USE OF ECOLOGICAL RISK ASSESSMENT TO GUIDE REMEDIATION AT THE TECK PINCHI LAKE MERCURY MINE

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ABSTRACT

The Pinchi Mine roasted cinnabar ore to recover metallic mercury, operating from 1940 to 1944 (historic) and from 1968 to 1975 (modern). After 1975, it was placed under long-term care and maintenance until remediation began in 2002. Waste materials from both operations remain on site, within the lake (historic operation), a Tailings Facility (modern) and other discrete locations. From 2004 – 2009 a terrestrial ecological risk assessment (ERA) was undertaken relying on literature, field investigations, habitat surveys, spatially explicit food chain modeling, and development of toxicity reference values for methylmercury and other metals. Ecological risks were evaluated for 40 wildlife species. Only those species feeding primarily on insects or on small mammals indicated potential risks, mainly from arsenic, inorganic mercury, and methyl mercury from the Mill Site and Tailings Facility. A post-closure risk reduction analysis indicated that remediation of these areas would reduce risks to wildlife to levels acceptable by risk managers. Other areas, with elevated inorganic mercury in soils were deemed to pose negligible to moderate risk and were not targeted for remediation, based on a weighed evaluation of potential risks to wildlife from contamination versus disturbance to naturally recovering habitat.

Key Words: Pinchi Mine, Ecological Risk Assessment, Wildlife, Mercury, Methyl mercury, Remediation

INTRODUCTION AND BACKGROUND

This paper is one of four papers prepared on the studies associated with closure activities at the Pinchi Lake Mine. The other papers include “Decommissioning and Remediation of the Pinchi Lake Mine (Donald, et al., 2013), “Pinchi Mine Closure – Demolition Debris Disposal” (Marsland, et al., 2013), and “Long Term Post Reclamation Management of the Pinchi Lake Mine” (Unger, et. al., 2013).

The Pinchi Mine is located in a heavily wooded wildland setting in central British Columbia (BC) on the north shore of Pinchi Lake, northwest of Fort St. James in the headwaters of the Fraser River system (**Figure 1**). Pinchi Lake is 25 km long and relatively narrow (1.2 km to 3.7 km) with a surface area of 55 km^2. The lake is oriented in an east-southeast to west-northwest direction, parallel with the geologically-controlled trend of other lakes in the region, including Stuart Lake, south of Pinchi Lake. The Ocock and Tsilcoh Rivers are the only named tributary streams entering Pinchi Lake. Pinchi Creek, situated at the southwest end of the lake is the only outflow from Pinchi Lake, discharging to Stuart Lake, and ultimately, the Fraser River.

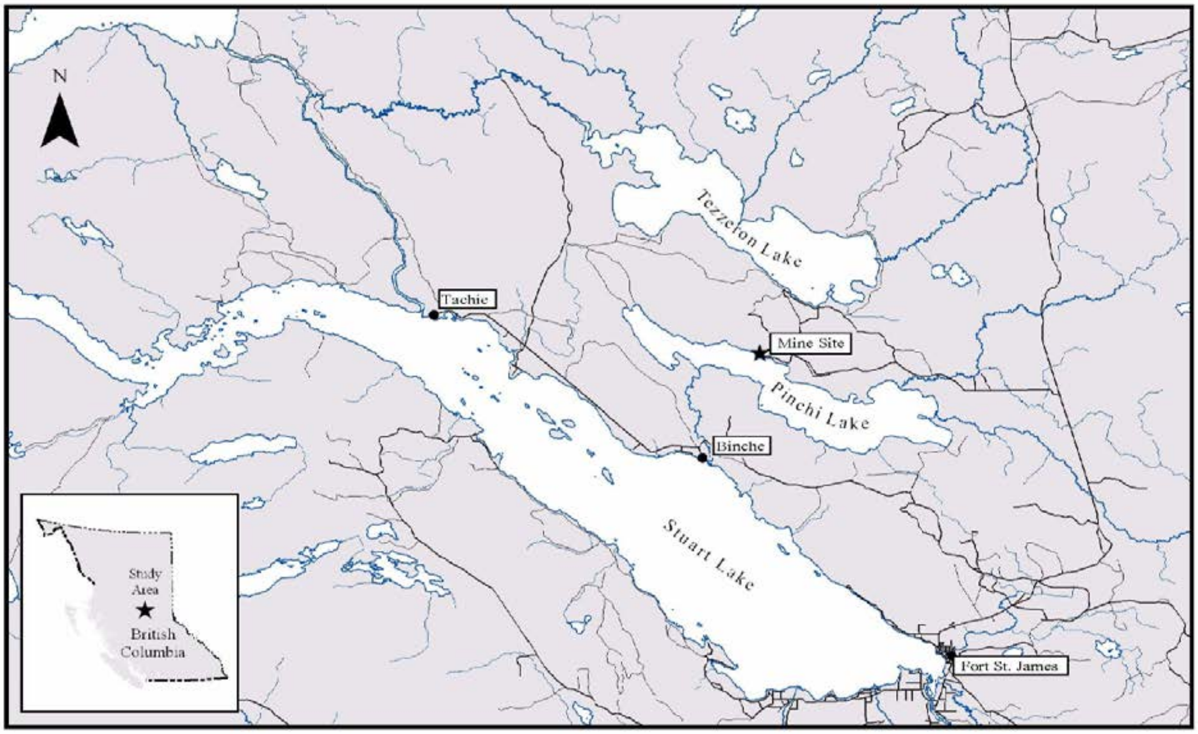

Figure 1 Map of Pinchi Lake region.

The Pinchi fault region, located in central BC, is naturally enriched in mercury because of the abundance of cinnabar mineralization in bedrock along several portions of the fault (Plouffe, 1995). Predecessor companies (now Teck Metals Ltd.) produced metallic mercury from the Pinchi Mercury Mine from 1940 to 1944 (historic operation) and from 1968 to 1975 (modern operation). Cinnabar ore was roasted without concentration during the historic operation and both the waste rock and the residue from roasting (calcine) was stockpiled or pushed into the lake. During the modern operation, ore was concentrated and then processed to recover metallic mercury. Residues from this operation were slurried to a large on-site Tailings Impoundment Area. Prior to full remediation, some wastes from both operations could be found in unmanaged, discrete areas. Prior to remediation the lake foreshore and small on-site ponds that gathered waste products from the mill had already been capped with clean fill and vegetated. Further details on mine operations can be found in Donald and Unger (2013) and in the Mine Closure Plan (Marsland Environmental Associates, 2009).

After mining ceased in 1975, the Pinchi Mine was under long-term care and maintenance and has been the subject of numerous aquatic and terrestrial investigations. Aquatic studies focused on mercury and methyl mercury in surface waters, plankton, and sediment (EVS et al., 1999), sediment toxicity and benthic community health (Baker and Mann, 2002) and fish (Baker, 2001; Mann et al., 2006; Baker et al., 2013). The terrestrial investigation is summarized here based on the Azimuth (2009) Ecological Risk

Assessment (ERA). It is important to note that this ERA greatly benefited from input by members of the Pinchi Mine Technical Working Group, which is composed of members/advisors of the Tl'azt'en Nation and the Nak'azdli Band (hereafter referred to as the First Nations) and Teck Metals.

Mercury is unique in that it can exist in both liquid and gaseous forms at ambient temperatures. During the roasting process there is unavoidable loss of elemental mercury that is dispersed to the atmosphere and carried along the prevailing wind direction. Thus, in addition to point-sources of mercury associated with discrete areas on-site, there may be non-point source accumulations in soil and terrestrial biota (e.g., soil invertebrates, small mammals) from aerial deposition away from the mine site. Atmospheric mercury is sequestered by vegetation, especially trees, and eventually accumulates in soil, almost exclusively within the humic layer where a small, available portion is taken up by invertebrates and other higher trophic organisms in the food web.

Although most mercury compounds are not highly soluble and thus not very bioavailable, mercury can be converted to the much more harmful methyl mercury form under certain conditions, a form that is easily bioaccumulated by biota. The process of methylation is highest in aquatic environments, particularly sediments of wetlands, marshes, lakes and streams, although some methylation can occur in soils. Methyl mercury concentrations increase through the food chain with highest concentrations in piscivorous fish and wildlife that feed on these fish. Understanding source, pathway and fate dynamics tends to drive most environmental studies, and ultimately, remediation efforts when unacceptable impacts are identified.

OBJECTIVE

This paper describes how Ecological Risk Assessment (ERA) was used to guide management decisions for closure of the Pinchi mercury mine. We report results of a multi-year study (2004 – 2008) that evaluated potential impacts from contamination related to former operations of the Pinchi Mine on the local terrestrial environment including soil invertebrates, plants and wildlife species. The ERA was conducted to guide a Mine Closure Plan that was developed under a Mines Act permit administered by the Ministry of Energy, Mines, and Petroleum Resources. Results of the ERA were used to guide management decisions to target areas for clean-up or remediation, versus areas that did not pose undue risks and should not be disturbed. Some unique features of this ERA include mercury as the main contaminant of concern, the use of meta-analysis (multiple data sets) for the wildlife ERA and the use of modeling alternate scenarios to determine risk reduction benefits for different management actions.

MINE SITE COMPONENTS

To assist in delineating and describing potential risks associated with different terrestrial habitats and Areas of Potential Concern (APECs) a number of discrete areas were describe and sampled (Figure 2). Some of these were associated with the historic mining operation (e.g., Old Mil, Old Town) while others were associated with current operations (e.g., Tailings Pond, Mill Site, Waste Rock). The main areas considered in this ERA included the following areas:

- The remediated Foreshore Calcine Area covers approximately 24,000 m^2 along the former Pinchi Lake shoreline and extends to the lake from the Old Mill site.
- A Tailings Impoundment Area on the eastern portion of the mine site bordering Ed Creek. Water is present on the pond and provides marshy habitat for aquatic organisms and wildlife species.
- The modern Mill Site included a crusher, fine ore bins, conveyors, and a mill building. This building processed and roasted sulphide ores where elemental mercury was condensed.
- The Old Mill site, north of the modern mill site, was in use during the historic operations and little remains of the surface facilities. It is currently an open hillside with a few shrubs and trees.
- Two open pits; the upper Main Zone pit has a single bench below surrounding terrain and a lower West Zone pit that is side cut into the hillside. Both are underlain by underground workings.
- Three waste rock dumps and one calcine dump, since re-vegetated.
- Four accessible mine adits and portals that provided access into underground workings.
- Several overgrown, forested areas east of the mine and downgradient of the predominant wind direction including Old Town, Gate Area, Mine Near-Field, Old Ed Creek and others (**Figure 2**).

ECOLOGICAL RISK ASSESSMENT FRAMEWORK

ERA is a process that evaluates the probability that adverse effects to ecological resources are occurring as a result of exposure to one or more stressors (e.g., toxic chemicals). The Pinchi Mine site is complex, given its long history of activity and large size. The site contains many contaminants (i.e., primarily mercury but also other metals such as antimony and arsenic), transport pathways, and receiving environments (both water and land). To address these challenges, the ERA was designed and conducted in a step-wise manner that incorporated many stages of refinement, as our knowledge of site conditions improved. For the terrestrial ERA, a formal risk assessment framework was adopted to present the methods and results of comprehensive desktop studies (e.g., literature reviews, modeling) and field studies that evaluated potential risks to wildlife as well as soil invertebrate and plant communities found on the mine site and surrounding lands (off-site). In addition, a wildlife habitat assessment was conducted to determine what wildlife species (including rare and endangered species) are using the site and adjacent lands and how they use the site.

The first step of the ERA was the Problem Formulation. This is a prescriptive process to: understand the nature, spatial extent, and magnitude of contamination, both on-site and off-site; identify contaminants of potential concern (COPCs) and their sources, transport, and fate; determine what wildlife receptors of concern (ROCs; including rare and endangered wildlife species), may be present on the site and surrounding lands; determine what exposure pathways are likely to be operable (i.e., routes from contaminant sources to receptors; for example, consumption of flying insects by bats); describe protection goals to serve as benchmarks of acceptable risks (e.g., no impacts to local wildlife populations) and finally, present conceptual models for the site that summarize exposure routes through which COPCs may affect wildlife ROCs in both terrestrial and aquatic systems.


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ISLE ISLAND
MNF MILL NEAR-FIELD
MMF MILL MID-FIELD
MS MILL SITE
NEC NEW ED CREEK SOIL
OEC OLD ED CREEK
MCR MINE CARETAKER'S RESIDENCE
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Figure 2

Based on the Problem Formulation, detailed analyses and risk characterization were performed to understand key issues likely to pose the greatest risks to terrestrial receptors. Specific objectives were to make risk predictions for each contaminant-pathway-receptor combination, conduct an uncertainty analysis and finally, describe risk conclusions to assist in making management decisions for the site. A key component of the ERA was to conduct field studies and comprehensive food chain modeling to: 1) determine whether contamination levels may be associated with any environmental effects, and 2) evaluate the potential benefits of remediating certain portions of the mine site.

FIELD METHODS

Several summer field campaigns were undertaken to support the Pinchi Mine terrestrial ERA between 2004 and 2008, with an initial focus within the mine site boundaries in the vicinity of principal APECs including the Mill, Concentrator and Roaster buildings and Tailings Pond. A full description of the methods used is provided in Azimuth (2009). Up to 15 sampling areas representative of different terrestrial habitats (e.g., Mill Near-field) and/or APECs (e.g., Tailings Pond, Old Mill) were selected for synoptic sampling of soil, vegetation, invertebrates, and small mammals. In subsequent years, sampling was extended off-site, up to 11 km east of the mine, along the prevailing wind direction, to determine the extent and magnitude of dispersal of metals and mercury in the local/regional context, and to put these data in perspective with on-site data.

Synoptic collections of soil (humic and inorganic), vegetation (tree leaves, needles, shrubs, sedges, grass, berries), ground and flying invertebrates and small mammals (principally dusky shrew *Sorex monticolus* and deer mouse *Peromyscus maniculatus*) were collected throughout each of the sampling areas and analysed for metals (mercury and in some tissues methyl mercury) as well as supporting parameters (i.e., pH, moisture content, and total organic carbon in soils, and moisture content in tissues).

Graphical and statistical comparisons of metals, mercury and methyl mercury concentration in environmental media were made and contrasted within (e.g., Tailings Pond, Mill Site) and across sampling areas, especially in relation to distance away from the concentrator / roaster area. Using these data, combined with results of a detailed habitat assessment to determine habitat quality and suitability by different wildlife species, a spatially explicit food chain model was constructed. This was achieved by combining exposure assessments of the various contaminants in environmental media (water, soil, sediment, dietary items) with wildlife species presence and habitat quality.

RISK ASSESSMENT APPROACH

Five main ERA components were integrated to assess potential risks to wildlife at the Pinchi Mine Site. These were a wildlife habitat assessment, exposure assessment, effects assessment, risk characterization and a post-closure risk reduction analysis. To evaluate potential risks to birds, mammals, and amphibians at site, the wildlife habitat assessment supported the identification of relevant ROCs (including listed species) and quantified ecological characteristics of the site for incorporation into the risk assessment process. That is, the relationship between habitat attributes (e.g., vegetation type, features of the landscape) and the ROCs' life history requirements (e.g., home range, foraging strategy) were described and delineated using GIS to derive a spatially explicit food chain model.

For the exposure assessment, a food chain model was developed that reflected the ecological characteristics of the site, representing a range of taxonomic groups and trophic levels along relevant exposure pathways. The modeling approach integrated many key factors including spatial extent and magnitude of contamination, COPC concentrations in environmental media, ingestion rate and dietary preference, habitat preference and COPC uptake efficiency. Screening of soils identified nine COPCs from the site including arsenic, antimony, cobalt, copper, molybdenum, nickel, selenium, inorganic mercury and methyl mercury. An example of the distribution of inorganic mercury within discrete areas of the site and at far-field locations is indicated in **Figure 3**.

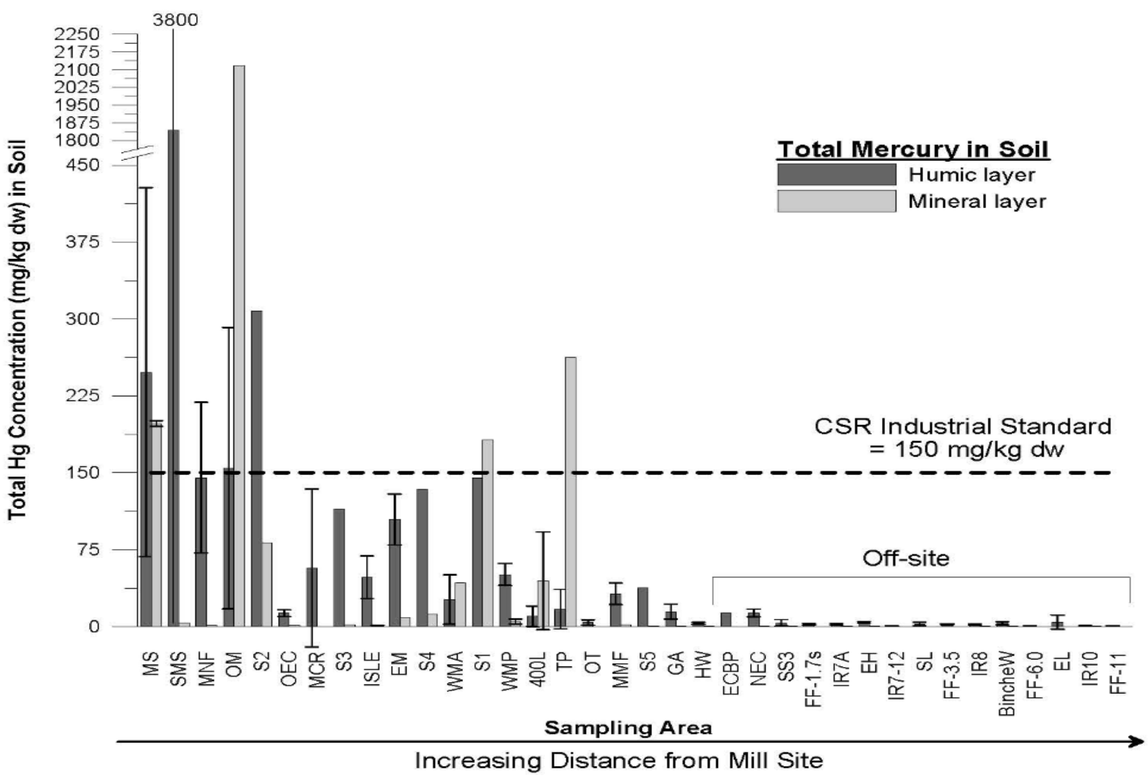


Figure 3. Total mercury concentration (mg/kg dw) in humic and mineral soils from Pinchi Mine on-site and off-site sampling areas, 2004 – 2007.

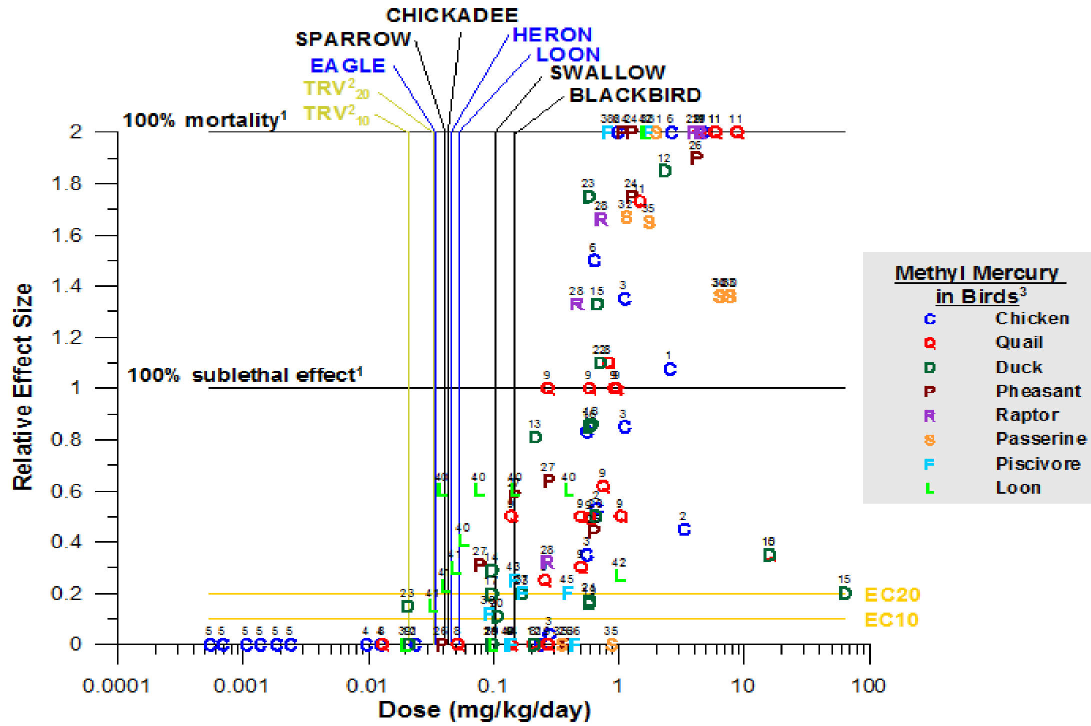
This figure depicts Hg concentrations in humic and inorganic soil layers separately, along a spatial gradient from near the mine to further away. With the exception of a discrete area of an elemental mercury spill at SMS, the only areas where mean mercury concentration in humic soils exceeded the CSR Industrial Standard (IL) of 150 mg/kg for toxicity to soil invertebrates (100 mg/kg for parkland) were the modern Mill Site and 20% of soil samples from the Old Mill sampling area. All other humic soils were well below CSR IL and concentrations diminished exponentially with increasing distance west and east of the mine. The highest mercury concentration in the inorganic mineral soil layer was from the Old Mill area. Soils surrounding the Old Mill area reflect elevated mercury concentrations remaining from the historic operation. In the humic layer, there was a net decrease in mercury concentration away from the mine with "background" concentrations (0.2-0.8 mg/kg) being reached no more than 10 km from the mine. Sequential leach analyses of mercury in the humic soils suggested that the majority of mercury is strongly bound to organic particles and is largely non-labile. However, there was also a clear signature of mercury and antimony enrichment of humic soils due to mining. The majority of this signature in humic soils disappeared between 2 km and 5 km from the mine. This pattern is also consistent with what has been seen at other mercury mines in the world (Gnamus and Horvat, 1999; Gnamus et al., 2000; Suchanek et al., 1995; Suchanek et al., 1998), with a spatially limited 'halo' effect in surface soils surrounding a point source.

The effects assessment evaluated potential toxicity of COPCs to wildlife ROCs by selecting benchmark doses that represented maximum acceptable exposure levels for each COPC and receptor group (i.e., birds, mammals, and amphibians). These benchmarks, or toxicity reference values (TRVs), were tailored to meet the protection goals stated in the problem formulation. More conservative TRVs were used to protect listed wildlife species (i.e., based on a 10% effects threshold), whereas slightly less conservative TRVs (i.e., 20%) were used to protect common species. Following this we determined the underlying dose-response data set for each COPC, by determining the relationship between reported COPC doses and levels of response for measurement endpoints such as reproduction, growth, or mortality. Each dose-response data set reflected multiple point estimates rather than single study point estimate TRVs. Furthermore, the shape of the dose-response relationship (e.g., steep or shallow increase in toxicity relative to changes in chemical dose) often differed between COPCs as well as ROCs. Consequently, information contained in dose-response data sets provided a more complete understanding of the probability, magnitude and types of effects associated with a predicted COPC dose for a particular wildlife species.

Figure 4 depicts the dose-response relationship for methyl mercury in birds, as an example of how effects to different species for different endpoints (growth, reproduction) are distributed across a spectrum of dietary intake doses (mg/kg body weight/day). Depicting the data in this format provides a transparent illustration of how potential effects may be manifest and expressed across species to derive TRVs that are intended to be protective of common and 'listed' species, which have different protection goals. We were not overly prescriptive when categorizing potential toxicity or effect. Rather, several factors were interpreted, including: shape and steepness of the dose-response relationship relative to the predicted dose; similarities in phylogeny, gastrointestinal physiology and/or body weight between wildlife ROCs and test organisms; and type of endpoint measured.

As part of the hazard evaluation, predicted COPC doses were compared to the appropriate toxicity reference values (TRVs) for a variety of metals for selected listed (i.e., rare, endangered) and common species. Hazard quotients (HQs) were calculated by dividing the predicted dose by the TRVs. A hazard quotient < 1 indicated that risks were negligible and warranted no further action, while an HQ > 1

indicated the possibility of adverse effects and further risk characterization was carried out. The risk evaluation took advantage of the dose-response relationships established as part of the effects assessment.



Footnotes:

1. The effect size y-axis scale extends from 0 to 2. Values falling between 0 and 1 represent sublethal effects (e.g., 0.5 corresponds to a 50% reduction in an endpoint such as reproductive output); values between 1 and 2 represent lethal effects (e.g., 1.5 corresponds to 50% mortality).

2. TRV_{10} was used for listed species. TRV_{20} was used for common species.

3. Numbers (#) adjacent to each data point provide links to citations for individual scientific study (see **Section 7 - References**).

Legend for Pinchi Mine ROCs:

EAGLE = bald eagle, MALLARD = mallard, SPARROW = song sparrow, CHICKADEE = black-capped chickadee, HERON = great blue heron (listed species), LOON = common loon, SWALLOW = cliff swallow, BLACKBIRD = red-winged blackbird

Figure 4. Predicted doses (mg/kg bw/d) of methyl mercury in selected bird ROCs relative to dose-response data set.

Specifically, predicted COPC doses for wildlife foraging in the Pinchi Mine study area were plotted against literature-derived dose-response data sets. This meta-analysis approach provided a means to qualitatively determine the probability and magnitude of potential effects to wild organisms and their populations. Finally, these data were used to conduct a post-closure risk reduction analysis to assess the implications (i.e., risk reductions) associated with remediation of specific areas of the mine site through modeling. These results were ultimately used to inform management decisions about the site and guide remediation. A discussion of results of each is presented in the following section.

RISK ASSESSMENT RESULTS

Of the 335 potential COPC/ROC combinations assessed, 288 combinations (i.e., approximately 85%) resulted in HQs less than one, indicating negligible risks to wildlife. The remaining 47 COPC/ROC combinations resulted in HQs greater than one, indicating a possibility of adverse effects. Accordingly, risk evaluation was conducted for those 47 combinations. For the purposes of this paper, we focus on methyl mercury. Moderate to high risks (i.e., 10 – 20% effect; >20% effect level to growth, reproduction, effects respectively) were predicted for five mammal species (dusky shrew, deer mouse, little brown bat, long-tailed weasel, and mink and seven bird species (song sparrow, black-capped chickadee, barn swallow, red-winged blackbird, American crow, great horned owl, and spotted sandpiper). The main drivers of risk were: consumption by insectivorous mammals and birds of ground insects and/or flying insects from the Mill Site, Tailings Impoundment Area, and to a lesser extent, Old Mill; and consumption by carnivorous mammals and birds of small mammals from the Mill Site and Tailings Impoundment Area. Other areas such as East Mine and Mine Near-field also contributed to elevated methyl mercury exposure, particularly in the case of the black-capped chickadee.

Finally, a post-closure risk reduction analysis was undertaken to quantify the potential benefits of remediating discrete portions of the mine site in order to guide the mine's Closure Plan. This was accomplished by identifying areas of the site posing the greatest potential risks and where the greatest risk reduction could be achieved through remediation by running alternate model scenarios that either included or removed the high exposure areas. The analysis focused on quantifying risk reductions associated with remediation of the Mill Site, Old Mill Site (from historic operations) and the Tailings Impoundment Area. For the purpose of the risk reduction analysis, we focused on arsenic, inorganic and methyl mercury because these COPCs were predicted to pose moderate to high potential risks to some insectivorous and carnivorous wildlife under current exposure conditions.

The risk reduction analysis predicted that remediation of the Mill Site and Tailings Impoundment Area would result in a considerable reduction in risks to wildlife, with a decrease of about 50% in the number of receptors with HQs greater than 1. It was also determined that remediation of the Old Mill area would not result in any major risk reduction. While small, discrete areas of the mine site also potentially posed some "residual" risks to insectivorous small mammals and birds (i.e., to five receptors with HQs greater than 1), these areas mostly consist of forested land, including Mill Near-field, East Mine, West Mine and Gate Area. To assist in weighing risk management options (i.e., cleaning-up some of those remaining on-site areas versus leaving them undisturbed), we attempted to place our risk predictions into context by determining the magnitude of risks and degree of uncertainty when extrapolating to local receptors. This involved a combination of on-site field studies and scrutiny of the dose-response data sets. These steps were important since the consequences of remediation activities in forested land (e.g., clearing forested areas and excavating/capping soils) could be significant and pose more risk than the contamination itself. For example, studies of small mammals indicated similar trapping success, health and condition between on-site forested areas and reference areas, suggesting that large impacts (e.g., at the level of local populations) are probably not occurring. However, uncertainty may remain regarding more subtle effects (e.g., at the level of individual organisms).

CONCLUSIONS

The terrestrial ERA of the Pinchi Mercury Mine identified nine COPCs based on comparisons of surface soil concentrations to provincial standards for contaminated sites. With the exception of antimony and mercury, surface soil contamination was limited to specific portions of the mine site where the most intense industrial activities took place, especially the Mill Site, Old Mill and Tailings Impoundment Area. Metal contamination appeared delineated and did not extend off-site, despite a known but small mine-related signature in soils based on historic aerial transport of mercury. As well, off-site soils contained mercury as cinnabar due to glacial erosion of the Pinchi Fault.

The ERA evaluated potential risks to 40 wildlife receptors, including species of traditional importance to First Nations. For wildlife receptors with large home range such as deer, moose, and bear, risks were considered to be negligible to low under pre-closure conditions. Of the remaining species, only those feeding primarily on insects (e.g., dusky shrew, little brown bat, black-capped chickadee, barn swallow, redwing blackbird) or on small mammals (e.g., long-tailed weasel) indicated a potential for unacceptable mine-related risks. These ranged from low magnitude (i.e., small effects on growth or reproduction) to high (i.e., large effects on growth or reproduction, and/or possible mortality) due mainly to dietary exposure to arsenic, inorganic mercury and methyl mercury. In most cases, the Mill Site and Tailings Pond were the primary contributors to predicted risks. A post-closure risk reduction analysis indicated that remediation of these areas would result in a significant reduction in predicted risks to wildlife. Remediation of the Old Mill Site did not identify any significant reductions in risks to wildlife.

The risk assessment also identified the existence of residual post-closure risks associated with other on-site areas, which mostly consisted of forested land such as Mill Near-field, East Mine, West Mine and Gate Area. These residual risks were considered low (<10% effect level) to moderate (10 – 20% effects) for insect-eating mammals and birds, although there was a moderate degree of uncertainty when extrapolating these predictions to local wildlife populations. Based on a weight-of-evidence approach, it was decided by risk managers that disruption to lands re-forested over the intervening 70+ years since cessation of the historic operation would be more damaging than potential residual risks posed by site COPCs. Whether predicted risks or their associated uncertainty are considered “acceptable” or “unacceptable” was ultimately a decision that involved input from risk managers, which included Teck, First Nations, and regulatory agencies. In the final Closure Plan, the Mill Site and Tailings Pond were fully remediated while the Old Mill site and adjacent, forested lands were left to continue to recover naturally. A long-term monitoring plan to verify risk predictions has been implemented at the Pinchi Mine.

REFERENCES

Azimuth Consulting Group (Azimuth). 2009. Pinchi Mine Ecological Risk Assessment. Prepared for: Teck Metals Bag 2000, Kimberley BC by Azimuth Consulting Group, Vancouver. June 2009.

Baker, R.F. and G.S. Mann. 2002. Assessment of Sediment Mercury Contamination, Pinchi Lake, BC. Report prepared by EVS Environment Consultants and Azimuth Consulting Group for Teck Cominco Metals Ltd. November 2002.

Baker, R.F., G.S. Mann and M. McConnell. 2013. Pinchi Lake Mercury Mine – Fish Mercury Study 2011. Prepared for Teck Metals, Kimberley BC by Azimuth Consulting Group Partnership. Vancouver BC. March, 2013.

Baker, R.F. 2001. Regional Survey of fish mercury concentrations, Pinchi Lake, BC. Report prepared by EVS Environment Consultants for Cominco Ltd. April 2001.

Donald, B., M. Unger and R. Marsland. 2013. Remediation of the Pinchi Lake Mine. Teck Metals Kimberley BC and Marsland Environmental Nelson BC.

EVS, NDM, and Frontier Geosciences (EVS Environment Consultants, Norecol Dames and Moore, and Frontier Geosciences). 1999. Pinchi Lake Mine: Mine site and lake investigation – environmental assessment report. AND Mine site and lake investigation data report. EVS Environment Consultants, Norecol Dames and Moore, and Frontier Geosciences for Cominco Ltd.

Gnamus, A. and M. Horvat. 1999. Mercury in terrestrial food webs of the Idrija mining area. p. 281-320. Ebinghaus, R., R. Turner, L. Lacerda, O. Vasiliev, W. Salomons, (eds). Mercury Contaminated Sites: Characterization, Risk Assessment and Remediation. Springer-Verlag, N.Y. 538 pp.

Gnamus, A., A. Byrne and M. Horvat. 2000. Mercury in the soil-plant-deer-predator food chain of a temperate forest in Slovenia. Environ. Sci. Technol. 34: 3337-3345.

Mann, G.S., R.F. Baker, M. McConnell and R. Gould. 2006. 2006 Regional fish mercury and Pinchi Lake ecology report. Prepared for Teck Cominco Metals, Kimberley BC by Azimuth Consulting Group Inc., Vancouver BC. June 2008.

Marsland Environmental Associates. 2009. Pinchi Lake Decommissioning and Reclamation Plan. Prepared for Teck Cominco Metals Ltd. April 2009.

Marsland, R., M. Unger and B. Donald. 2013. Pinchi Lake Mine Closure – Demolition debris disposal. Marsland Environmental Nelson BC and Teck Metals Kimberley BC.

Plouffe, A. 1995. Glacial dispersal of mercury from bedrock mineralization along Pinchi Fault, north central British Columbia. Water, Air and Soil Poll. 80: 1109-1112.

Suchanek, T., P. Richerson, L. Mullen, L. Brister, J. Becker, A. Maxson, and D. Slotton. 1997. The role of the sulphur bank mercury mine site in the dynamics of mercury transport and bioaccumulation within the Clear Lake aquatic ecosystem. Interim Final Report. U.C. Davis : Clear Lake Mercury Studies., US Environmental Protection Agency Region IX Superfund Program: 103 pp.

Suchanek, T., L.H. Mullen, B. Lamphere, P. Richerson, C. Woodmansee, D. Slotton, E. Harner, and L. Woodward. 1998. Redistribution of mercury from contaminated lake sediments of Clear Lake, California. Water, Air, and Soil Pollution. 104: 77-102.

Unger, M., B. Donald and R. Marsland. 2013. Long term post-reclamation monitoring of the Pinchi Lake Mine. Teck Metals Kimberley BC and Marsland Environmental, Nelson BC.