

The Exposure Assessment component generally represents the greatest site-specific effort in the risk assessment process. This component involves characterizing the temporal and spatial distributions of contaminants at the site, as well as the ways in which people can be exposed (i.e., in residential settings, at work or while engaging in agricultural or recreational activities) and the specific exposure characteristics (e.g., contact rates, exposure frequency, exposure duration) to be used in deriving site-specific exposure estimates. Collectively, this information is used to calculate "intakes" or doses of each chemical for each exposure scenario evaluated.

For the Trail Phase 4 HHRA, intake refers to the amount of a chemical that enters the mouth or lungs. Chemical-specific intakes for each exposure pathway are estimated using equations that incorporate several factors that pertain to exposure and which may vary for different exposure scenarios or receptor populations. These exposure factors or "variables" are described below:

Local playground

- Medium-specific PCOC concentration—The site-specific PCOC concentration in soil, outdoor dust, indoor dust, ambient air, fish tissue, and homegrown produce concentration to which a person is exposed
- Contact rate—The amount of water, food, dust, soil, or air that a person may take into his or her body (i.e., drink, eat, breathe) over a specified time
- Intake fraction—Fraction of media contacted that is assumed to be from the contaminated source

Hiking in the Trail vicinity

- Absorption factor—An adjustment factor to account for relative absorption of a chemical from the medium of interest compared to absorption from the exposure medium in the toxicity study(ies) used to derive the toxicity value
- Exposure frequency—How often a person could be exposed to the chemical
- Exposure duration—How long a person could be exposed to the chemical
- Body weight—The typical mass (in kilograms) for each age group of people who may be exposed
- Exposure averaging time—The time (in days) over which exposure is averaged (e.g., over a lifetime for chemicals that might cause cancer or more than a year for other chemicals).

Probabilistic assessments are conducted by Monte Carlo analysis using Crystal Ball® software. Analyses employ a combination of parameter distributions and point estimates, depending on the specific input parameter.

Each Phase 4 exposure scenario (i.e., residential, commercial, agricultural, recreational) is characterized by a number of assumptions regarding the frequency of contact with potentially contaminated media, duration of exposure, and other parameters unique to that population. For residential and commercial scenarios, Phase 4 calculates exposures for a young child (6 months to 5 years old) and for a combined exposure period as an adult plus as a young child. The adult plus child scenario was selected because it allows for the calculation of risks for a resident who spends time as both a child and adult (or teenager) in Trail. For the commercial scenario, the child is included based on potential exposures at commercial daycare centers. Agricultural exposures in Phase 4 are assessed for adults only based on a worker scenario with potential exposure duration from teenage years through retirement. For the ATV/dirt bike exposures, it is assumed that no young children participate and that the entire exposure duration applies to adults (which are assumed to include teenagers).

Some of the exposure factors used in prior phases (Phases 1 through 3), were also used in Phase 4. Other factors were obtained from regulatory guidance and/or other published literature, including Richardson (1997), BCMoE (1996), Health Canada (2004), and USEPA (1989; 1991; 1997a; 2001; 2004). When available, Canadian exposure information was used preferentially over U.S. or European data. Information on regional behavior patterns was also considered, as appropriate.

Phase 4 uses both probabilistic and nonprobabilistic (i.e., single point estimate) approaches to characterize site-specific exposure estimates. For exposure scenarios previously evaluated in Phase 3, a probabilistic approach is used. For Phase 4 exposure scenarios not evaluated in prior phases (i.e., fish ingestion, recreational ATV/dirt bike use), a point estimate approach is used.

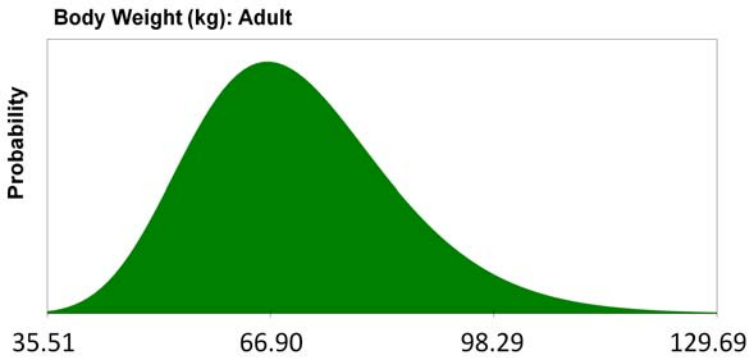


Figure S-4. Lognormal Distribution of Adult Body Weight (Richardson 1997)

Exposure factors incorporated in the risk assessment are in the form of either distributions or point estimates depending on the parameter, information available, and whether the exposure scenario was evaluated with probabilistic or deterministic approaches. Figure S-4 provides an example of one of the input distributions used in the Phase 4 probabilistic assessments. For this distribution, adult body weight averaged 70.7 kg with a standard deviation of 14.5 kg. Use of this input distribution along with distributions for other exposure inputs allows for a determination of the possible range and distribution of estimated risks for the population of individuals within the Trail community. Distributions of estimated risk also allow for selection of a risk estimate in terms of the portion of the population potentially receiving greater exposure over the range of exposures represented by the input distributions.

In contrast, for deterministic assessments in Phase 4 (i.e., ATV/dirt bike use and ingestion of locally caught fish), the mean adult body weight from the distribution shown in Figure S-4 is used as point estimate. Combined with other typical or reasonable maximum exposure inputs, the deterministic assessments yield single point estimates of risk for an individual with a typical or reasonable maximum exposure rather than a range of risks estimated for the population.

Toxicity Assessment: Evaluating Dose-Response Relationships

Total cancer risk estimates for Phase 4 consider an individual's exposure to multiple carcinogens and via multiple pathways.

The Toxicity Assessment summarizes health effects that may be associated with exposure to PCOCs. The Toxicity Assessment includes classification of toxicants as carcinogens or noncarcinogens, compilation of toxicity criteria or benchmarks, and description of the relationship between different levels of exposure to a PCOC and the corresponding change in effect on the exposed organism (i.e., the dose-response relationship). The focus is on effects associated with long-term exposures and on effects that could be associated with the contaminant concentrations and pathways of exposure that are relevant to the Trail exposure setting.

Noncancer risk estimates for different Phase 4 PCOCs are not summed because toxicity values for these PCOCs are based on effects on different organs or systems within the body and are unlikely to be additive.

Toxicity values for carcinogenic and noncarcinogenic health effects are developed for many chemicals by government agencies, including Health Canada, EPA, Agency for Toxic Substances and Disease Registry, and World Health Organization (WHO). These toxicity values are numerical expressions of chemical dose and response, and vary based on factors such as the route of exposure (e.g., oral or inhalation) and duration of exposure.

Duration of exposure is an important factor to consider when selecting appropriate toxicity values for the HHRA. This is because the exposure levels that cause toxic effects vary depending on how long the exposure

occurs. For example, with continuous exposure to a chemical for many years (typically referred to as chronic exposure), much lower concentrations (and resulting doses) of a chemical could be associated with toxic effects, compared to concentrations that would be identified as causing toxic effects in a person who is exposed to a chemical for only 1 day (referred to as an acute exposure). Intermediate duration exposures (referred to as subchronic exposures) are more likely to lead to toxic effects at intermediate concentrations. The Phase 4 HHRA evaluates risks associated with scenarios involving subchronic and chronic exposures to PCOCs; acute exposures are not considered. This approach is health-protective because the concentrations of PCOCs in the environment that can lead to chronic or subchronic effects are typically much lower than those that result in acute effects.

Risk Characterization: Integrating Exposure and Toxicity

Risk = Exposure x Toxicity

The Risk Characterization component summarizes risk estimates generated from integration of the exposure and toxicity assessments to determine what health risks might be experienced by residents. An analysis of uncertainties associated with the estimates is also provided in the risk characterization.

When a hazard index is less than 1.0, no adverse health effects are expected. If it is greater than 1.0, then further risk evaluation is needed.

Noncancer health risks are characterized by comparing estimated exposures with threshold acceptable levels. If individuals are exposed to levels of PCOCs less than or equal to an acceptable level, such as a tolerable daily intake (TDI) or tolerable concentration, no adverse health effects are expected. Exposures above the acceptable level do not mean that adverse human health effects will occur, but rather that further evaluation is required. The ratio of an individual's average daily intake for a given PCOC to that PCOC's acceptable level is referred to as the "hazard quotient." When exposure to a PCOC occurs by multiple pathways, hazard quotients for each pathway are summed to give the "hazard index" for that PCOC.

Interpretation of risk results should include quantification not only of incremental risks but also of incremental exposures versus background. Because metals are widely distributed in the environment and food supply from many natural and anthropogenic sources, it is useful for the community to understand the magnitude of possible risk reduction from smelter operations versus from other sources of exposure.

The cancer risk estimates presented in the Phase 4 HHRA are intended to represent the incremental probability that an individual will develop cancer during his or her lifetime due to nonoccupational exposure to smelter-related chemicals. The term "incremental" reflects the fact that the calculated risk associated with site-related exposure is in addition to the background risk of cancer experienced by all individuals in the course of daily life.

Phase 4 cancer risk estimates are interpreted in the context of the BCMoE default acceptable risk level of 1 in 100,000 (CSR 2007). Estimates are also compared with a 1 in 10,000 risk level above which EPA generally considers that a response action is warranted (USEPA 1997c). The 1 in 10,000 risk level could be considered as a reasonable alternate acceptable risk level for the Trail site, at least in the shorter term.

Risk estimates and the uncertainty associated with them are interpreted and qualified in the Phase 4 HHRA risk characterization, which focuses on site-wide risks, but also presents neighborhood risks for East Trail, Rivervale, Tadanac, Waneta, and West Trail. Additional conservatism is

introduced to the risk characterization by evaluating risks to people living in these neighborhoods, which are closest to the facility and for which exposures (and thus risks) are expected to be the highest.

For Phase 4 probabilistic risks, typical risks are estimated using the average or median from the risk distribution. Reasonable maximum exposures are estimated using the 90th or 95th percentile of the risk distributions. Non-probabilistic risk estimates in Phase 4 also employ exposure assumptions that result in both typical and reasonable maximum risk estimates.

For all relevant scenarios, risks calculated for ingestion of indoor dust, ingestion of soil, ingestion of outdoor dust, and ingestion of produce are added together to obtain combined risk estimates. Risks via inhalation of ambient air are calculated separately and added only to risks via ingestion for neighborhoods in which an air monitoring station is located. Risks from ingestion of fish and from recreational use of ATVs and dirt bikes are not specific to neighborhoods and were calculated separately from all other pathways.

For probabilistic assessments, measures of central tendency risks (e.g., average and median of the distribution) and reasonable maximum risks (e.g., 90th and 95th percentile of the distribution) are presented. Health Canada (2007) considers the 95th percentile to be sufficiently protective; the guidance states: “It is believed that day-to-day and year-to-year variations in individuals’ exposures over a life stage or over a life time will result in the vast majority of individual risks being essentially negligible if the 95th percentile risk estimate is essentially negligible.”

For Phase 4 probabilistic assessments, the impact of certain input parameter distributions on risk outcomes is tested using a quantitative sensitivity analysis.

West end view of the Trail smelter

PHASE 4 ASSESSMENT RESULTS

A summary of Phase 4 HHRA results for each scenario is presented below.

Residential Scenario

Phase 4 noncancer risks are below levels of concern for residential receptors assessed on a site-wide basis.

Site-wide, noncancer risks are below levels of concern for residential receptors as shown in Table S-1. Noncancer hazard indices based on combined exposures to thallium in soil, dust, and homegrown produce slightly exceed 1.0 for the child scenario evaluated for the East Trail, Rivervale, Tadanac, and West Trail neighborhoods. For Tadanac, combined exposures to arsenic (adult plus child) also slightly exceed 1.0. The slight exceedances of a hazard index of 1.0 in these neighborhoods do not approach levels of exposure known to increase health risks. All other neighborhood-specific noncancer risks are below levels of concern. Consequently, it is judged to be highly unlikely that noncancer health effects would occur in Trail residents due to community exposure to smelter-related chemicals.

Site-wide 95th percentile incremental risk estimates for all pathways are greater than 1 in 100,000 but do not exceed 1 in 10,000.

The highest predicted residential cancer risks (1 in 10,000) are expected to occur in East Trail and Tadanac based on combined exposures to soil, dust, air, and homegrown produce.

Site-wide and neighborhood 95th percentile risks exceed the BCMoE default acceptable cancer risk of 1 in 100,000 for all pathways. However, none of the 95th percentile site-wide cancer risks exceeded a 1 in 10,000 level, above which EPA generally considers that a response action is warranted (USEPA 1997b). For Phase 4 neighborhoods, total residential cancer risk for all pathways summed is predicted to be highest in East Trail and Tadanac (both at approximately 1 in 10,000) as shown in Figure S-5.

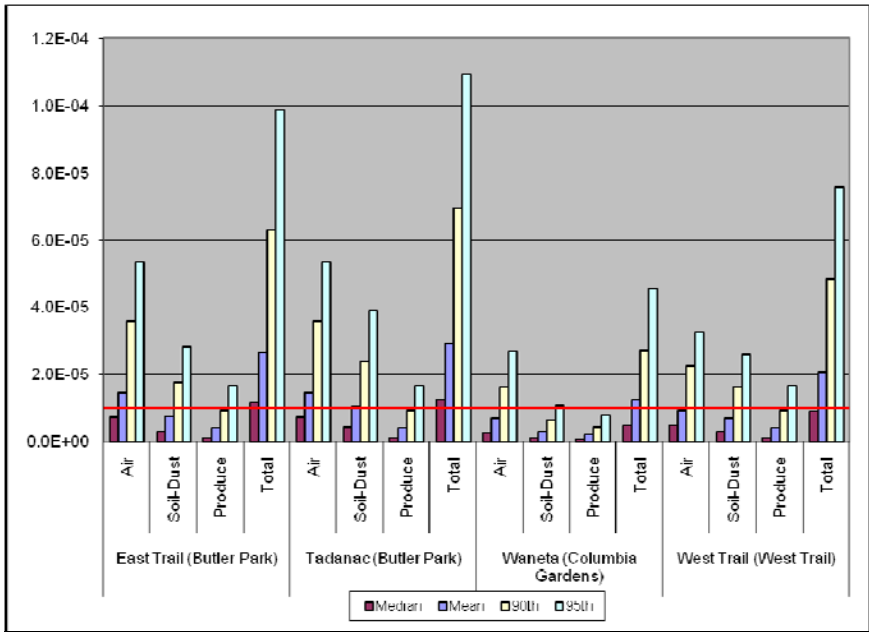


Figure S-5. Total Cancer Risk Estimates: Residential Scenario

Table S-1. Summary of Site-Wide Noncancer Risks

			Median	Mean	90th	95th
Soil/ Dust	Adult + Child	antimony	0.006	0.020	0.045	0.082
		arsenic	0.034	0.108	0.249	0.434
		cadmium	0.001	0.001	0.003	0.005
		selenium	0.000	0.000	0.000	0.000
		silver	0.000	0.001	0.003	0.005
		thallium	0.006	0.021	0.045	0.081
		tin	0.012	0.045	0.101	0.183
		zinc	0.002	0.007	0.016	0.029
	Child	antimony	0.011	0.032	0.076	0.124
		arsenic	0.003	0.010	0.024	0.042
		selenium	0.000	0.000	0.000	0.001
		silver	0.001	0.002	0.004	0.008
		thallium	0.010	0.034	0.074	0.128
		tin	0.019	0.072	0.164	0.287
		zinc	0.003	0.012	0.026	0.045
Produce	Adult + Child	antimony	0.017	0.029	0.056	0.085
		arsenic	0.025	0.063	0.144	0.237
		cadmium	0.017	0.051	0.091	0.163
		thallium	0.114	0.200	0.413	0.622
	Child	antimony	0.020	0.036	0.073	0.113
		arsenic	0.002	0.005	0.011	0.019
		thallium	0.143	0.257	0.552	0.831
Soil/Dust + Produce	Adult + Child	antimony	0.023	0.049	0.102	0.167
		arsenic	0.059	0.171	0.394	0.671
		cadmium	0.017	0.052	0.094	0.168
		thallium	0.120	0.221	0.458	0.703
	Child	antimony	0.031	0.068	0.148	0.236
		arsenic	0.005	0.015	0.035	0.060
		thallium	0.152	0.290	0.625	0.959

Note:
Cadmium risks calculated for Adult + Child scenario only

Broken down by exposure routes, the total estimated 95th percentile site-wide cancer risk from ingestion is 3 in 100,000. Two-thirds of this estimated risk is due to ingestion of arsenic in soil, indoor dust, and outdoor dust and the other third is due to ingestion of homegrown produce.

Air exposures are predicted to contribute more than half of the total site wide risks, based on the Birchbank air monitoring station data.

Estimates of 95th percentile lifetime cancer risks via inhalation of air on a neighborhood basis range from 2 in 100,000 to 7 in 100,000 and are primarily attributable to arsenic with a much smaller contribution from cadmium. If the maximum air monitoring station risk (Birchbank at 7 in 100,000) is added to the site wide risks for ingestion of soil, indoor dust, and outdoor dust and ingestion of produce, total risks equal 1 in 10,000.

A probabilistic assessment of background cancer risk for arsenic and cadmium, two of the main risk drivers for the site, is included in Phase 4. Background risk estimates for arsenic included exposure from air, food, drinking water, soil, and cigarette smoke. For cadmium, only air background risk estimates were included for comparison to site-related cancer risks. Based on this evaluation, estimated 95th percentile background risk from arsenic exposure is 8 in 100,000, with the majority of risk coming from exposure to arsenic in food. The estimated 95th percentile background risk from exposure to cadmium in air is 1 in 1,000,000. Figure S-6 shows the worst-case incremental risk above background estimated for Trail residents (East Trail) due to site-related exposures to arsenic in air, soil/dust, and homegrown produce.

Commercial and Agricultural Scenarios

The highest commercial cancer risk came from the Butler Park station, where the risk due to inhalation of arsenic and cadmium in air was 2 in 100,000.

The highest cancer risk for the agricultural scenario for Waneta was very low at 0.004 in 100,000.

Estimated site-wide noncancer risks are also below target risk levels for the commercial and agricultural exposure scenarios. For both scenarios, noncancer risk estimates were based on ingestion of cadmium and antimony in soil, indoor dust, and outdoor dust; for the agricultural scenario, the total noncancer risk estimates also included exposure to antimony via inhaled particulates. Consequently, there is no elevated risk of noncancer health effects for commercial or agricultural workers.

Air monitoring station at Butler Park

Cancer risk estimates for the commercial and agricultural scenarios were restricted to the inhalation route because the PCOCs for soil (antimony and cadmium) are not carcinogens via the oral exposure route. Commercial risks were assessed using ambient air data measured at the Butler Park, Columbia Gardens, and West Trail monitoring stations and agricultural risks were assessed using particulate concentration in air estimated from soil concentrations. Estimated 95th percentile incremental lifetime cancer risks for the commercial scenario were at or above the 1 in 100,000 risk level for all three air monitoring stations, but below the 1 in 10,000 level.

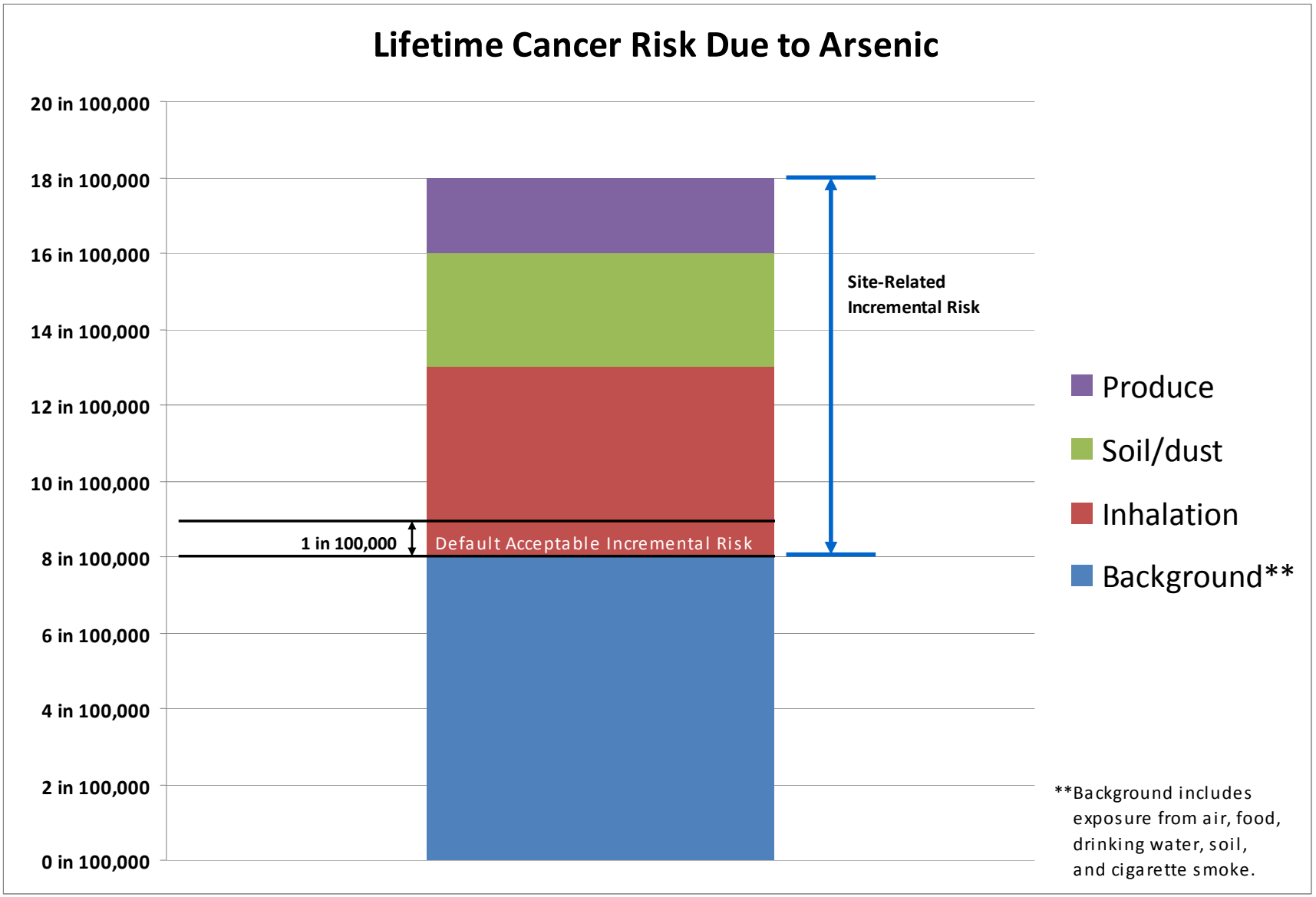


Figure S-6. Lifetime Cancer Risk due to Arsenic

Fish Consumption

The fish consumption risks estimated in this assessment are conservatively derived by applying the full consumption rate to each species of local, freshwater fish evaluated. An alternative approach would have been to assume each species of local, freshwater fish represents only a portion of an individual's total fish consumption and to apportion the consumption rate accordingly.

For fish consumers, estimated 95th percentile hazard quotients for mercury exceed 1.0 for walleye and rainbow trout. Chromium risks only exceed 1.0 when a suspect high concentration value from one sample is included. For arsenic, selenium, thallium, and vanadium, all hazard quotients are less than 1.0. Based on these results, exclusive consumption of walleye or rainbow trout from the Columbia River in the vicinity of Trail may pose a noncancer health risk for exposure to mercury, particularly for children consuming these fish.

Estimated lifetime incremental cancer risks (for arsenic) for typical (average) ingestion of locally caught fish are all below the 1 in 100,000 level. Estimated 95th percentile risks range from 2 in 100,000 for mountain whitefish to 7 in 100,000 for rainbow trout.

A local fishing pier

Off-Road Vehicle Use

Exposures to soil and dust from off-road vehicle recreation are not expected to pose an unacceptable health risk

Hazard indices for the total pathway exposures by ATV/dirt bike user are well below 1.0, and the screening of soil data resulted in no carcinogens being included in the PCOC list for the ATV/dirt bike use area. Consequently, this recreational activity is not associated with any adverse health risks due to smelter operations.

SENSITIVITY OF RISK RESULTS TO SELECTED INPUTS AND ASSUMPTIONS

Gyro Park in spring

Risk assessments inherently include uncertainty from a variety of sources. One major source of uncertainty is the toxicity dose-response. Typically adverse health effects have only been observed at very high exposures. In risk assessments, predictions of adverse effects at much lower doses are typically designed to overestimate risk in order to be health protective. The magnitude of this uncertainty can be large, especially for carcinogenic effects. For arsenic, for example, low dose risks could be negligible.

Uncertainties in calculating potential exposures may arise from many of the assumptions. For many parameters, we have a good idea of the typical or average values, but less reliable estimates of the full range of values that may apply to a particular population. In Trail, we have a strong dataset measuring the concentrations of PCOCs in air, soil and dust. In contrast, for homegrown produce there is greater uncertainty in how representative the measured PCOC concentrations are of the produce around the community and also in how the measured concentrations relate to the PCOC concentrations in garden soil. Uncertainty in contact rates is also variable. We have a good understanding of how much air people breathe each day, but a much more limited database telling us how much soil or dust people might ingest.

In general, a conservative approach was used in selecting parameters, assumptions, and methodologies in this risk assessment, thus tending to overestimate exposures and risks.

The uncertainty evaluation specifically addresses the uncertainty in the exposures assessment and takes all of these factors into account to put the risk estimates into context. Factors that may tend to over- or underestimate risks can be identified and the relative magnitude of the uncertainty for each factor evaluated. The probabilistic outputs for this HHRA include a ranking of the input distributions that contribute most to the variability in output distributions. Table S-2 provides detail on specific sources of uncertainty and variability for selected input parameters to the probabilistic exposure model.

For the residential and commercial inhalation pathways (adult plus child cancer risk), the input distributions with the greatest impact on results are the metal concentrations in air.

The uncertainty associated with the soil ingestion rates, and the fact that the impact on variability is large, suggest the possible need for refinement of this parameter.

The spread of the cancer risk output distributions for consumption of homegrown produce by Trail residents is affected by all parameter distribution inputs. The factors with the largest impact on cancer risk outputs are (in general order of decreasing importance) exposure duration, produce concentration, and child produce consumption rate. The hazard quotient outputs are most affected by produce concentrations but also by child produce consumption rates.

Table S-2. Sources of Uncertainty and Variability in Probabilistic Exposure Parameters

Input	Source(s) of Variability	Source(s) of Uncertainty
All Pathways		
Exposure Duration	differences in residence time	no site specific data; using U.S. data - residence time may be longer in Trail
Body Weight	differences among individuals	
Exposure Frequency	differences in individuals activity patterns	no site specific data
Ingestion of Soil, Indoor Dust, and Outdoor Dust		
Soil Concentrations	range throughout Trail; distance from smelter may play a role for some metals	analytical methodology limitations for some data (SALM vs. TLP)[a]; smaller datasets for some metals in some areas of Trail; distribution fitting
Indoor Dust Data	range throughout Trail; distance from smelter may play a role for some metals	data lacking for several metals; data 10 years old; distribution fitting
Outdoor Dust Data	range throughout Trail; distance from smelter plays a role for some metals	data missing for some neighborhoods; distribution fitting
Soil Ingestion Rates	differences in individuals' activity patterns	limited studies; no site specific data; short term study design used to derive rates
Fractional Intake: Soil, Indoor Dust, and Outdoor Dust	differences in individuals' activity patterns	no site specific data
Ingestion of Produce		
Produce Concentrations	range throughout Trail; distance from smelter plays a role for some metals; differences in garden soil concentrations	smaller datasets for some metals in some areas in Trail; distribution fitting
Produce Ingestion Rates	differences among individuals	no site specific data; older data; short term study design used to derive rates
Inhalation		
Air Data	range throughout Trail; distance from smelter plays a role for some metals	limited to air monitoring stations
Inhalation Rates	differences in individuals' activity patterns	differences in Canadian and U.S. rates
Particulate Concentration in Air	differences in individuals' activity patterns	no site specific data; does not include estimate for rangeland

Note:
[a] SALM = Strong Acid Leachable Metals (method); TLP = Trail Lead Program

For ingestion of soil, indoor dust, and outdoor dust (residential and commercial), the parameter distribution with the greatest impact on the risk estimates is the child soil ingestion rate. For the agricultural scenario, inhalation risk estimates are most sensitive to exposure duration for cancer risks and particulate concentration in air for noncancer risks.

A sensitivity analysis evaluates the relative impact of individual parameters on the risk outcome and can help identify the key contributors to uncertainty in risk estimates.

For selected exposure pathways, the HHRA includes a quantitative sensitivity analysis in which risks are calculated using alternate assumptions for some exposure parameters. The following inputs were altered: arsenic concentration in air, adult plus child exposure duration, child soil ingestion rate, and antimony concentration in soil. Testing of most probable alternate inputs for these parameters produced slightly different risk results; for some parameters, use of the alternate input distribution increased risk estimates, while for others it resulted in decreased risks.

USE OF BIOMONITORING TO ASSESS EXPOSURES

Biomonitoring studies can be particularly valuable in providing an integrated picture of exposures when residents may be exposed by multiple pathways and locations.

According to the BC CSR, acceptable risk levels other than the specified default values may be considered if recommended by the Medical Health Officer after public consultation. Recommended alternate levels may be based on "biometrics" (e.g., blood lead levels) but must be specific numerical risk levels. This approach is widely accepted as a means of tracking exposures to lead and is being used in Trail to monitor ongoing efforts to manage and reduce lead exposures. Biomonitoring studies can also be effective methods of assessing exposures to arsenic, cadmium and thallium, other elements of potential concern in Trail.

Evidence from a biomonitoring study conducted in Trail suggests that exposures to thallium among Trail residents are only slightly higher than background. Based on that study, Phase 4 risk results for thallium may be overestimates.

After a preliminary 2001 study by Teck Cominco, the Interior Health Authority conducted a thallium biomonitoring study of 50 adult Trail residents in 2002. Geometric mean urinary thallium results for Trail were 0.25 µg/L, whereas for a study of the U.S. population, the geometric mean values were 0.17 µg/L from 1999 to 2000 and 0.16 µg/L from 2001 to 2002. This comparison suggests that residents in Trail may be experiencing slightly higher exposures than those received by the general U.S. population, but overall, exposures are well below those of concern. All results were below 2 µg/L, well below the WHO guideline value of 5 µg/L. In the Phase 4 risk assessment, upper end thallium exposures were estimated to be slightly above the acceptable risk level for noncancer health effects. The biomonitoring data provide biometric evidence that acceptable exposure levels are not, in fact, likely to be exceeded.

Biomonitoring studies may provide greater insights into the relative importance of different exposure media at Trail, as well as the effectiveness of remediation and intervention processes.

A similar biomonitoring study for arsenic could illustrate whether the risk assessment overestimates risks for arsenic as well. Cadmium biomonitoring is not recommended at this time due to the low predicted risk relative to arsenic. Studies focusing on environmental exposures have relied upon measurement of "speciated arsenic" in the urine, which includes inorganic arsenic, monomethyl arsenic and dimethyl arsenic, but excludes the more complex organic arsenicals from seafood. Typical levels of speciated arsenic (i.e., inorganic arsenic, monomethyl arsenic and dimethyl arsenic) range from 5 to 20 µg/L. A recent study in Middleport, New York (Exponent 2004) used reference levels for speciated and inorganic arsenic in urine of 40 and 20 µg/L, respectively. An arsenic biomonitoring study in Trail could allow a general determination of whether exposures are sufficient to be detected, and if they are elevated could provide insight into the relative importance of different exposure media. Furthermore, if biomonitoring studies in Trail found that exposures to lead and other site metals were correlated, that could suggest that some of the same factors driving lead exposures are driving exposures to other metals. This analysis could provide insight into the effectiveness of remediation and intervention processes.

SETTING REMEDIATION GOALS

View of gulch with Trail smelter

Another issue that has been raised in Trail is how to identify higher priority areas, "hot spots," where metals might be present at sufficiently elevated concentrations to warrant remediation or other actions to reduce the potential for human contact. Hilts (2007) describes one method for identifying hot spots for metals in Trail soil. Specifically, this paper proposes a cleanup level for lead concentrations in soil that is based on the draft protocol for classifying site risk levels (BCMoE 2007).

For instance, BCMoE proposes an "Upper Cap" concentration for lead (5,000 mg/kg) for classifying "high risk sites" for direct BCMoE oversight and review. Areas where soil lead exceeds this upper cap would likely require some type of "immediate response." Due to strong correlations between lead and other site-related metals, the ability of this cleanup level for lead to address other metals in soil can also be assessed. For example, based on statistical analysis of Trail soil data, the 5,000 mg/kg soil lead upper cap correlates roughly to a soil arsenic concentration of 215 mg/kg. This soil arsenic concentration is well below the draft protocol upper cap soil arsenic concentration of 1,000 mg/kg indicating that soil response actions taken based on lead would also be sufficient to address BCMoE-defined high risk sites for arsenic in soil.

It is also possible to use the Phase 4 HHRA to estimate the "risk reduction benefit" of addressing properties that exceed the proposed upper cap standard. For instance, risk-based soil concentrations of nonlead metals of interest at Trail could be back-calculated using reasonable maximum exposure inputs from the Phase 4 HHRA and specific noncancer and cancer target risk levels (e.g., a hazard quotient of 1 or cancer risk level of 1 in 10,000). As shown in Table S-3, when used in conjunction with upper cap soil lead concentrations, these risk-based concentrations may help quantify the additional risk reduction benefit for other metals at different risk levels that would be achieved by immediate response actions at high risk lead sites.

Table S-3. Comparison of Risk Reduction Benefits Estimated for Different Soil Lead Response Scenarios

			Percent of all residential soil samples exceeding risk-based concentration[a]	
Nonlead Metal	Target Risk Level	Risk-based soil concentration	Without soil lead response actions	If high risk yards are addressed for soil lead concentrations exceeding 5,000 mg/kg
Arsenic	Noncancer, 1	76	12.4%	10.9%
Thallium	Noncancer, 1	8.3	0.7%	0.7%
Arsenic	Cancer, 1 in 10,000	185.7	1.6%	0.5%
Arsenic	Cancer, 1 in 100,000	19.5	59.8%	59.0%

[a] Risk-based concentrations are calculated based on reasonable maximum exposure assumptions for soil and dust as described in the Phase 4 HHRA and correspond to an upper end value (i.e., 95th percentile) of the predicted risk distribution for a given risk target level.

Example of a residential produce garden sampled during Phase 4

As shown in Table S-3, addressing high risk residential yards for lead via BCMoE's draft protocol would result in a slight risk reduction for exposure to arsenic in soil (12.4 to 10.9 percent) and no reduction in risk for exposure to thallium in soil based on a noncancer target risk level of 1. Minimal differences are also noted for arsenic at the 1 in 100,000 risk target. However, for the cancer-based soil concentration derived at the 1 in 10,000 target risk level, a greater risk reduction for arsenic is expected (from 1.6 to 0.5 percent). The increased risk reduction at this target risk level corresponds to the higher soil concentration at this risk level (185.7 mg/kg) versus those calculated for the other cancer and noncancer risk targets (19.5 and 76 mg/kg, respectively). The very small percentage of soil samples with arsenic concentrations exceeding the 1 in 10,000 risk-based concentration supports the relationship between soil lead and soil arsenic noted previously (i.e., the 5,000 mg/kg soil lead upper cap correlates roughly to a soil arsenic concentration of 215 mg/kg).

These risk-based concentrations may also be used to assess the need for secondary responses regarding garden soil at Trail residences. Currently, a residential garden soil replacement program is in place at Trail, which allows Trail families of children with elevated blood lead levels the option of soil replacement in their vegetable garden plots if soil lead concentrations exceed 1,000 mg/kg. Based on evaluation of garden soil samples in Phase 4, none of the gardens with soil lead concentrations at or below the 1,000 mg/kg soil replacement level would exceed risk-based soil concentrations for other metals corresponding to a noncancer target risk level of 1 or a cancer target risk level of 1 in 10,000. However, 29 percent of the gardens with less than 1,000 mg/kg lead would be expected to exceed the risk-based soil concentration at the 1 in 100,000 cancer risk target level.

CONCLUSIONS

Recreation along the river near Trail

Site-wide, noncancer risks are below levels of concern for residents. For neighborhoods closest to the site, noncancer hazard indices slightly exceed 1.0 for thallium and arsenic. The slight exceedances of a hazard index of 1.0 in these neighborhoods do not approach levels of exposure known to increase health risks. All other neighborhood-specific noncancer risks are below levels of concern. Consequently, it is judged to be highly unlikely that Trail residents are at risk for noncancer health effects. Furthermore, the urinary thallium biomonitoring study conducted at Trail suggests that thallium risks may be overestimated. Noncancer and cancer risks to agricultural workers are well below levels of concern. For commercial scenarios, noncancer risks are also below target risk levels.

Site-wide and neighborhood 95th percentile risks exceed the BCMoE target cancer risk for all pathways. However, all 95th percentile site-wide cancer risks are below 1 in 10,000. For one neighborhood assessed in Phase 3 (East Trail), total residential cancer risks for all pathways summed is equal to 1 in 10,000. For ingestion of soil, indoor dust, and outdoor dust and ingestion of produce, 95th percentile cancer risks both equal 2 in 100,000. Risks via inhalation of air range from 2 in 100,000 to 7 in 100,000 at the 95th percentile. If risks at the air monitoring station with maximum risks (Birchbank at 7 in 100,000) are added to the site-wide risks for ingestion of soil, indoor dust, and outdoor dust and ingestion of produce, total risks slightly exceed 10 in 100,000.

REFERENCES

Ames, N. 2001. Acceptable level of human health risks resulting from smelter contaminants in the Trail area. Prepared by Nelson Ames, MD, MHSc, Medical Health Officer, Kootenay Boundary Community Health Services Society, Castlegar, B.C.

BCMoE. 1996. Overview of CSST procedures for derivation of soil quality matrix standards. Risk Assessment Unit, Environmental Protection Unit, British Columbia Ministry of the Environment, Victoria, B.C.

BCMoE. 2006. Supplemental guidance for risk assessments. British Columbia Ministry of the Environment. Victoria, B.C. December.

BCMoE. 2007. Draft Protocol 12: Classifying Site Risk Levels. http://www.env.gov.bc.ca/epd/remediation/requests_for_comments/archives/feb07/protocol12.htm. British Columbia Ministry of the Environment, Victoria, B.C.

CSR. 2007. Contaminated Sites Regulation. B.C. Reg. 375/1996. Deposited December 16, 1996, with amendments up to July 1, 2007.

Exponent. 1997. Human health risk assessment for Trail, British Columbia. Phase 1: Problem formulation. Exponent Environmental Group, Boulder, CO.

Exponent. 1998a. Human health risk assessment for Trail, British Columbia. Phase 2: Screening-level deterministic risk calculation. Exponent Environmental Group, Boulder, CO.

Exponent. 1998b. Technical memorandum 2.1. Prepared for the Trail Lead Program, Trail, British Columbia, by Exponent Environmental Group, Boulder, CO. July.

Exponent. 1998c. Technical memorandum 2.2. Prepared for the Trail Lead Program, Trail B.C. Exponent Environmental Group, Boulder, CO. July.

Exponent. 2000a. Human health risk assessment for Trail, British Columbia. Phase 3: Revised Screening-Level Deterministic Risk Assessment. Exponent Environmental Group, Boulder, CO.

Exponent. 2000b. Revised Table 7. Summary of residential/homegrown produce data, 1998–1999. Addendum to: Exponent. 2000. Human Health Risk Assessment for Trail, British Columbia. Phase 3: Revised Screening-Level Deterministic Risk Assessment. Exponent Environmental Group, Boulder, CO. April 13.

Exponent. 2004. Middleport environmental exposure investigation. Prepared for FMC Corporation, Philadelphia, PA. Exponent, Bellevue, WA. July.

Fox, G. 2004. Trail human health risk assessment. Memorandum of review comments, dated July 19, 2004. B.C. Ministry of Water, Land, and Air Protection, Victoria, B.C.

Fox, G. 2007. Personal communication (email with Glenn Harris, June 18, 2007, regarding Work Plan Human Health Risk Assessment (HHRA) for Offsite Impacts from Trail,

B.C. Smelter: Phase 4 - Additional Data Collection and Probabilistic Risk Calculations. Integral Consulting Inc. June.

Golder Associates. 1993. Quantitative human health risk assessment—Phase 1 review of methods and framework recommendation. Prepared for the Ministry of Environment, Land, and Parks, Environmental Protection Division. Golder Associates Ltd., Burnaby, B.C.

Health Canada. 2004. Federal contaminated site risk assessment in Canada. Part I: Guidance of human health preliminary quantitative risk assessment (PQRA). Health Canada, Environmental Health Assessment Services, Safe Environments Programme, ON, Canada.

Health Canada. 2007. Guidance on complex site specific human health risk assessment of chemicals (SSRACHEM). Draft Final. Contaminated Sites Division, Health Canada. Health Canada, Ottawa, ON.

Hilts, S. 2007. Defining “acceptable risk levels” and how to reach them: A discussion paper for the Trail Wide Area Site. Prepared by Steve Hilts, Superintendent, Environmental Remediation, Teck Cominco Metals Ltd. September 2007. Teck Cominco, Trail, B.C.

Integral. 2008. Human health risk assessment (HHRA) for offsite impacts from Trail, B.C. smelter. Phase 4—additional data collection and probabilistic risk calculations. Prepared for Teck Cominco Metals Ltd., Trail, B.C. Integral Consulting Inc., Mercer Island, WA. August 12.

Richardson, G.M. 1997. Compendium of Canadian human exposure factors for risk assessment. O’Connor Associates Environmental Inc., Ottawa, ON.

Trail Lead Program. 2001. Identification, evaluation, and selection of remedial options. Trail Community Lead Task Force, Trail, B.C.

USEPA. 1989. Risk assessment guidance for superfund (RAGS), Volume I, Human Health Evaluation Manual (part A). EPA-540/1-89-002. OSWER Directive 9285.7-01A. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

USEPA. 1991. Risk assessment guidance for Superfund (RAGS): Volume I. Human Health Evaluation Manual Supplemental Guidance—Standard Default Exposure Factors [interim final]. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Toxics Integration Branch, Washington, D.C. Cited in Richardson 1997.

USEPA. 1997a. Exposure factors handbook—Volume 1. General factors. EPA/600/P-95/002Fa. U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Washington, DC, and Versar Inc., Exposure Assessment Division, Springfield, VA.

USEPA. 1997b. Rules of thumb for Superfund remedy selection. EPA/540/R-97/013. August. Office of Solid Waste and Emergency Response, Washington DC.

USEPA. 2001. Appendix A. Justification and supporting documentation for the input parameters. Rocky Flats human health risk assessment. U.S. Environmental Protection Agency. Appendix to Task 3 Report: Calculation of surface radionuclide soil action levels for plutonium, americium, and uranium. Appendices. Prepared by: EPA, Colorado Department of Public Health & Environment, U.S. Department of Energy. July 23, 2002.

USEPA. 2004. Risk assessment guidance for Superfund (RAGS): Volume 1—Human health evaluation manual (Part E, Supplemental guidance for dermal risk assessment), Final. EPA/540/R/99/005. OSWER 9285.7-02EP. PB99-963312. U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation, Washington, DC.