ENVIRONMENTAL RISK ASSESSMENT RELATED TO ZINC AND COPPER CONTAMINATION IN SOILS FOLLOWING A MINE CLOSURE IN A BOREAL FOREST ECOSYSTEM

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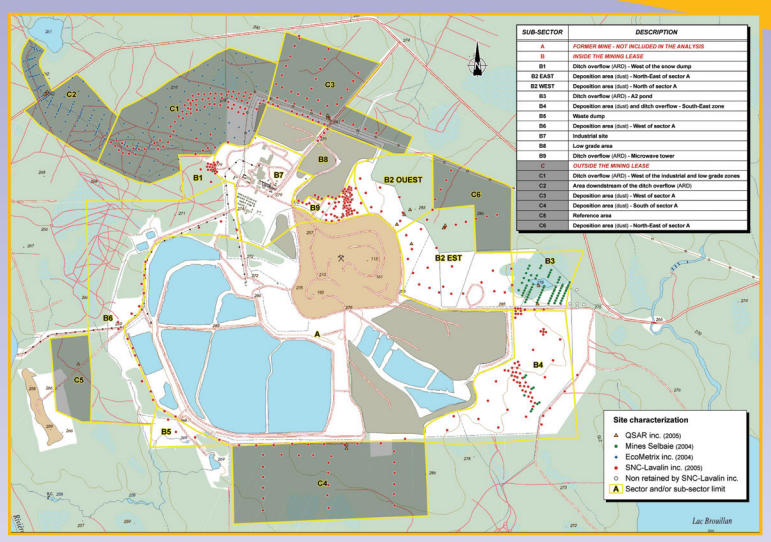
1 ABSTRACT

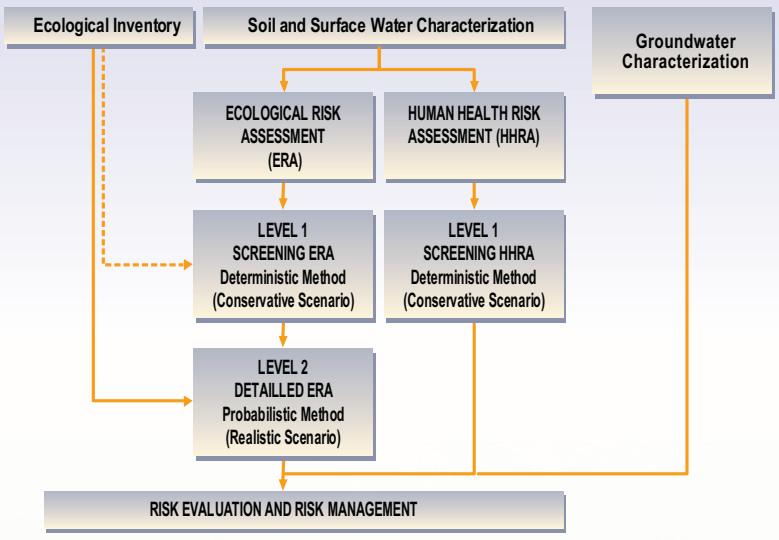
The environmental risk assessment of metals in soils within the boreal ecosystem presents unique challenges by their specific environmental conditions. Using recent guidelines and frameworks by national and international organizations (e.g. MERAG, U.S.EPA), as well as the more traditional approaches used in ecological risk assessment, this project aims at assessing risks for ecological target receptors exposed to soils contaminated by Zn and Cu-enriched dust deposition from the mining activities and to soil contaminated by acid rock drainage (ARD) and defining management actions for the areas of concern. The Mines Selbaie mining site is located ~700 km North-West of Montréal (Québec, Canada). This presentation will describe the particular problem formulation for the peat bog forest ecosystem, the extent of the soil contamination, the conceptual model, and the assessment endpoints. Risk was calculated based on screening benchmarks for target receptors (e.g. plants, birds, mammals, etc.). For dust deposition, no significant exposure nor effect was identified, along transects following the source and the gradient of contamination (i.e., the mining area), based on direct field observations (ecological inventory) and chemical analyses of spruce buds, tree rings and other indigenous plant samples. The final step will be the overall risk characterization combining the most recent toxicological data and exposure measurements.

2 CONTEXT AND OBJECTIVE

- The mining site (Mines Selbaie) is located at 700 km North-West of Montréal (Québec). Between 1980 and 2004, the mining activities consisted in extracting and concentrating zinc and copper deposits from an underground mine and an open pit.
- Since the mine closure in 2004, many sectors have been rehabilitated. Almost 2 000 000 m^3 of contaminated soils were removed/excavated to reduce the identifiable impact on the forest ecosystem.
- This study aims at defining a rehabilitation plan based on a risk assessment approach considering the major environmental impact related to soil excavations in the fragile boreal ecosystem. The air deposition of Zn and Cu-enriched dusts emitted during the mining operations and the accidental spills of acid rock drainage (ARD) define the extent of the soil contamination.This paper will present the main results of the Ecological Risk Assessment (ERA).



3 GENERAL APPROACH AND METHODOLOGY



3.1 Soil Characterization

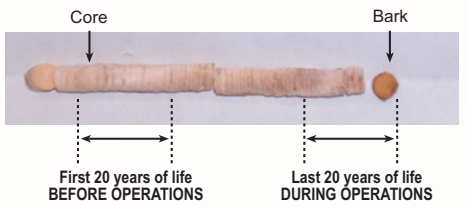
- The locations of the soil sampling stations were based on:
  - the deposition gradient of dust according to the prevailing winds;
  - the direction of the acid water overflow from the ditches.
- Soil samples were taken from 15 sub-sectors inside (sector B) and outside (sector C) the property limits (mining lease). Sector A was excluded from the study since it was covered by a specific regulation (Mining Act).
- More than 1 000 soils samples (mostly surface soils sampled between 0 and 30 cm) were collected and analysed for Zn, Cu, Cd, Pb, As, Ag, Cr, Mn, and Mo contents between April 2004 and November 2005.
- The locations of the sampling stations were established for the follow-up study of surface water quality on site (i.e., ARD and clean water). The stations located in the B an C sectors were used.
- The water samples were collected from ditches and streams in the B and C sectors from spring to fall 2005. The elements measured in the water were Zn, Cu, and Cd.

3.2 Surface Water Characterization

- The locations of the sampling stations were established for the follow-up study of surface water quality on site (i.e., ARD and clean water). The stations located in the B an C sectors were used.
- The water samples were collected from ditches and streams in the B and C sectors. Sector A was not included in the evaluation.
- The water samples were collected periodically from spring 2004 to fall 2005.
- The elements measured in the water were Zn, Cu, and Cd.

3.3 Ecological Inventory

- In July 2005, 18 transects oriented downwind or upwind of the source (dust deposition or ditch overflow) were completed in the B and C sectors.
- The floristic (dominance) and faunic (presence) characteristics were noted at selected sampling stations along the transects (see figure below).
- Plant specimens were collected at each station based on the dominance or the ecological relevancy.
- Tree rings of black spruce were also sampled to determine their metal exposure over time (i.e., before and after the mining operations).
- Soil samples were taken at each station along the transect.
- In total 42 soil samples, 25 spruce buds, 26 black spruce tree rings, 24 Labrador tea leaves, 43 other plant samples were collected.



3.4 ERA Approach

INITIAL METHODOLOGICAL CHOICES

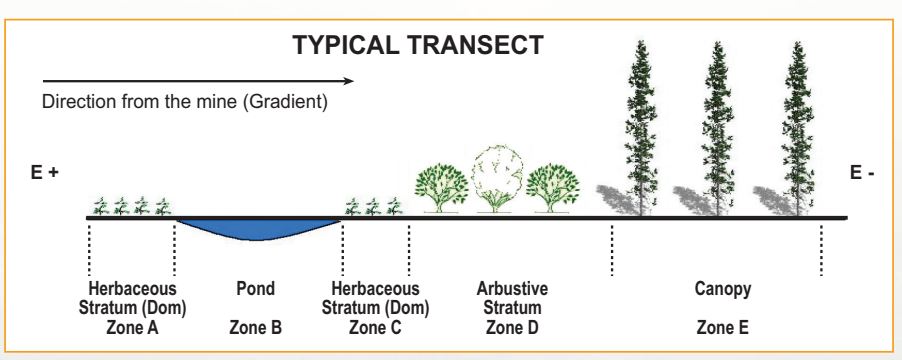
- 10 ecological receptors (soils organisms, mammals, birds)
- 9 chemicals of concern (COC): Zn, Cu, Cd, Pb, As, Ag, Cr, Mn, and Mo
- Ingestion pathway only
- Toxicological Reference Values (TRVs) based on the provincial recommendations for industrial use (CEAEQ)
- Risk calculation (risk index or hazard ratio) based on the ratio of the exposure dose (mg/kg/d) or exposure concentrations (mg/kg) over its specific TRV

LEVEL 1 (SCREENING): Deterministic Method

- Soil concentration: UCL (95%) of the arithmetic mean by sub-sectors
- Plant concentration: uptake factor/regression (Oak Ridge National Laboratory - ORNL)
- Soil invertebrate and small mammal concentration: uptake factor/regression (ORNL)
- Water concentration: (K_d)
- Exposure parameters: literature review
- **Risk index (hazard ratio): point estimate**

LEVEL 2 (DETAILLED): Probabilistic Method

- Soil concentration: mean + SD (lognormal distribution)
- Plant concentration: measured values + SD
- Soil invertebrate concentration: literature review
- Small mammal concentration: uptake factor/regression (ORNL)
- Water concentration: measured concentration by sub-sectors
- Exposure parameters (including variability)
- Monte Carlo simulations (Crystal Ball)
- **Risk index: Probability Density Function (PDF)**



4 RESULTS AND DISCUSSION

4.1 ERA – Level 1 (Screening)

- There exists a potential risk, for Zn and Cu for soil contact organisms (plants, soil invertebrates, soil microorganisms), at the screening level, for 13 of the 15 sub-sectors.
- The RI < 1 (no risk) for Cu and Zn for all mammals and birds, except for the Meadow Vole (Cu, 2 of the 15 sub-sectors) and the Savannah Sparrow (Cu, 8 of the 15 sub-sectors); the sub-sectors are mainly located near the industrial site and in the ditch overflow areas.
- **Conclusion**: Level 2 calculations (Monte Carlo simulations) have been accomplished or all receptors at risk after the level 1 analysis for Cu and Zn in 13 out of 15 sub-sectors.

Risk Index (RI) for Receptors and COCs Exceeding 1.0 for Specific Sub-Sectors

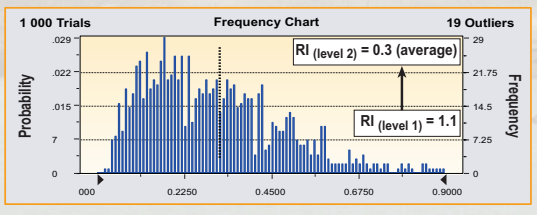
Metal	Sub-sector	Meadow vole	Savannah sparrow	Plants	Soil invertebrates	Soil Microorganisms
Copper	**Whole site**		**2,1**	**3,2**	**1,8**	
	B1	1,1	1,6	9,2	5,1	
	B2-East		2,5	5,2	2,9	
	B2-West		1,8	1,8	3,2	
	B3	1,1	2,5	9,6	5,4	
	B4		1,3	1,9	1,1	
	B5			1,3		
	B6					
	B8			16,7	9,4	1,7
	B9		1,1	5,6	3,2	
	C1			1,2		
	C2		1,0	2,8	1,6	
	C3		3,6	7,9	4,4	
	C4			1,0		
	C5					
	C6					**1,1**
Zinc	**Whole site**			**3,1**	**2,3**	3,4
	B1			9,8	7,2	1,7
	B2-East			4,9	3,6	1,4
	B2-West			4,0	2,9	2,6
	B3			7,4	5,5	
	B4			1,1		
	B5			1,8	1,3	
	B6					5,3
	B8			15,3	11,2	2,3
	B9			6,7	5,0	
	C1			1,2		1,1
	C2			3,2	2,4	2,2
	C3			6,3	4,7	
	C4					
	C5					
	C6			1,7	1,3	

4.2 ERA – Level 2

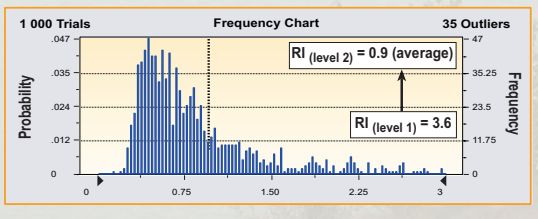
- Based on the probabilistic calculations (level 2), mammals (Meadow vole) and birds (Savannah sparrow) are not at risk ($RI_{average} < 1$).
- For soil organisms (plants, invertebrates, microorganisms), there is a theoretical risk for 7 of the 15 sub-sectors with an average RI ranging from >1 to 10:
  - B1, B3 et B9 are affected by the ditch overflow of ARD;
  - B2 East and West and C3 are affected by dust deposition;
  - B8 is affected by a residual contamination along the access road leading to the industrial site.
- **Plants show the highest RI compared to other soil organisms.**

4.2 ERA – Level 2 (continued)

RI (PDF) for Meadow Vole Exposed to Copper in Sub-Sector B3



RI (PDF) for Savannah Sparrow Exposed to Copper in Sub-Sector C3



4.3 Ecological Inventory (Site Visit)

FLORA

- 74 plants species (excluding bryophytes)
- 5 tree species (dominant: black spruce)
- 26 shrub species (dominant: Labrador tea)
- 43 herbaceous species (dominant: horsetail)

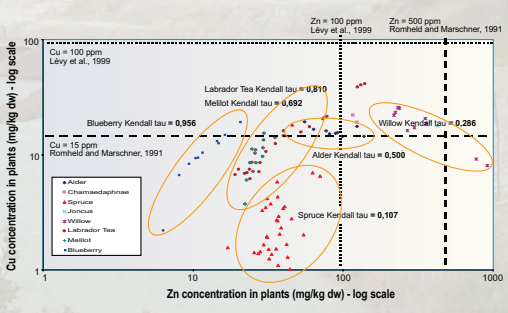
FAUNA

- 10 bird species (dominant: sparrow)
- 5 mammals (dominant: hare)
- 2 amphibians
- Aquatic and terrestrial insects
- Fish (cyprinidae)

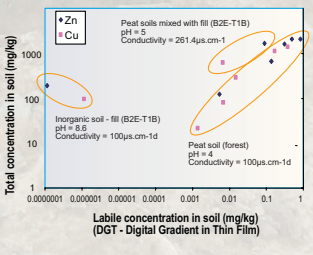
The contaminated soil gradient (E⁺ vs E⁰) is not identifiable through direct observations of the forest ecosystem.

4.4 Bioconcentration and Bioavailability

Relationship (correlation) Between Copper and Zinc Concentration in Plants



Relationship Between Total Zn and Cu Concentration and the Labile Form (DGT) in Soil



- Most of the plants species do not exceed the phytotoxicity levels for Zn and Cu.
- Blueberry (leaves and fruits) and Labrador tea show a positive correlation ($p < 0.05$) between Cu and Zn concentration; there exist no relationship for spruce ($p > 0.05$).
- There exist a negative but non significant ($p > 0.05$) correlation between these metals for willow and Alder.
- The small sample size did not allow the calculation of correlation values for other plant species.
- The Zn and Cu concentrations during the mine operations (last 20 years of life) in tree rings was 2 to 5 times higher than in the pre-exposure period (first 20 years of life). However, these levels were well below the phytotoxicity limits for these metals.
- The bioavailability of metals in soil (labile form vs. total concentration) depends on the type of soil (inorganic till vs. peat moss) which affect the pH and the biochemical activity of the soil.

5 CONCLUSION

- On the preliminary basis there is no risk for mammals and birds; there exists a potential risk for soil organisms.
- Direct field observations and measurements show no direct effect nor impact on the local fauna and flora in the area affected by dust deposition.
- Direct effects on plants are clearly identifiable in the areas affected of ARD – low pH values (ditch overflow).
- Based on its sensitivity and its potential risk the terrestrial plants are indicator species of the ecosystem health.
- It is recommended to conduct a follow-up study of the plant growth and development in areas at risk (soil affected by both dust deposition and ARD – low pH values).
- No toxicity tests are recommended at this stage since the risk management will be targeted on the population and the community levels (forest ecosystem), not on the effects on individual organisms.

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