RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

UQAT
UNIVERSITÉ DU QUÉBEC
EN ABITIBI-TÉMISCAMINGUE

POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

Active treatment and management of mine effluents in cold climate

Prof. Carmen M. Neculita

CarmenMihaela.Neculita@uqat.ca

CANADA RESEARCH CHAIR
Treatment and Management of Mine Water

Seminar, Palacky University, Olomouc, May 20, 2025

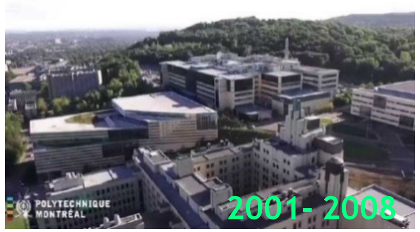
Outline

- Introduction
  - Personal presentation
  - RIME – UQAT: Who we are, what we do
- Mine water: contaminants and treatment processes
  - Examples: active vs passive treatment, synthetic vs real effluents, lab vs field-scale
- Concluding remarks
- Potential collaboration opportunities

Outline

- Introduction
  - Personal presentation
  - RIME – UQAT: Who we are, what we do
- Mine water: contaminants and treatment processes
  - Examples: active vs passive treatment, synthetic vs real effluents, lab vs field-scale
- Concluding remarks
- Potential collaboration opportunities

Personal presentation: Training and professional experience



MINISTRY OF ENVIRONMENT
1995 - 2001

Canada Research Chair, CRC Tier 1 (Senior) (2022 - 2029)

Canada Research Chair, CRC Tier 2 (Junior) (2011 - 2021): 2 x 5-year terms

Full Professor (since 2017)
Associate Professor (2011 - 2017)
University of Quebec, QC

Visiting Professor (2019-2020)
SUT (Silesian University of Technology), Politechnika Śląska, Poland

Visiting Professor (2025)
Huelva University, Spain

Assistant Professor
Civil and Environmental Engineering Department, KAIST, South Korea

PhD (2004 – 2008)
MSc (2001 – 2003)
Polytechnique Montreal, QC
(Mineral Engineering)

Associate Researcher (2008)
Polytechnique Montreal (Civil, Geological, and Mining Engineering), QC

Scientist (2008)
Natural Resources Canada (NRCan), CANMET, Ottawa, ON

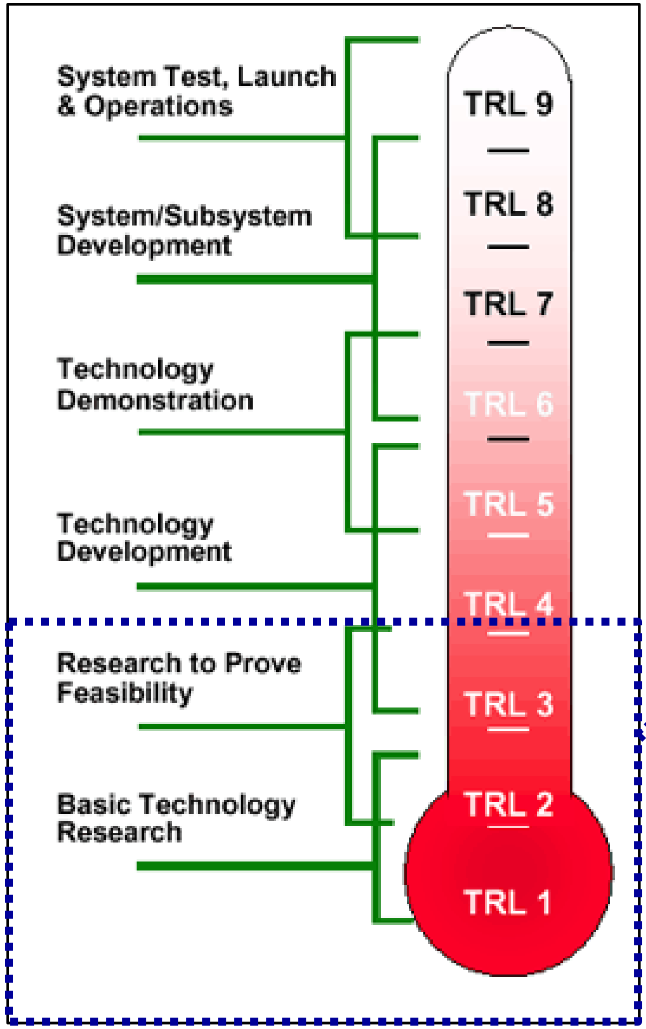
Chemical Engineer
Environmental Protection Agencies, Ministry of Environment, Romania

Chemical Engineer
Sulfur Mining Company, Calimani Mountains, Carpathians, Romania

Chemical Engineering Degree
Technical University Iasi (Major: Organic Chemistry), Romania

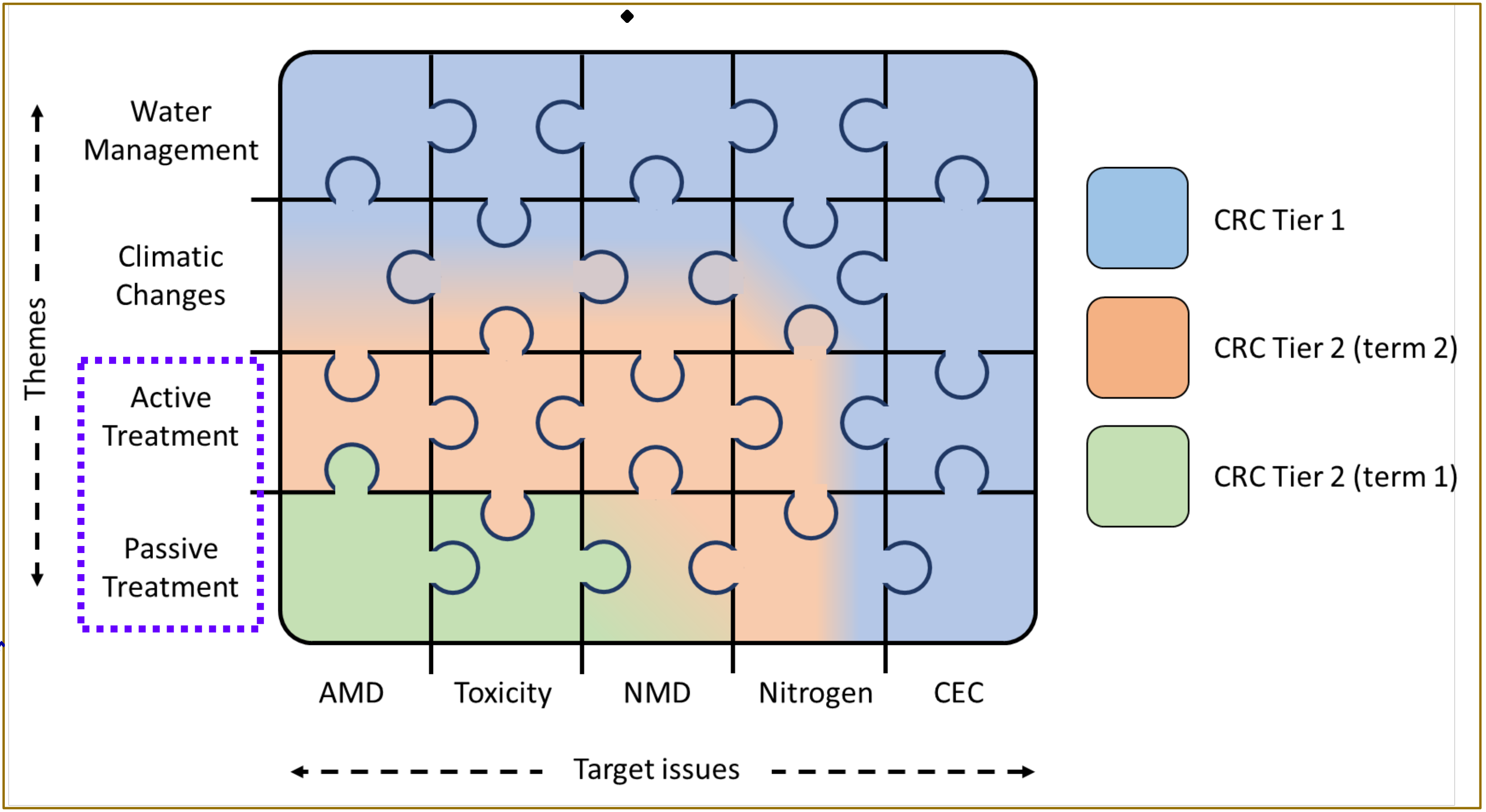
CRC frame: Research focus and knowledge development

Focus of research



[NASA, Internet sources]

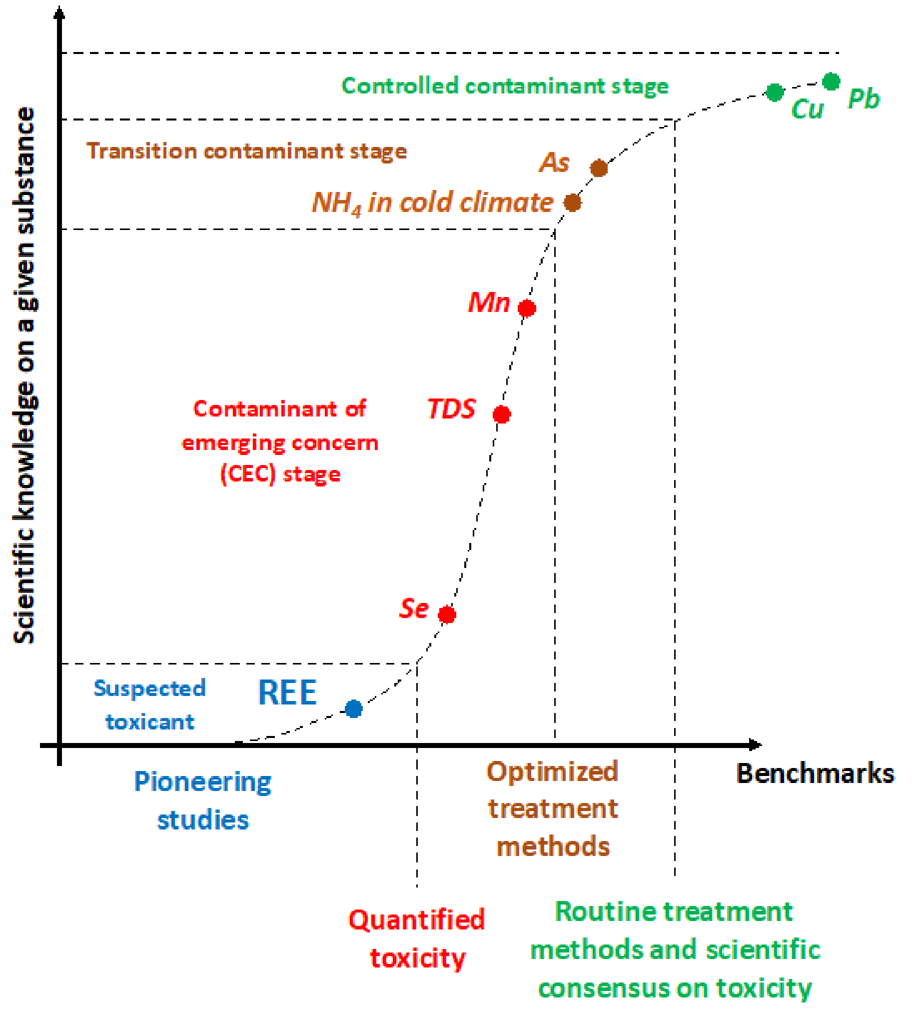
Focus of knowledge to be developed



CEC: Contaminants of Emerging Concern

UQAT

CRC frame: Research focus and knowledge development



CEC definitions based on scientific knowledge of different substances in mine water.
REE: Rare Earth Elements; TDS: Total Dissolved Solids.

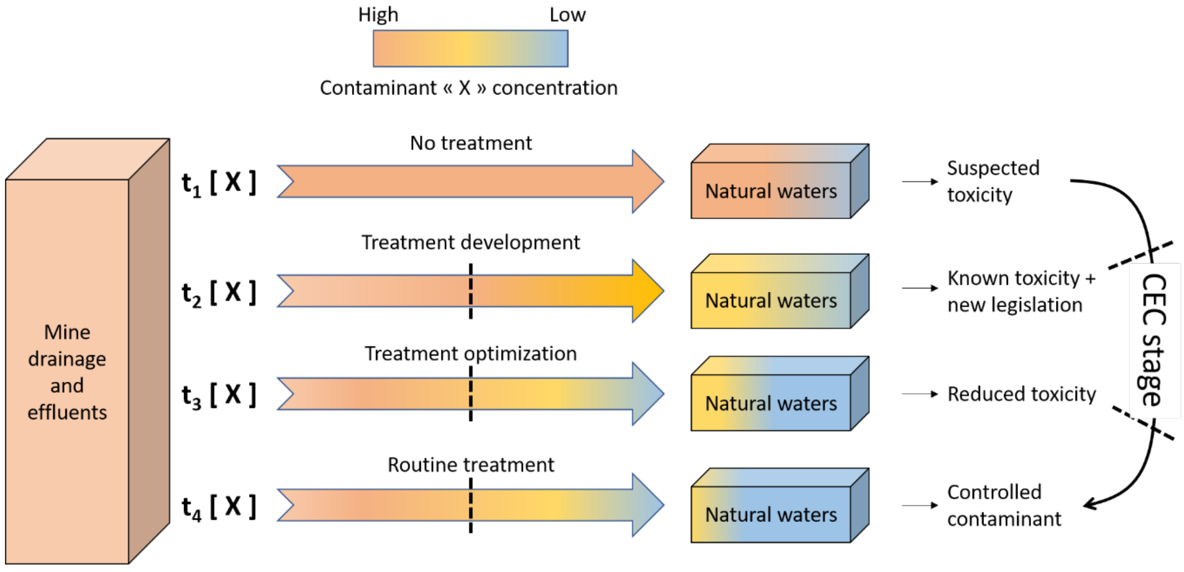
Four groups of contaminants

1) New (rare earth elements: REE, Se, Mn)

2) Difficult / complex to treat (salinity, thiosalts)

3) Common (As, Cu, Sb), but with very low thresholds in sensitive environments (e.g., cold conditions)

4) Nitrogen compounds (NH_3-N, nitrites, nitrates), regulated but also controlled via aquatic toxicity, for mines in operation and new mines



(Neculita et al., 2018, 2020; Ryskie et al., 2021)

UQAT

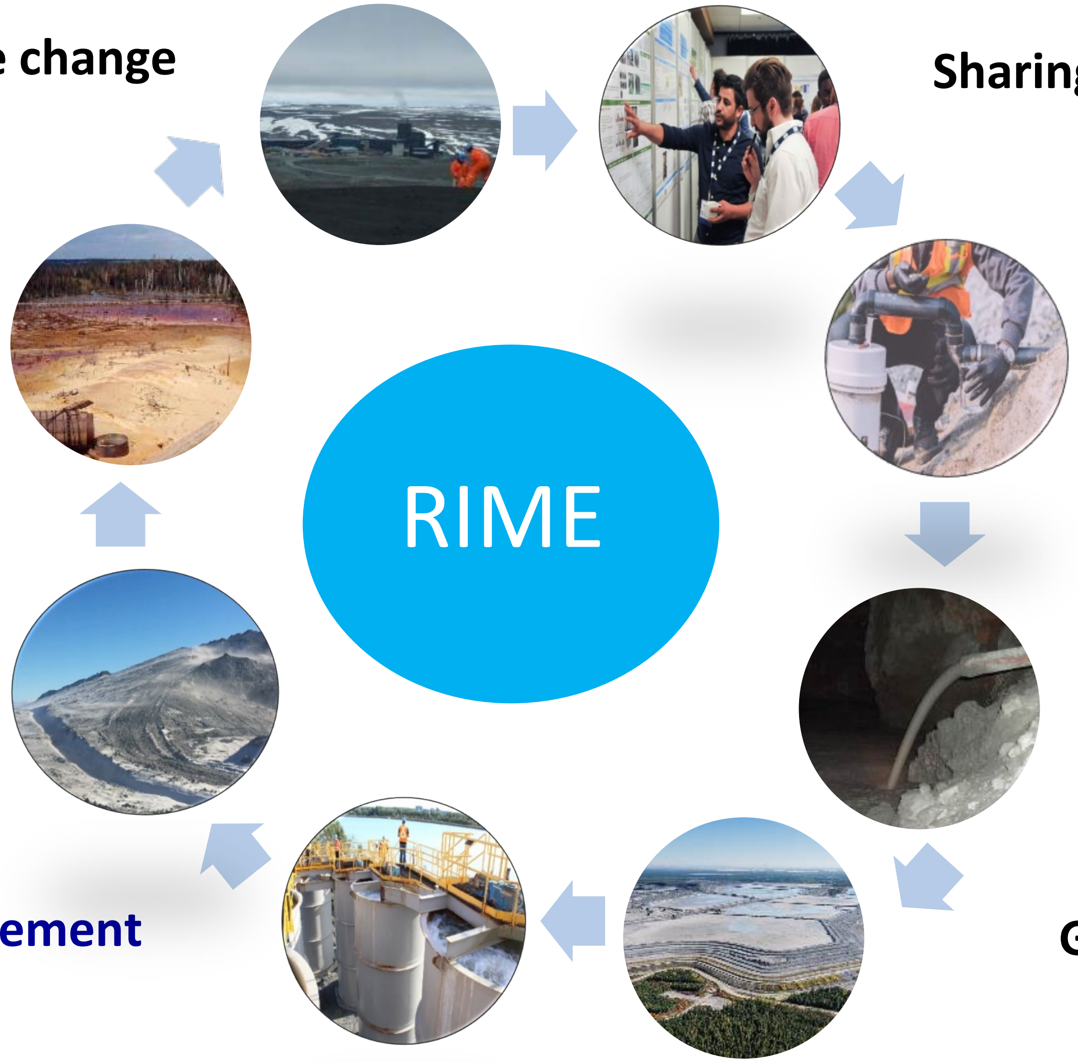
RIME UQAT-Polytechnique Montreal: Research topics

Arctic conditions and climate change

Sharing knowledge with communities

Site reclamation and revitalisation

Geology, geoenvironmental characterisation
Prediction of mining effluents quality



Contaminants transport in the environment

Integrated management of mine waste
Valorisation of mine waste

Water treatment and management

Geotechnical stability of tailings impoundments

Created in 2012, as a joint research program on the life-mine cycle

https://www.uqat.ca/uqat/departements/irme/

UQAT

RIME: Industrial partners mine sites









(https://www.uqat.ca/)

ResMinA: Government partnership, access to more mine sites

- REHABILITATION OF ABANDONED MINE SITES
  - **2023-2028** : Investment of MRNF (Ministry of Natural Resources and Forestry) of 1.2 M$ at RIME-UQAT
  - Research work on **12 abandoned but rehabilitated mine sites** (8 in AT) and **13 non-rehabilitated** (8 in AT) with Directorate of mine site rehabilitation
- → Development of **research projects** (ongoing and upcoming)

Cross-cutting themes

Integration of social aspects

Integration of climate changes

Confirmed themes

Monitoring optimisation post-rehabilitation

Passive water treatment systems

Severely oxidized tailings

Vegetation integration

Emergent themes

Biodiversity

Circular economy and valorization

Combined strategies of tailings valorization

RIME: Research team & infrastructure, UQAT

Team

- **18** professors
- **14** technicians & professionals
- **5** administrative staff
- **> 180** graduate students (advised to completion
  > 20 nationalities)
- **> 300** internships

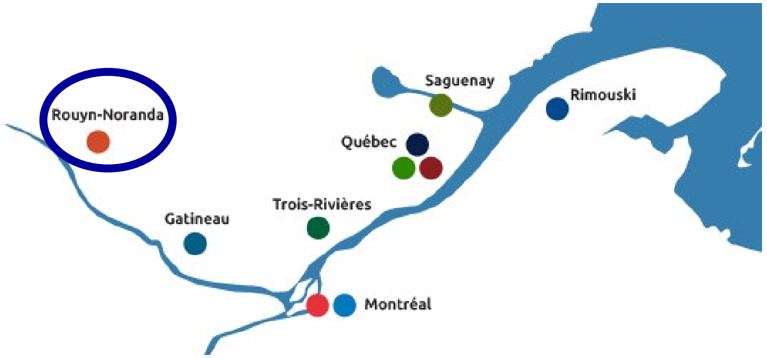
Laboratories & research facilities (technological platform)

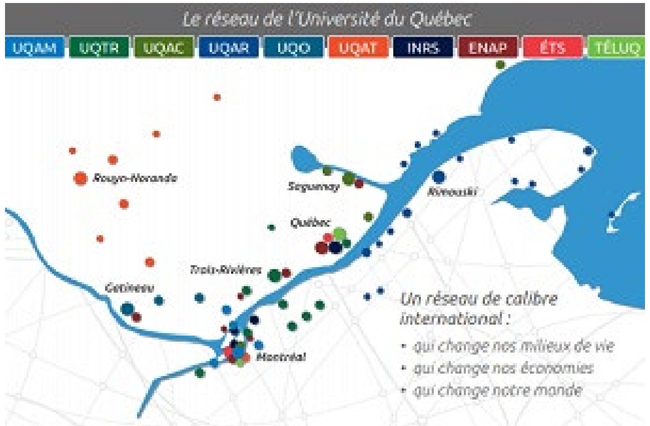
- URSTM (Research & Service Unit in Mineral Technology)
- Infrastructure: Microscopy · Geophysics
  · Analytical Chemistry · Geotechnical and hydrogeology
  · Backfills · XRD · Climate conditions simulations chamber
  · Floating cells · Mobile laboratory

(https://www.uqat.ca/)

UQAT: University of Quebec in Abitibi-Témiscamingue

- University of Quebec: 10-University Network



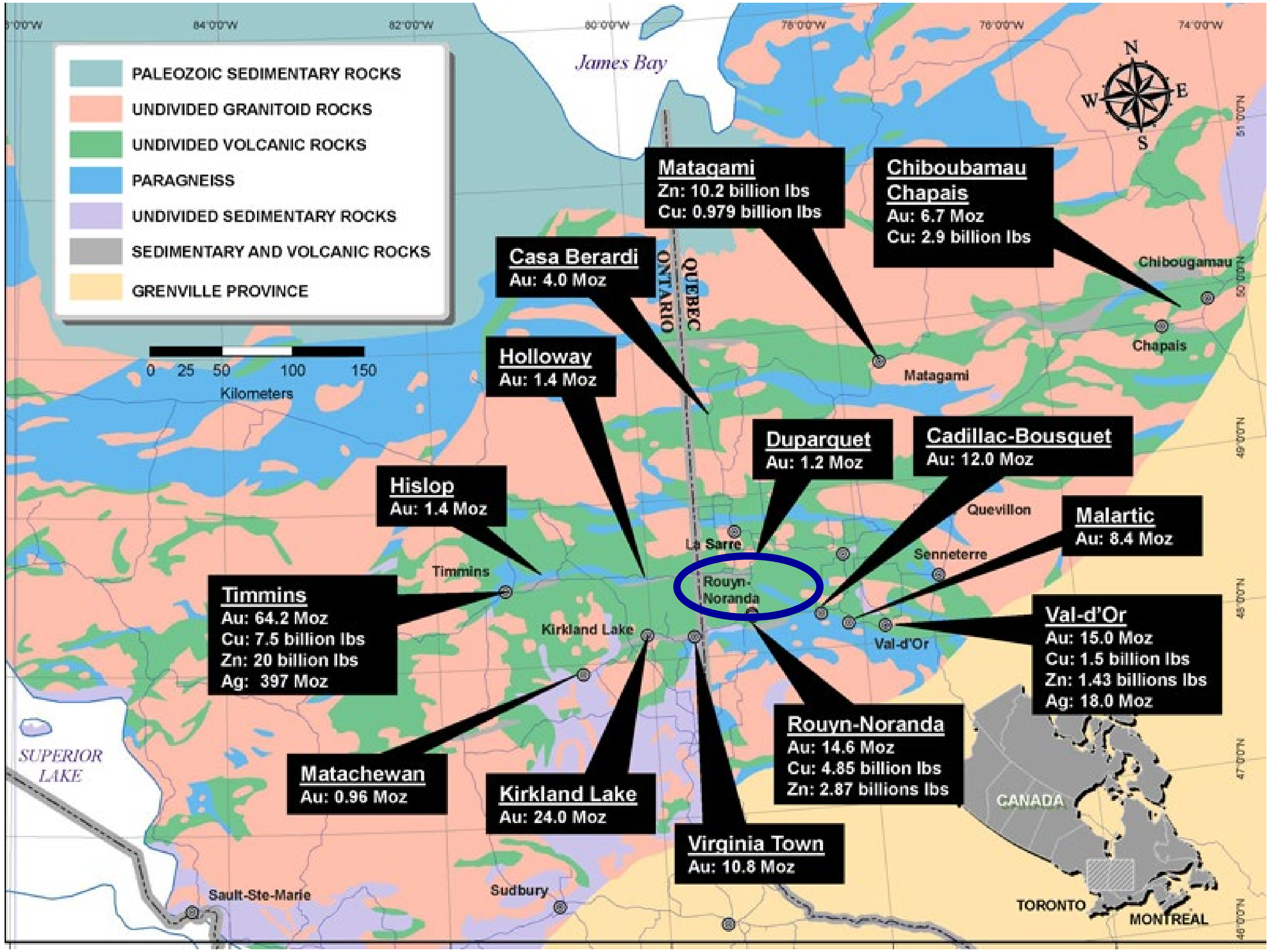


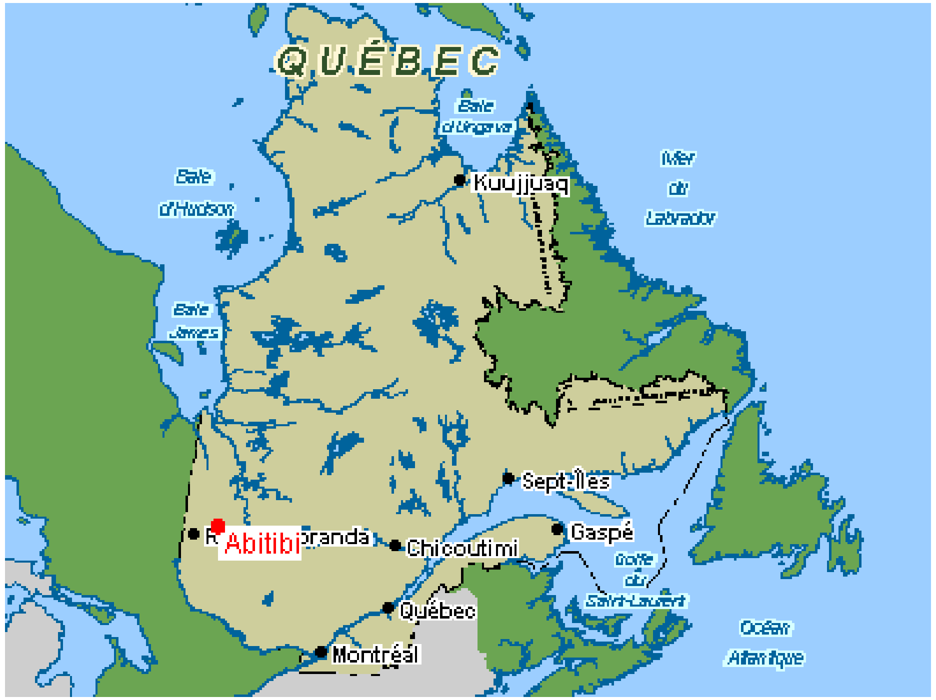
- 10 departments, 3 campuses
  - 2 research institutes: RIME (mines) and IRF (forestry)
- 385 professors and lecturers
- 283 staff
- 6,300 students
- 150 programs
- 12 Research Chairs (**2 CRC, Tier 1**)
- $10.5M research/year

UQAT

(https://www.uqat.ca/)

UQAT: Located in an historical mining region (Gold Valley)





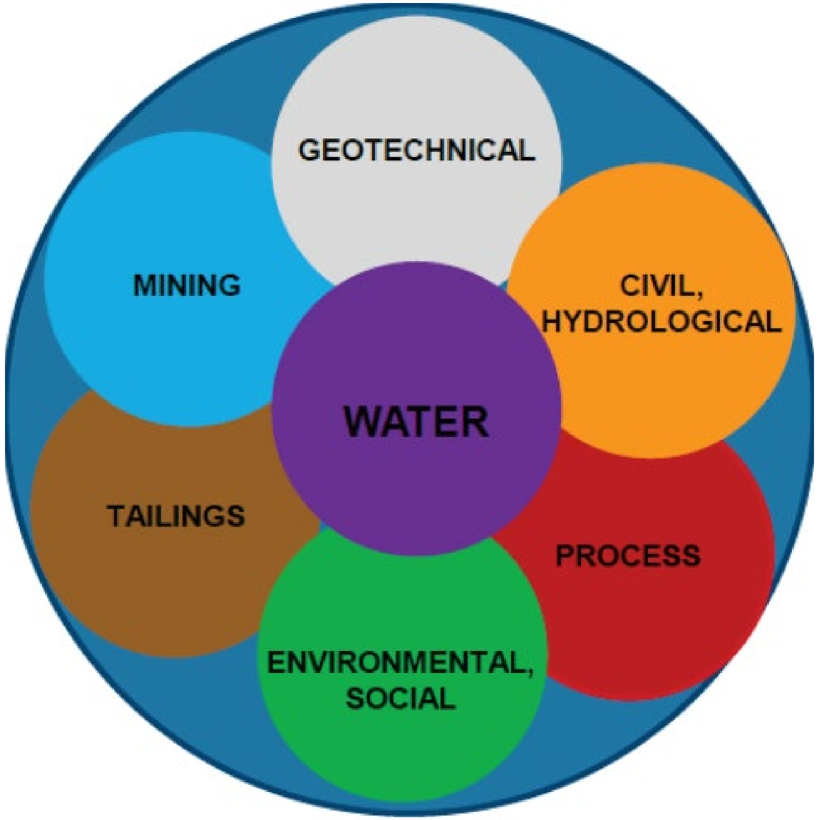
(Images: Internet sources)

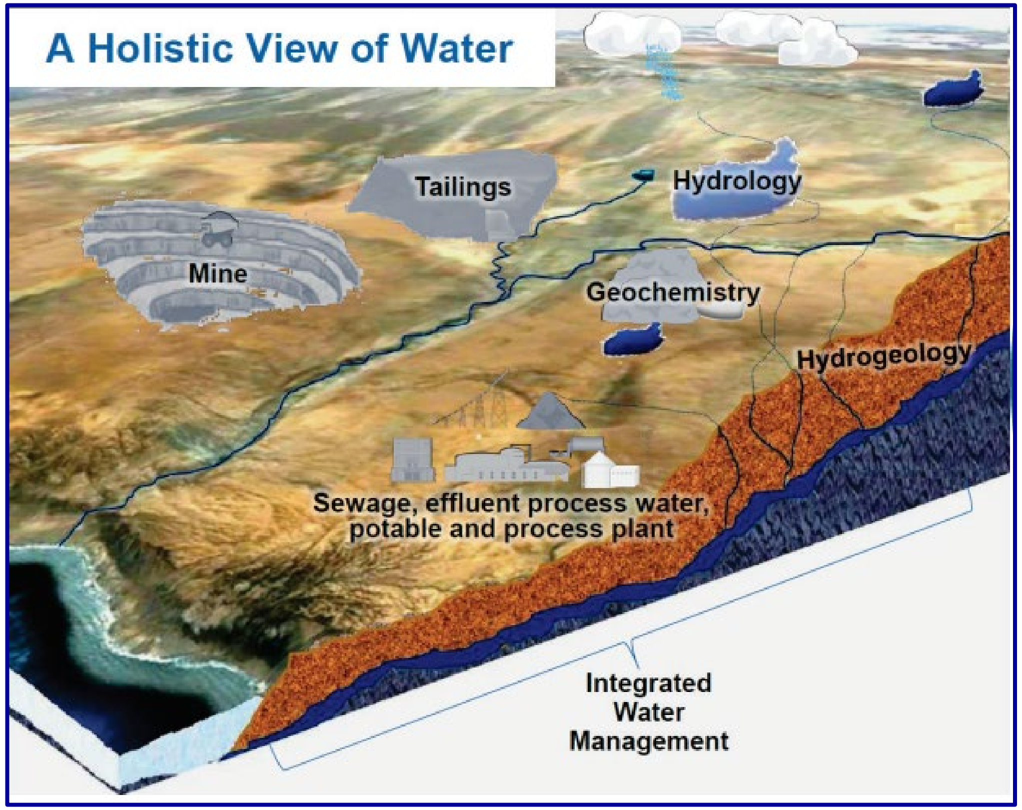
Outline

- Introduction
  - Personal presentation
  - RIME – UQAT: Who we are, what we do
- Mine water: contaminants & treatment processes
  - Examples: active vs passive treatment, synthetic vs real effluents, lab vs field-scale
- Concluding remarks
- Potential collaboration opportunities

Context: Mines & water

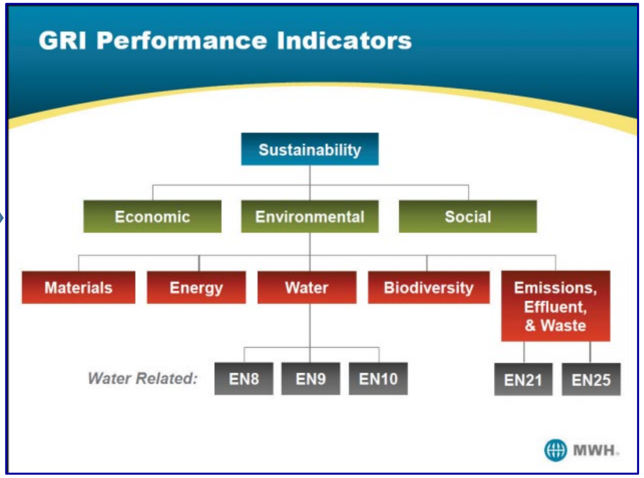
- **Water**: **<u>central</u>** in all activities on a mining site
- An integrated vision of water management = the only acceptable modern approach





Context: Mines & water

Water management vs treatment



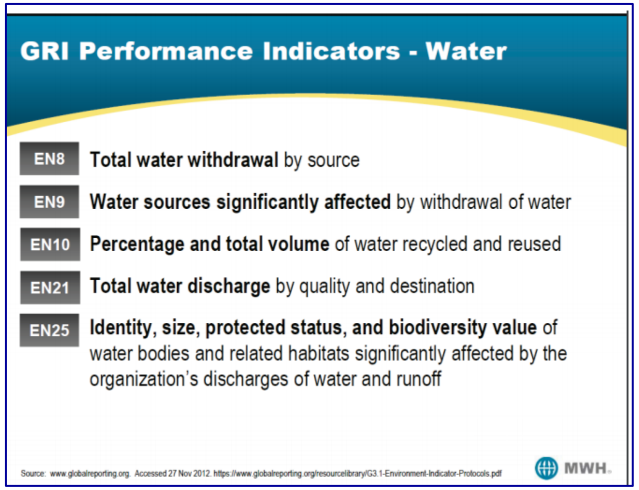
Contamination source control

Contaminant charge control

Water use control (reduce consumption)

Water quality [strict] control

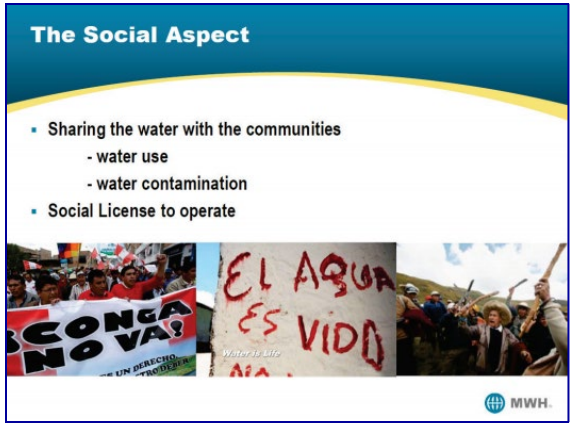
- Pollution prevention at all potential sources on the mine
- Minimization of potential impacts by mitigation measures
- Recovery and beneficial use of water on mine complex
- Treatment of mine water for beneficial use and discharge



GRI: Global Reporting Initiative

(GARD; Watson, 2014)

Context: Mines & water



[Watson, 2014]

- **Problem**: **Water Contamination**
  - **Mine water = Mine drainage (runoff water) + Process water (mine effluents)**
  - <u>Consumption</u> (single use) **<<<** **<u>use</u>** (multiple uses: recirculation, recycling)

2. **Challenges**: specific to the mine site, but in an evolving context
   - **Dependence on mineral resources** → exploitation of low-grade deposits (= more aggressive metallurgical treatment, complex quality of the mine water generated)
   - **Climate change, unpredictable quality/quantity** (> restrictive regulations, advanced treatment requirements)
   - **Social acceptability of new mining projects**: <u>shared use vs contamination of water</u>

3. **Available solutions:** <u>active and passive treatment processes</u>
   - Objectives: minimal liquid discharge (MLD) or zero liquid discharge (ZLD)

4. **Applied research needs**: gradually identified

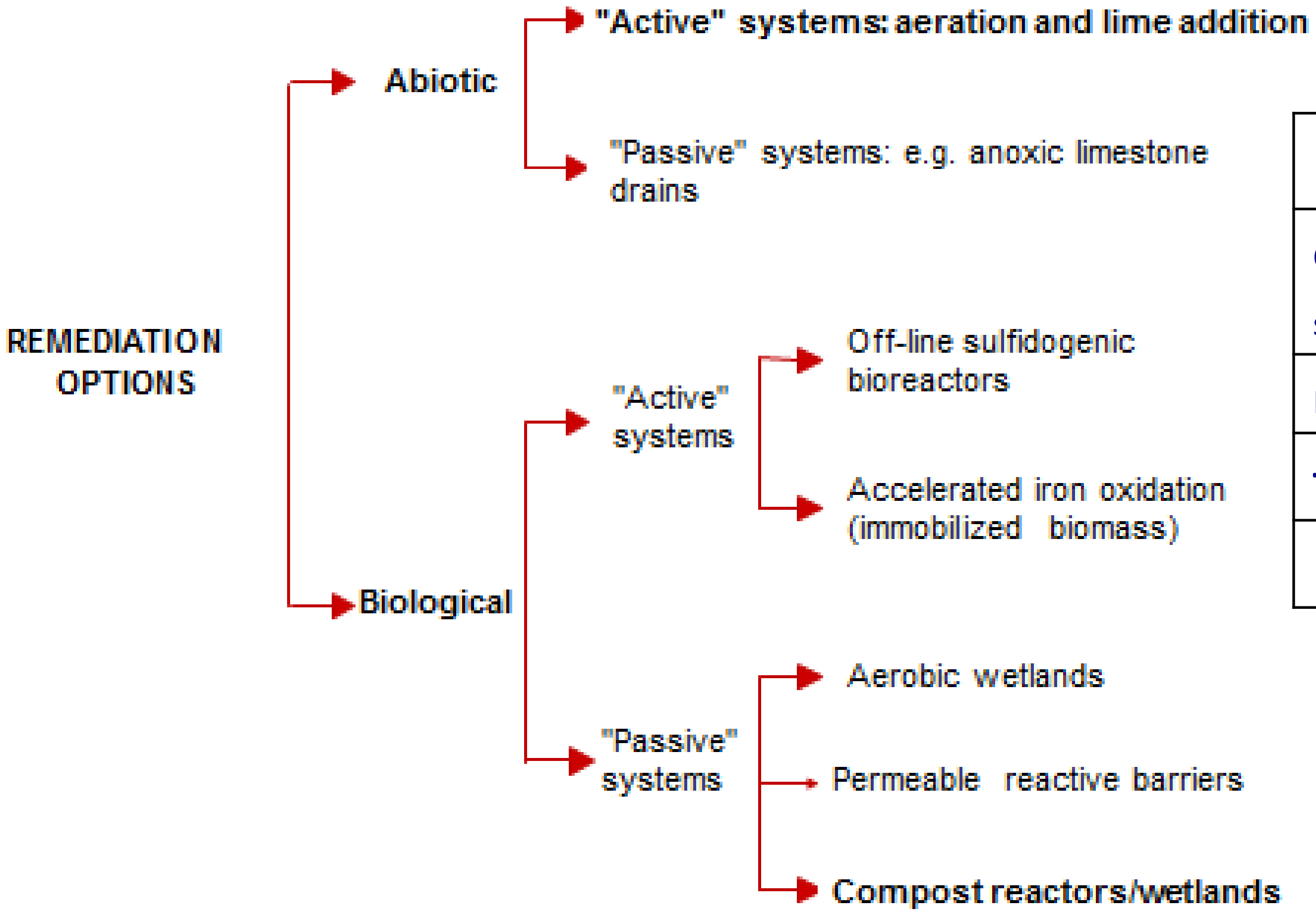
RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

Mine water: classical contaminants, treatment issues

Contaminants	**Mine drainage** (runoff water)		**N & S-based compounds** (mine effluents)
	AMD (acid mine drainage)	NMD (neutral mine drainage)	CN^-, SCN^-, NH_3-N, thiosalts (thiosulfate, tri/tetrathionate)
Sources	Metal sulfides + O_2 + water		NaCN, blasting agents (ANFO – ammonium nitrate fuel oil), flotation collectors (xanthates)
Characteristics	**pH < 3; high (>1g/L) metal & sulfates []**	**Metal [] > criteria**	Ore dependent, **but [] > criteria**
Why prevent or treat?	Regulation, environmental and social impacts		
Challenges	**Several contaminants**	**High contaminant mobility**	**Complexity (toxicity, costs, flowrates)**
Treatment issues	Sludge management (quantity, stability)	Limited knowledge	Low kinetics of N oxidation
Research work (RIME)	**Passive & active treatment adapted solutions to an evolutive context, including cold climate**		

Mine drainage treatment: Classification of methods

Without contribution (abiotic) or with contribution of microorganisms (biological)

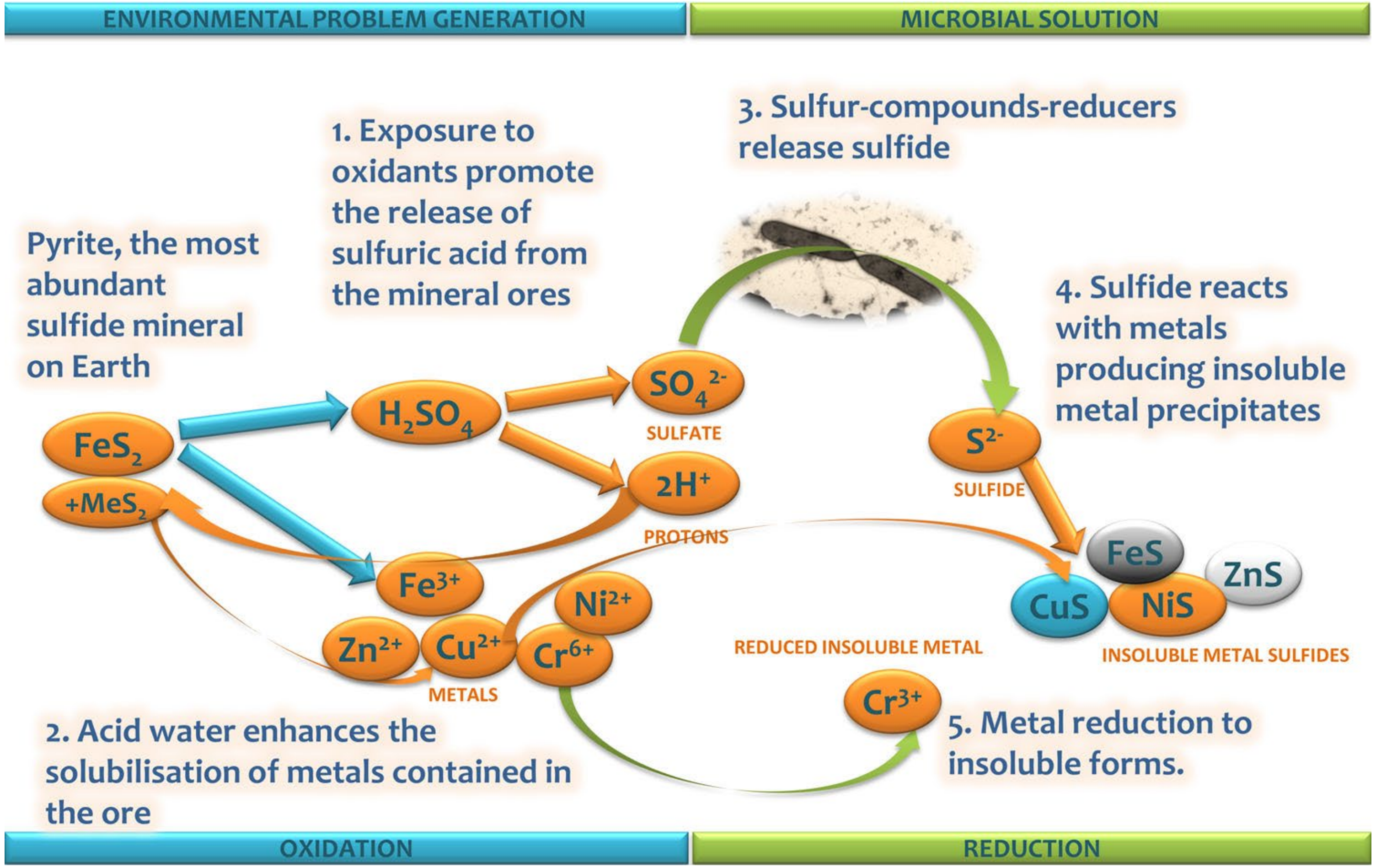


Active methods	Passive methods (polishing)
Continuous addition of chemicals / substrates	Integration of chemicals / substrates during construction
Electricity needs (pumping, aeration)	Gravity flow, natural aeration
Treatment plant required	**Pseudo-natural systems**
Mine sites in operation	Closed & abandoned mine sites

(Johnson, 2013; Neculita et al., 2021)

Mine drainage treatment: Classification of methods

Without contribution (abiotic) or with contribution of microorganisms (biological)



Active methods	Passive methods (polishing)
Continuous addition of chemicals / substrates	Integration of chemicals / substrates during construction
Electricity needs (pumping, aeration)	Gravity flow, natural aeration
Treatment plant required	**Pseudo-natural systems**
Mine sites in operation	Closed & abandoned mine sites

(Andrea-Sanchez et al., 2016)

Mine drainage treatment: Classification of methods

Without contribution (abiotic) or with contribution of microorganisms (biological)

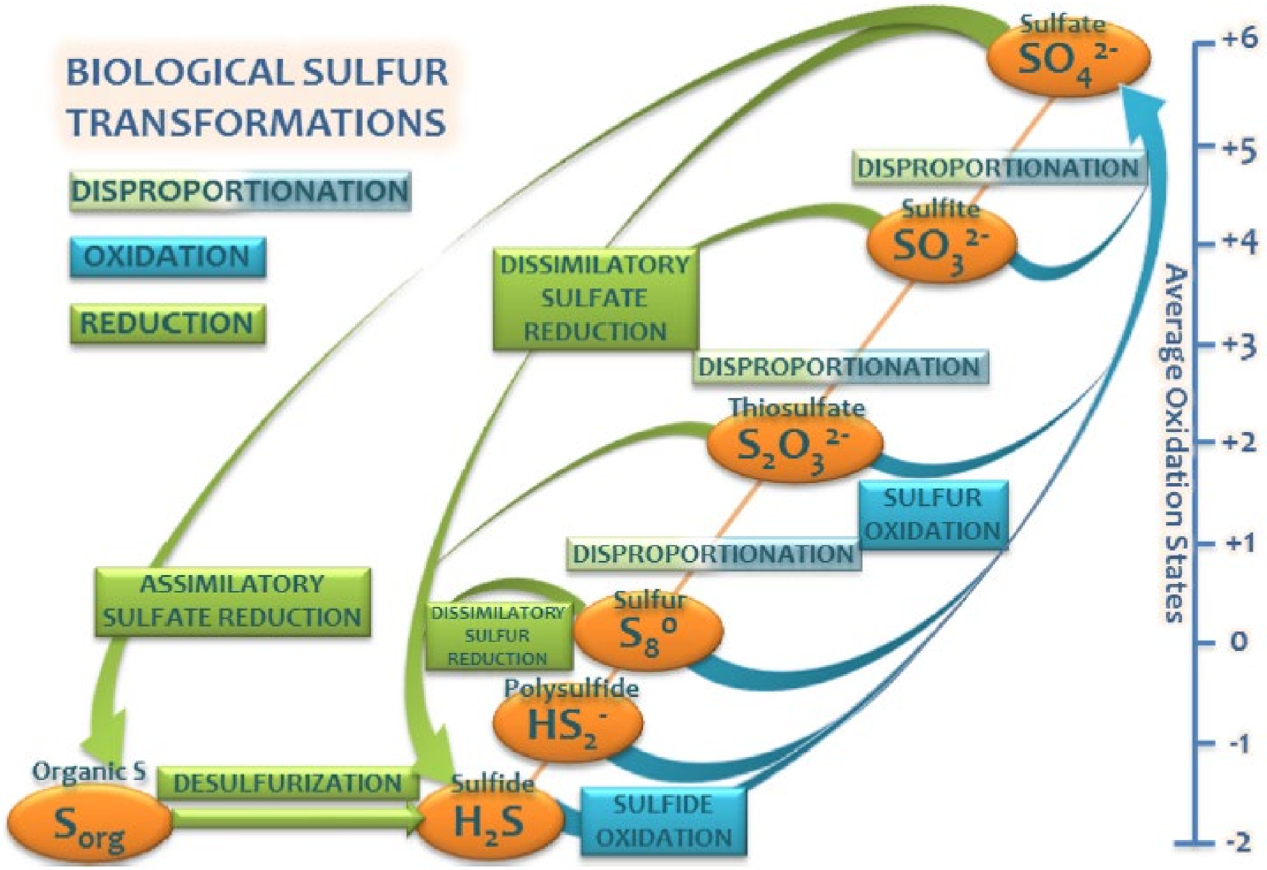
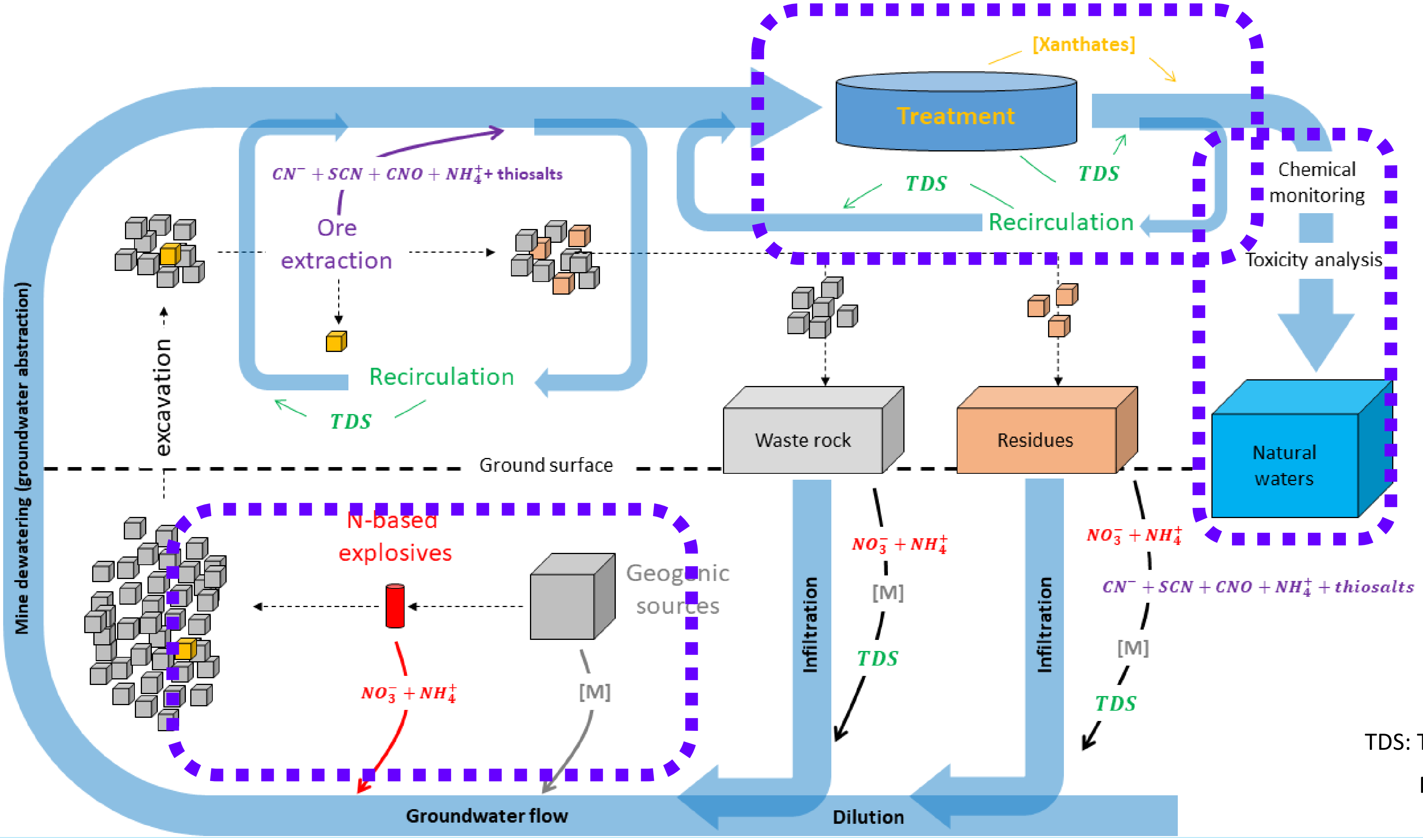


Fig. 1. Biological sulfur transformations.

Active methods	Passive methods (polishing)
Continuous addition of chemicals / substrates	Integration of chemicals / substrates during construction
Electricity needs (pumping, aeration)	Gravity flow, natural aeration
Treatment plant required	**Pseudo-natural systems**
Mine sites in operation	Closed & abandoned mine sites

(Andrea-Sanchez et al., 2014)

Contaminants of Emerging Concern (CEC): Sources and issues



TDS: Total Dissolved Solids

M: metallic elements

(Ryskie et al., 2021)

CEC in mine water: issues

- Not [necessarily] new chemicals
- Data [often] scarce (qualitative & quantitative)
- Detection methods nonexistent or in various stages of development
- Potentially present for a long time, but presence/significance now increasingly recognized
- No internationally agreed definition for emerging contaminants or CECs (OECD, 2012)
- Contaminants present and addressed before, but suddenly need to be mitigated to a new order of magnitude
- Could change geographically or for a different sector of activity

(Neculita et al., 2018, 2019; Ryskie et al., 2021)

Impact of cold temperature on mine water quality

- Contaminant sources and mitigation
  - Accelerated oxidation of reactive S-based species (elemental S, sulfides), after freeze / thaw (F/T) repeated cycles, leading to increased concentrations of thiosalts (*delayed acidity of mine water due to sulfuric acid generation*)
  - Slower kinetics of oxidation of N-based contaminants

(Schudle et al., 2019; Ryskie et al., 2021)

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

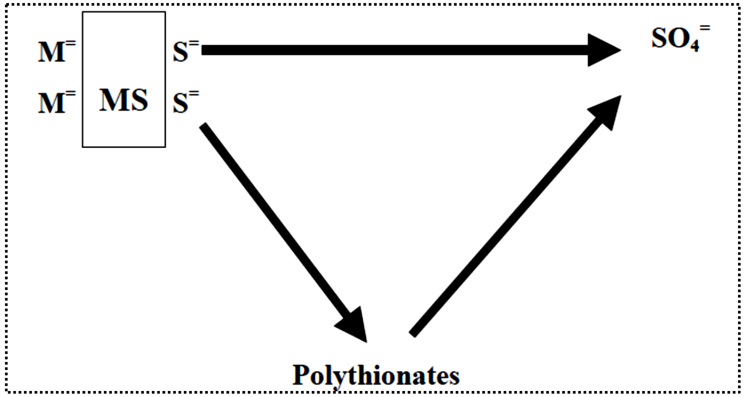
Thiosalts (polythionates): speciation

TABLE 19.1
Geomicrobially Important Forms of Sulfur and Their Oxide States

Compound	Formula	Oxidation State(s) of Sulfur
Sulfide	S^{2-}	−2
Polysulfide	S_n^{2-}	−2, 0
Sulfur[a]	S_8	0
Hyposulfite (dithionite)	$S_2O_4^{2-}$	+3
Sulfite	SO_3^{2-}	+4
Thiosulfate[b]	$S_2O_3^{2-}$	−1, +5
Dithionate	$S_2O_6^{2-}$	+4
Trithionate	$S_3O_6^{2-}$	−2, +6
Tetrathionate	$S_4O_6^{2-}$	−2, +6
Pentathionate	$S_5O_6^{2-}$	−2, +6
Sulfate	SO_4^{2-}	+6

[a] Occurs in an octagonal ring in crystalline form.

[b] Outer sulfur has an oxidation state of −1; the inner sulfur has an oxidation state of +5.



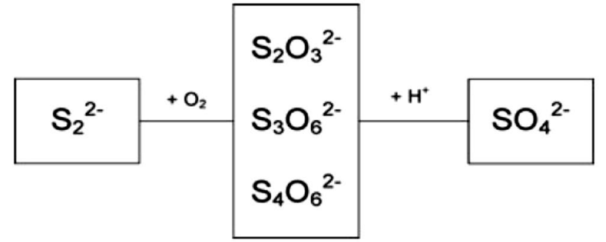


FIGURE 5. General reaction pathway of sulfide oxidation (Suzuki, 1999)

Thiosalts (polythionates): generation (1/2)

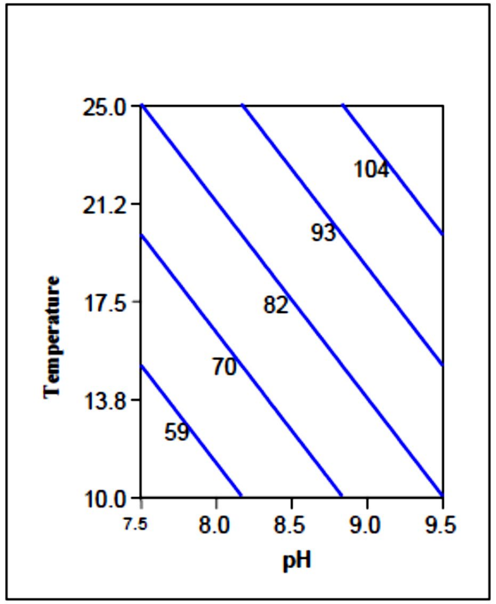


Figure 18. Effect of pH and temperature on thiosalts generation for residence time of 22 minutes

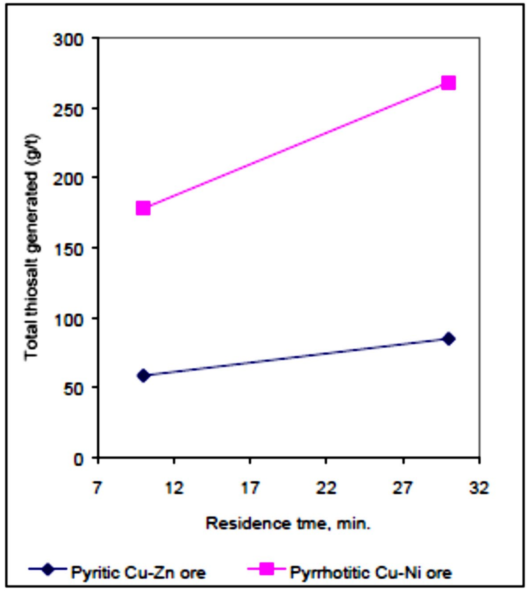


Figure 19. Effect of residence time on thiosalts generation

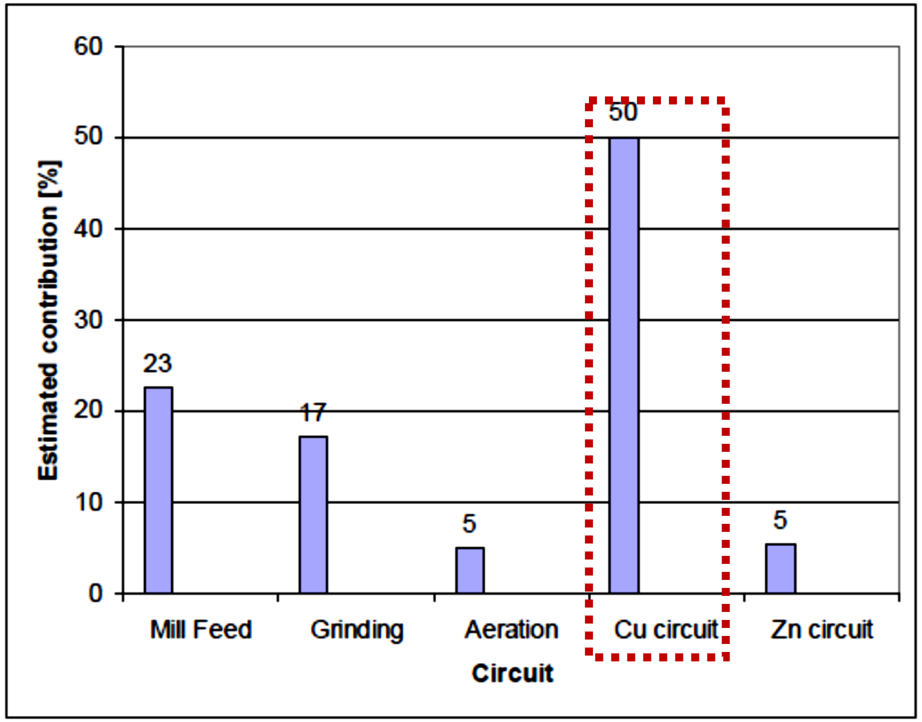


Figure 28. Distribution of the total thiosalts among the major process and the ore.

(CANMET, 1999)

Thiosalts (polythionates): generation (2/2)

- Boliden Mineral AB, Sweden

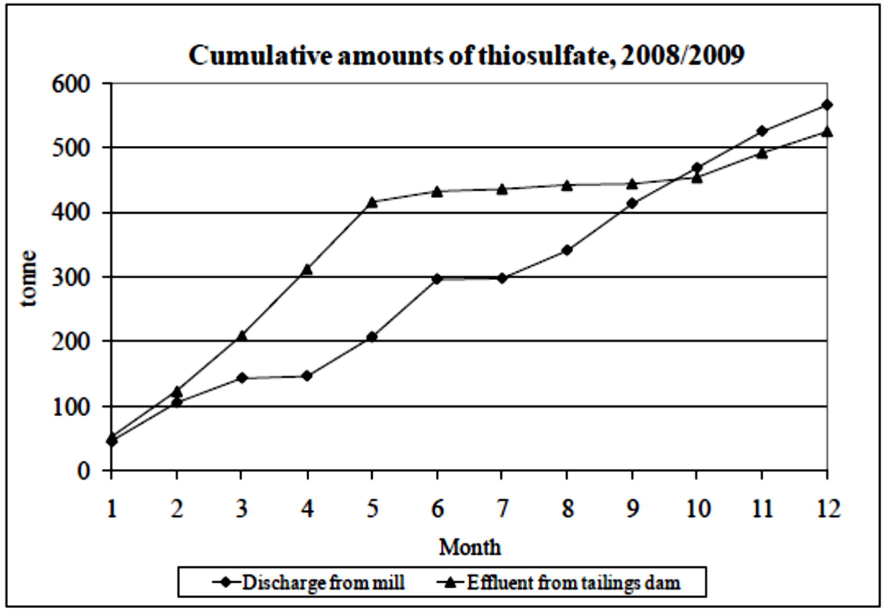


FIGURE 2.2. CUMULATIVE AMOUNTS OF THIOSULPHATE IN DISCHARGED WATER VOLUMES..

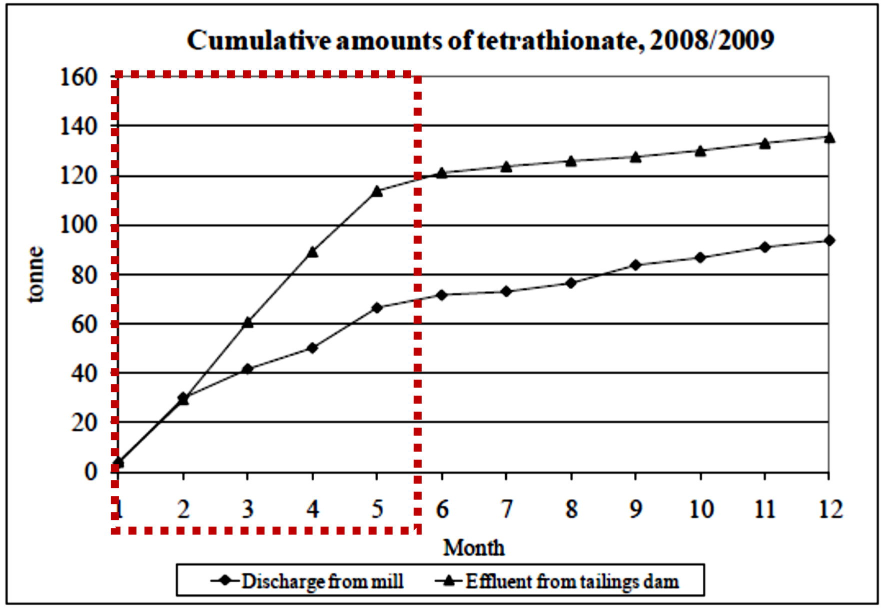


FIGURE 2.3. CUMULATIVE AMOUNTS OF TETRATHIONATE IN DISCHARGED WATERS.

(Forsberg, 2011)

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

Impact of cold on thiosalts generation: Raglan Mine, Glencore Canada

Underground Ni-Cu-Co mines, Nunavik region, QC

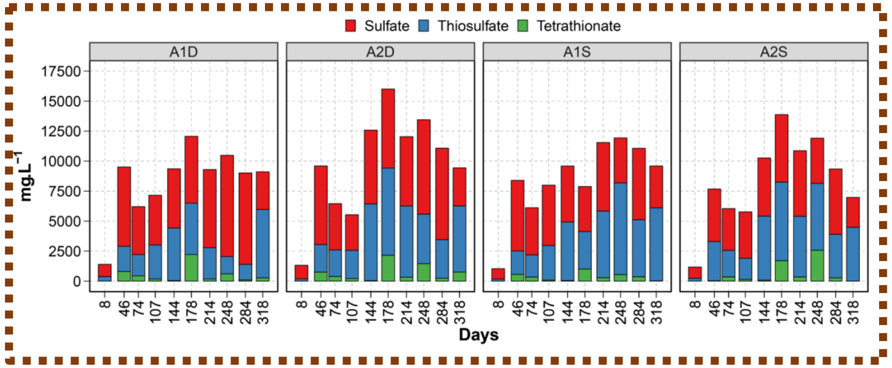
Table 1: Bulk chemistry of the Raglan tailings as determined by ICP-AES (± 10%, 1SD).

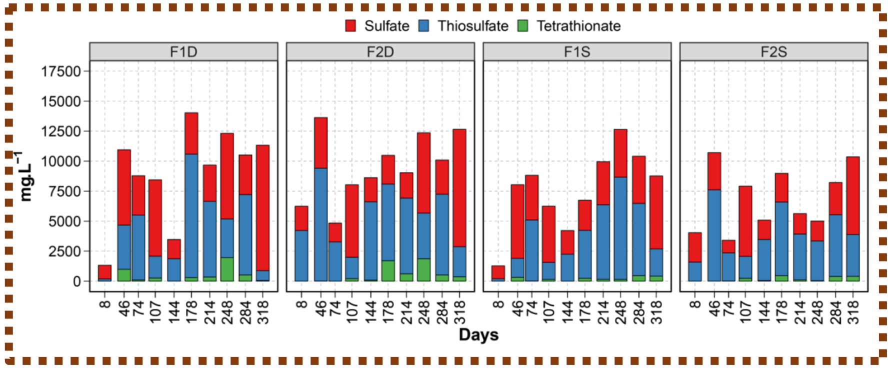
Element	Al	C[1]	Ca	Cr	Fe	K	Mg	Na	Ni	S	S[1]	Ti
%	2.3	0.22	1.4	1.51	20.7	0.46	9.49	3.2	3.17	9.4	10.8	1.17
Element	**As**	**Ba**	**Be**	**Bi**	**Cd**	**Co**	**Cu**	**Li**	**Mn**	**Mo**	**Pb**	**Zn**
ppm	< 5	114	< 5	80	37	49	631	18	671	7.74	54	110

[1] Determined by infrared absorption

- Thiosulfate
  - 170 to 7 200 mg/L ambient columns
  - **190 to 10 000 mg/L, FT columns**
- Tetrathionate
  - 8.5 to 2 200 mg/L, ambient columns
  - **7.4 to 2 600 mg/L, FT columns**
- Sulfate
  - 870 to 8 400 mg/L, ambient columns
  - **1 000 to 10 000 mg/L, FT columns**

Laboratory column leaching tests on sulfidic tailings: ambient vs arctic conditions





Concentrations of sulfate (red), thiosulfate (blue), and tetrathionate (green) in leachates from ambient (left) and **freeze/thaw (F/T)** columns (right)

Thiosalts impact on a natural stream quality

Kidd Metalurgical Mine, Timmins, ON, Canada

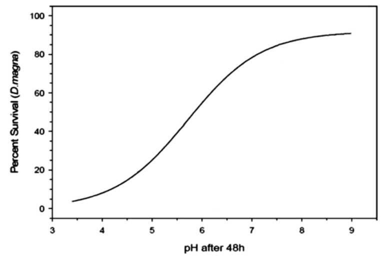


FIGURE 8. Trend for *Daphnia magna* survival as a result of pH change (modified from Schwartz et al., 2006).

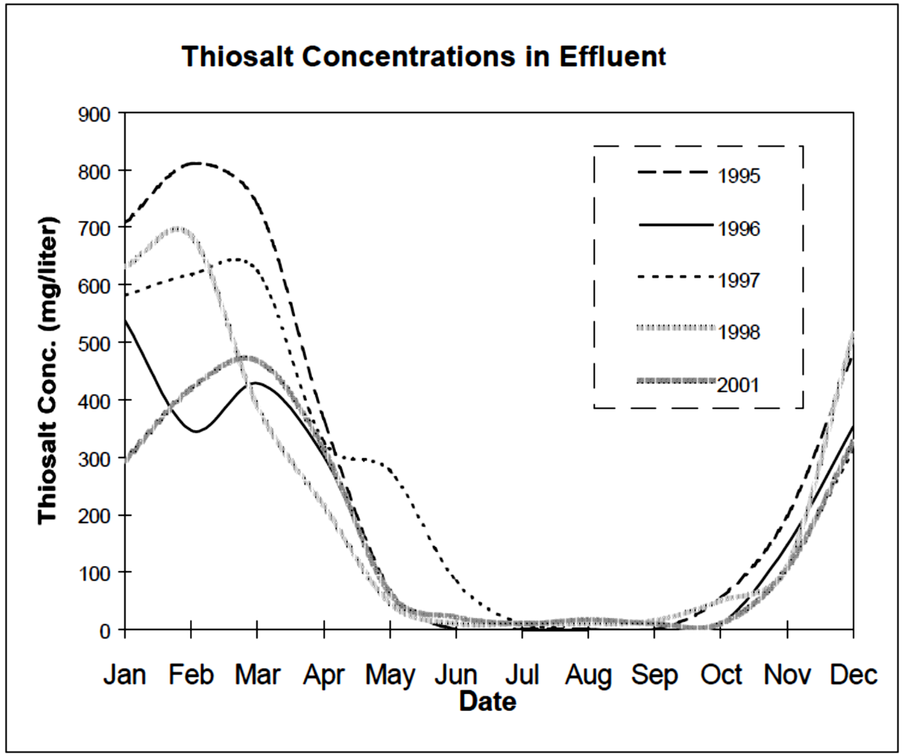


Figure 1. Thiosalt Concentration in Effluent

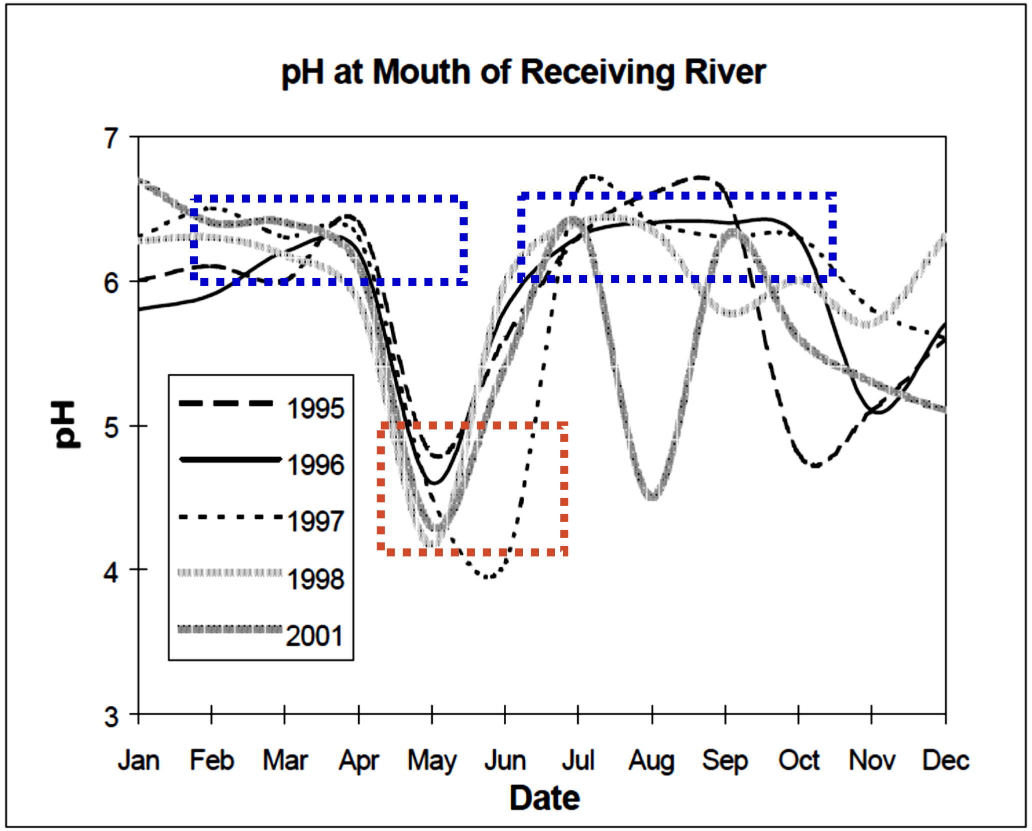


Figure 2. pH at Mouth of Receiving Stream

(Kuyucak & Yaschyshyn, 2007)

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

Canadian legislation requirements: physicochemical + toxicity

- Organisms to be exposed to whole effluent (100%, undiluted)
  - Requirement-constraint: representative of all animals in the aquatic ecosystem
  - **Objective: To prevent toxicity to aquatic life; *Daphnia magna* test = the most failed one**

Toxicity test	Organism	Latin name	Legislation
Acute	Rainbow trout	*Oncorhynchus mykiss*	D019 & MDMER
	Water flea	*Daphnia magna*	D019 & MDMER
Sublethal	Fathead minnow	*Pimephales promelas*	MDMER
	Little water flea	*Ceriodaphnia dubia*	MDMER
	Green algae	*Pseudokirchneriella subcapitata*	MDMER
	Small duckweed	*Lemna minor*	MDMER

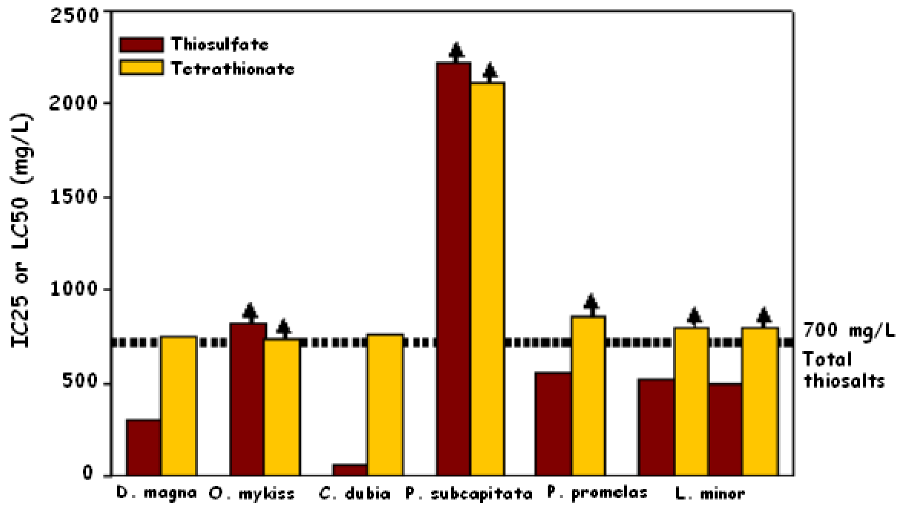
D019: Quebec's Guidelines pertaining to mine effluents discharge in natural environment (2025)

MDMER: Metal and Diamond Mining effluent Regulations (2025)

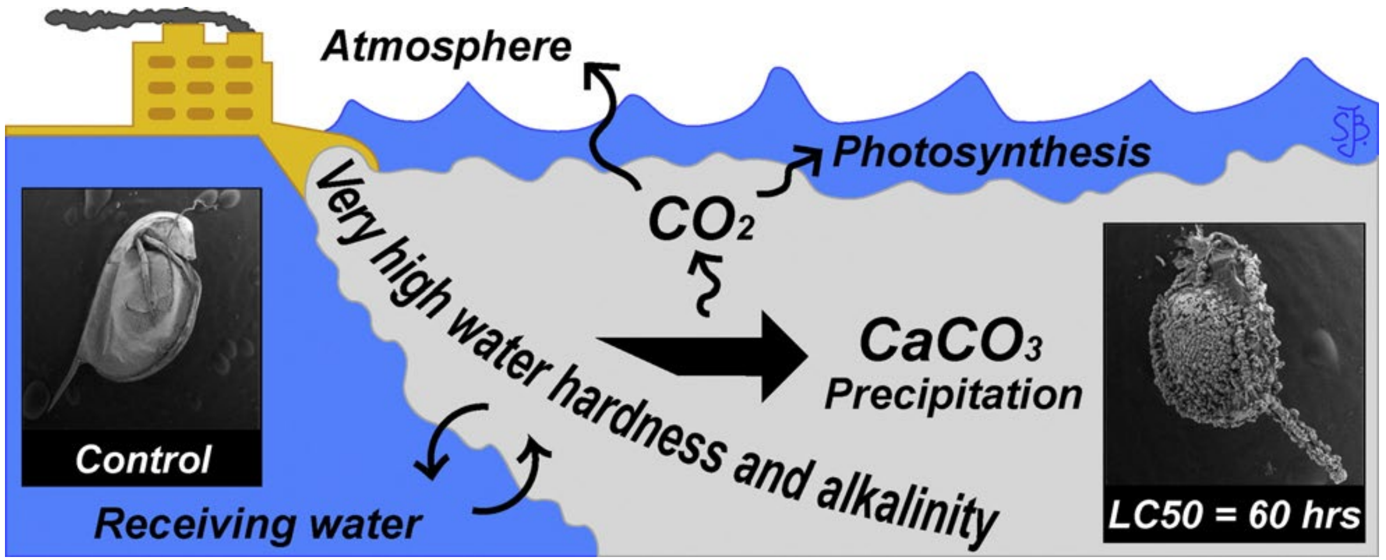
Thiosalts impact on aquatic organisms

Table 1: Toxicity Thresholds of Thiosalts Species to Various Test Organisms

Test Type	Test Organism	Thiosulphate	Tetrathionate
Acute	Rainbow trout	LC50 >800 ppm	LC50 >800 ppm
	Daphnia magna	LC50 ~300 ppm	LC50 ~750 ppm
Sublethal	*Lemna minor*	$IC25_{dry\ wt}$ = 498 ppm $IC25_{FC}$ = 525 ppm	$IC25_{dry\ wt}$ >798 ppm $IC25_{FC}$ >798 ppm
	Ceriodaphnia dubia	IC25 = 59 ppm	IC25 = 562 ppm
	Fathead minnow	IC25 = 665 ppm	IC25 >891 ppm
	Selanastrum capricornutum	IC50 >2220 ppm	IC50 >2110 ppm



- The least expensive approach
  - Correction of water pH and alkalinity (neutralize H_2SO_4)
  - **BUT undesirable effects**



(CANMET, 1999; Miranda-Trevino et al., 2013; Bogart et al., 2016)

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

Adapted treatment options

- Limit impact of cold temperature (& high salinity) of mine water
  - *FTE (freeze/thaw evaporation process)*
  - Electrocoagulation
  - Electro-Fenton
  - Microbubbles ozonation

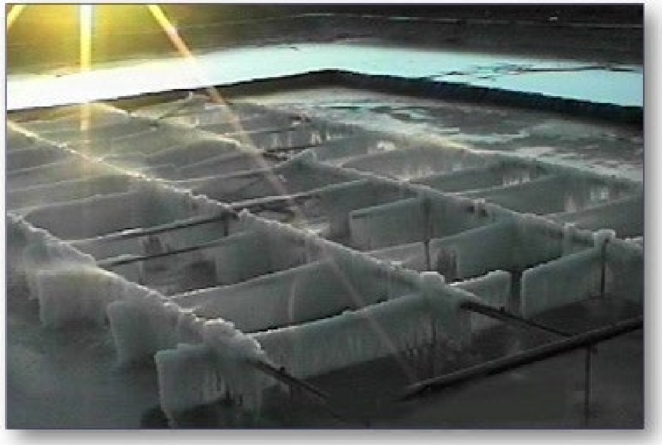
Adapted treatment options

- FTE (freeze/thaw evaporation process)
  - Clean water (snow/ice) separation from brine
  - **Brine treatment & management**
  - **Volatile contaminants fate (degradation ?)**

Constituents Removed by FTE® Process

The FTE® process has been proven in commercial operations to be capable of removing over 90% of the following types of produced water constituents:

- Total suspended solids (TSS)
- Total dissolved solids (TDS)
- Total recoverable petroleum hydrocarbons (TRPH)
- Volatile organic compounds
- Semi-volatile organic compounds
- Heavy metals



The Spray Grid System Used to Support Freezing Operations at the First FTE® Field Demonstration near Farmington, NM. (Photo Courtesy of BC Technologies, Ltd.)

Fig. 1. Photo of site layout with pump and tarp.

Fig. 2. Spray ice mound after completion.

(Biggar et al., 2005; http://www.polarbearwater.net/14273/index.html)

Adapted treatment options

- FTE (freeze/thaw evaporation process)
  - Example from a mine in Alberta, Canada

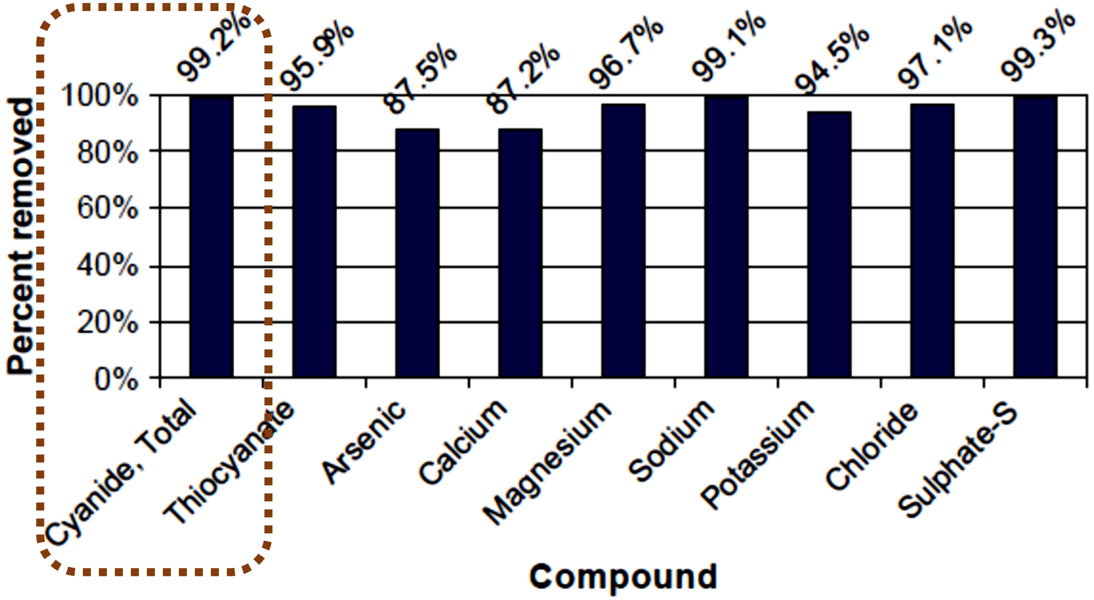


Fig. 14. Reduction in individual species concentration from supply water to melt water at 39% of core thawing.

Table 2
Comparison of average chemical concentrations (±1Standard Deviation) of supply and runoff water samples from the tailings lake

Species	Supply water (n=4) mg/L	Runoff (n=5) mg/L	Difference (%)
Cyanide, total	47±8	72±11	31
Thiocyanate	254±10	321±25	16
Arsenic	0.039±0.004	0.068±0.006	56
Calcium	27.9±2.3	35.4±4	16
Magnesium	6.1±0.6	9.3±1.4	32
Sodium	272±19	417±63	32
Potassium	7.3±0.9	10.6±1.8	27
Chloride	120±15	171±29	23
Sulphate-S	217±17	296±44	17

n=number of samples.

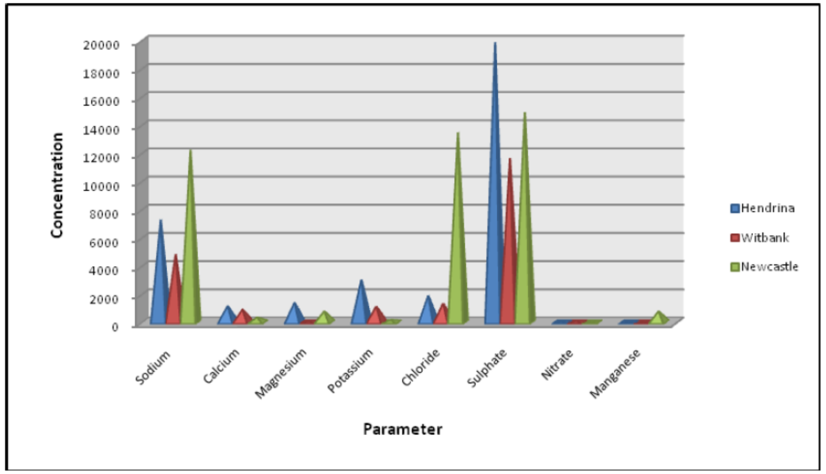


Figure 2. Composition of brine from the treatment of various coal mines.

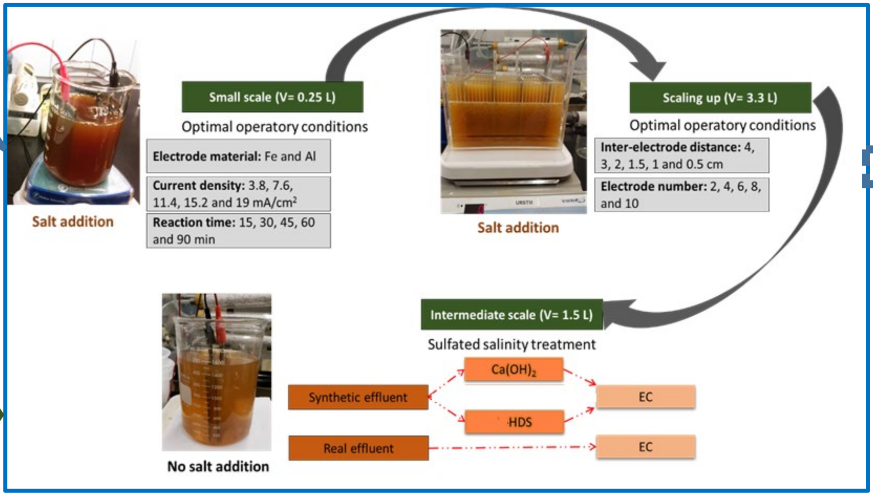
Active treatment: electrocoagulation (EC)

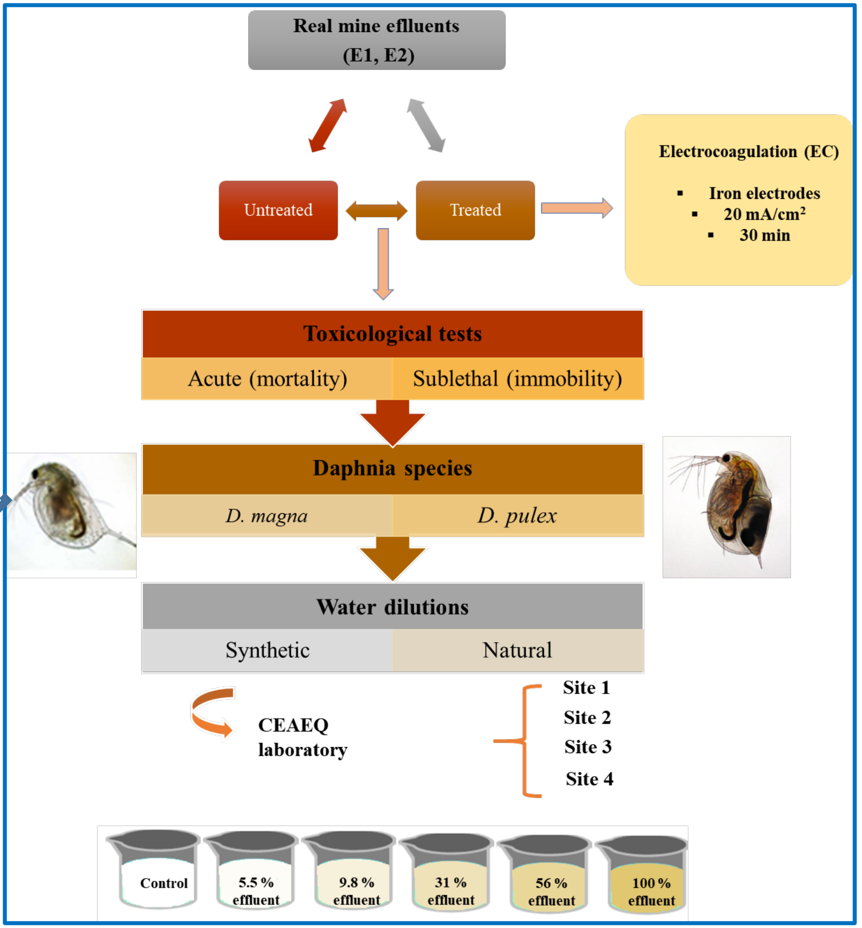
- **Salinity**

Treatment vs toxicity: EC

Effect of counterions and optimization (upscaling)

Study of the performance of the EC process, comparison with chemical precipitation





(Foudhaili et al., 2020)

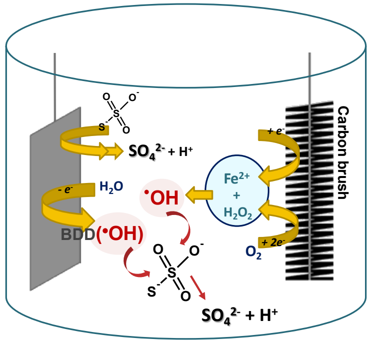
34

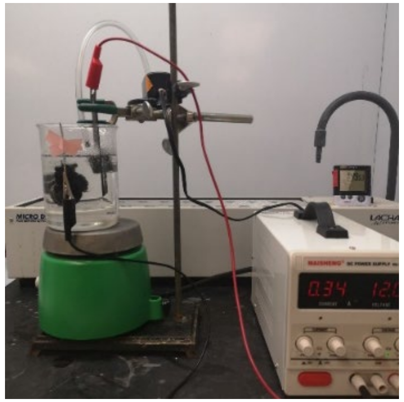
Active treatment: electro-Fenton (EF)

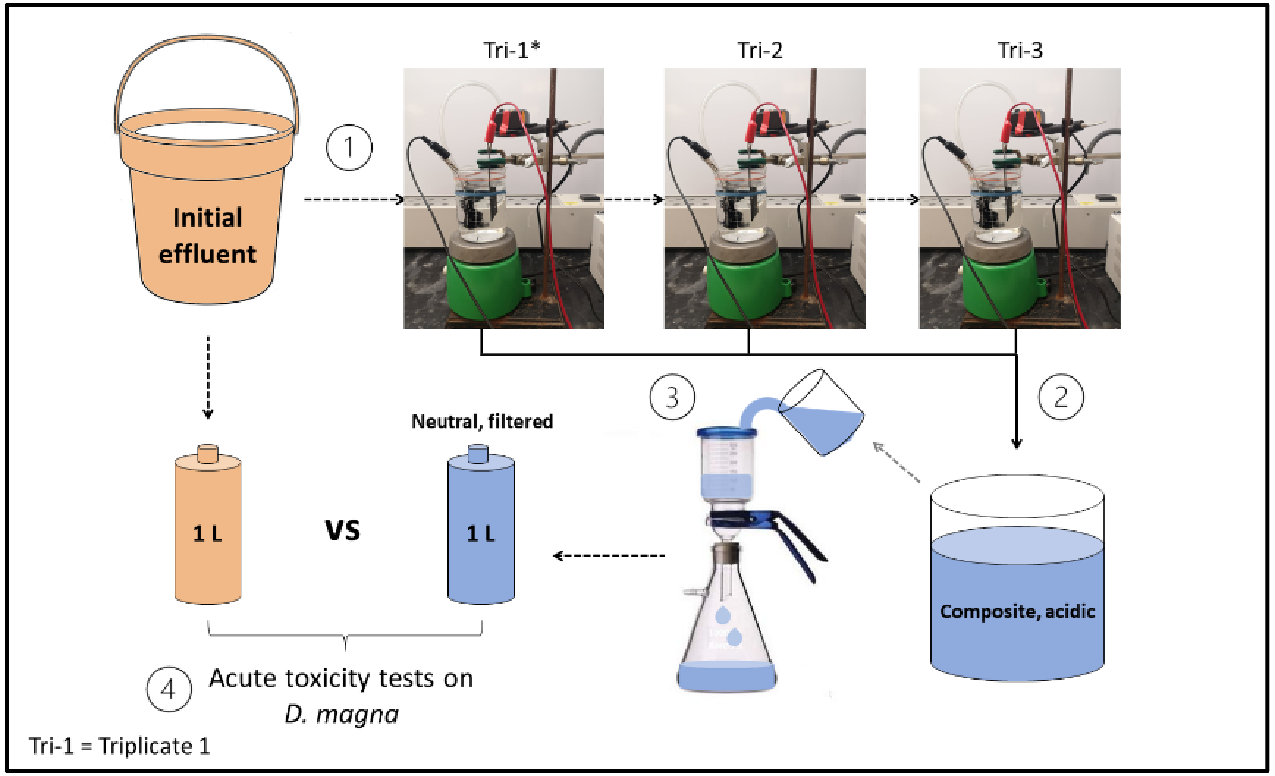
- **Thiosalts (meta-stable S oxides in water)**

Treatment vs toxicity: EF

Study of optimal operating conditions, on synthetic and real effluents

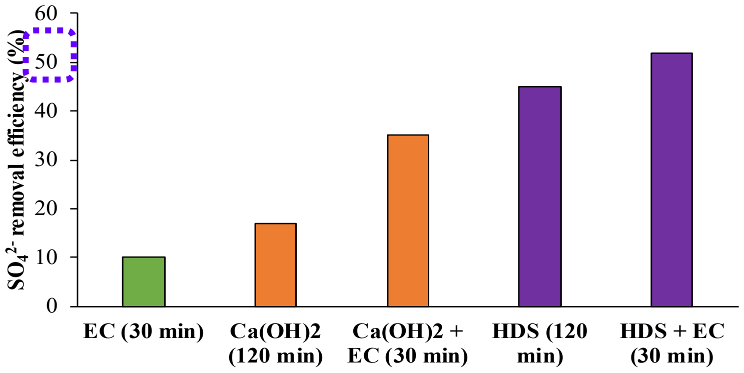




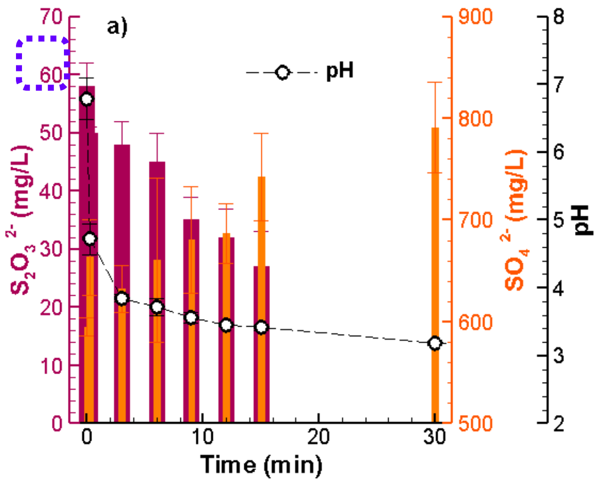


1-2 Active treatment: EC vs EF

- **Salinity vs thiosalts (meta-stable S oxides)**



- **Satisfactory efficiency**
  - Sulfated salinity via EC (left)
  - Thiosalts via EF (right)



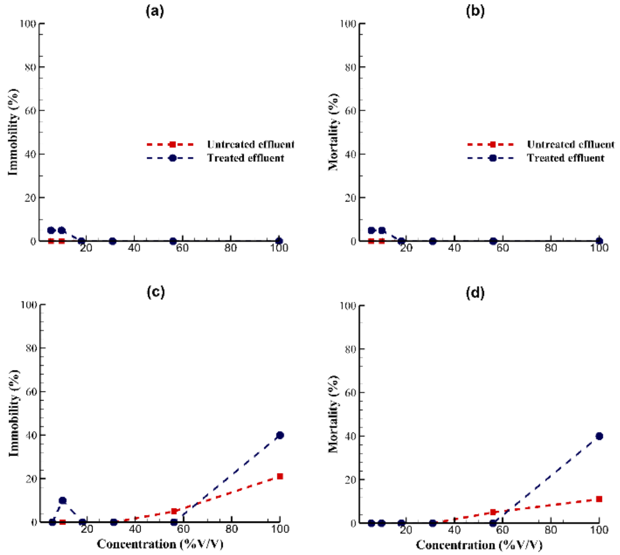


Fig. 1 Immobility and mortality evolution of untreated and treated E1 with *D. magna* (a, b) and *D. pulex* (c, d) using reconstituted hard water

- **Toxicity elimination (water flea)**
  - *Daphnia pullex* (specific for cold water): more sensitive than *Daphnia magna* (standard test)
  - Drastic, by EC & EF

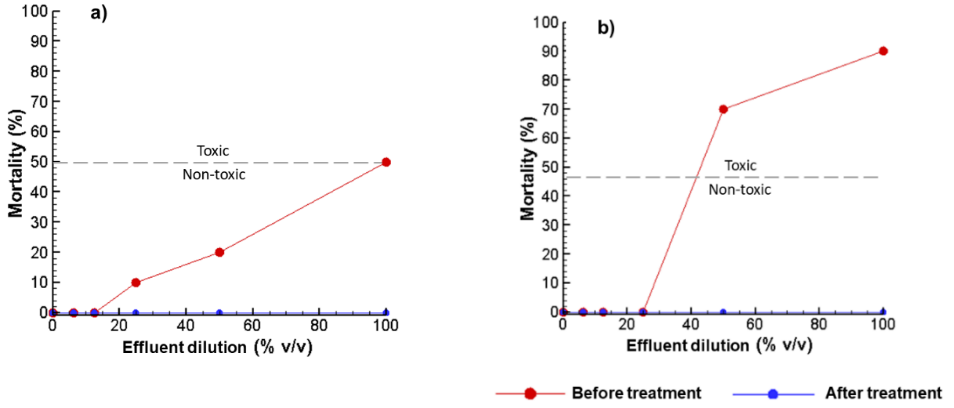


Fig. 4 Mortality evolution of *D. magna* for (un-)treated effluents (a) MEhigh and (b) MElow

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

3a

Active treatment: N-based contaminants advanced oxidation in cold water

- **Microbubbles O_3**
  - **In development**: few studies (lab)
  - **Contaminants**: redox sensitive
  - **Principle**: oxidation
  - **Performance**: variable
  - **Tests pilot-scale**: scarce
  - **Full-scale applications**: N/A

Test	Real effluents	Specifications	Efficiency (%)	$g\ O_3$/ $g\ N\text{-}NH_3$
Batch (no flow)	R	**pH 9, 20-40 mg/L NH_3-N**	27.8	242
	G		39.9	65.0
	C		84.4	51.4
	H		78.4	52.5
	I		**99.3**	**35.1**
With flow	**I**	Flow: 1.11 L/min Duration: 570 min	**99.1**	44.6

(Kunthia et al., 2015; Ryskie et al., 2020)

Lab experimental pilot: microbubbles O_3

3a

- #1: 300 L reactor (too large)
- External lab (college research center) (2015-2016)

- #2: 18 L reactor (easy to use)
- UQAT lab, since 2019

3a

Microbubbles O_3: real sole effluents

Table 1
Physicochemical characteristics (in mg/L except pH) of real effluents before treatment.

Effluent	pH	Eh (mV)	T (°C)	NH_3-N	NO_2^-	NO_3^-	OCN^-	SCN^-	Total CN^-	Cu	Fe	Mn	Zn
R	9.5	260	10	22.3	10.6	59	20.7	43	15.0	20.2	0.29	0.03	3.43
G	9.1	171	23	43.4	< 0.04	110	35.9	< 0.05	0.19	0.08	0.26	0.02	0.23
C	9.0	295	22	34.6	6	48	15.8	135	0.04	1.52	0.50	0.30	0.29
H	9.3	287	24	22.8	< 0.04	< 0.02	32.8	< 0.05	0.01	< 0.05	0.65	0.03	19.5
M	9.0	242	22	32.3	< 0.04	173	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	2.22	0.40

Table 2
Physicochemical characteristics (in mg/L, except pH) of real mine effluents after treatment.

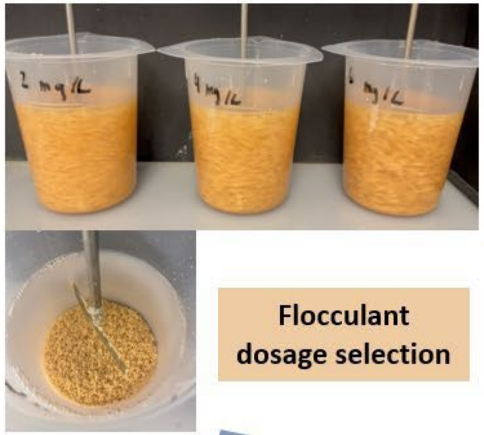
Effluent	pH	Eh (mV)	T (°C)	NH_3-N	NO_3^-	OCN^-	Total CN^-	Cu	Fe	Mn	Zn
R	8.7	350	27	16.1	125	< 0.05	0.43	0.54	0.06	0.02	5.74
G	9.2	404	40	26.1	206	27.1	0.23	0.13	0.56	0.06	0.82
C	9.3	382	36	5.4	151	12.5	0.05	< 0.05	< 0.05	0.06	< 0.05
H	9.1	404	28	4.9	99	21.9	0.01	0.06	0.41	0.16	0.70
M	9.6	534	36	0.2	275	< 0.05	< 0.05	< 0.05	< 0.05	< 0.001	0.22

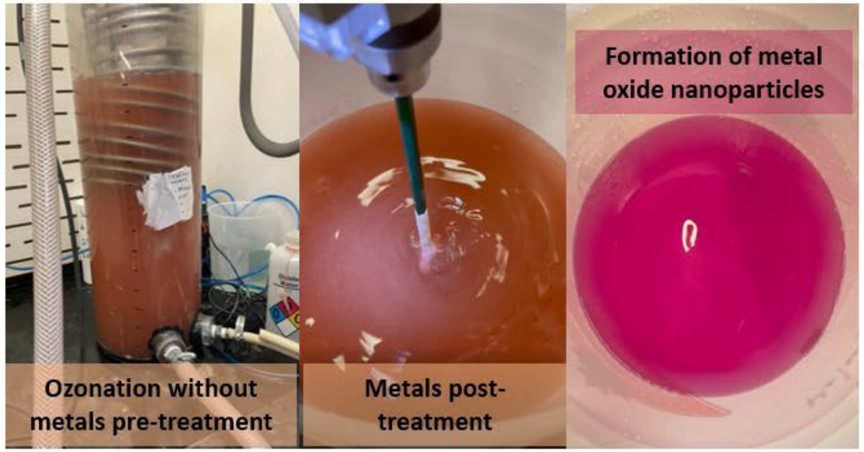
(Ryskie et al., 2020)

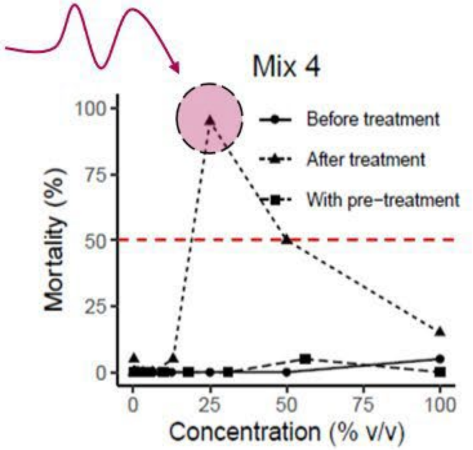
3b

Microbubbles O_3: mixed effluents

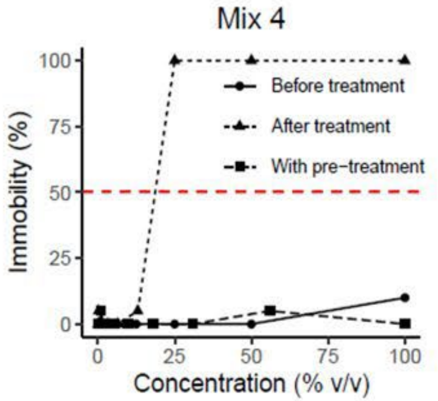
Without metal pretreatment







With metal pretreatment



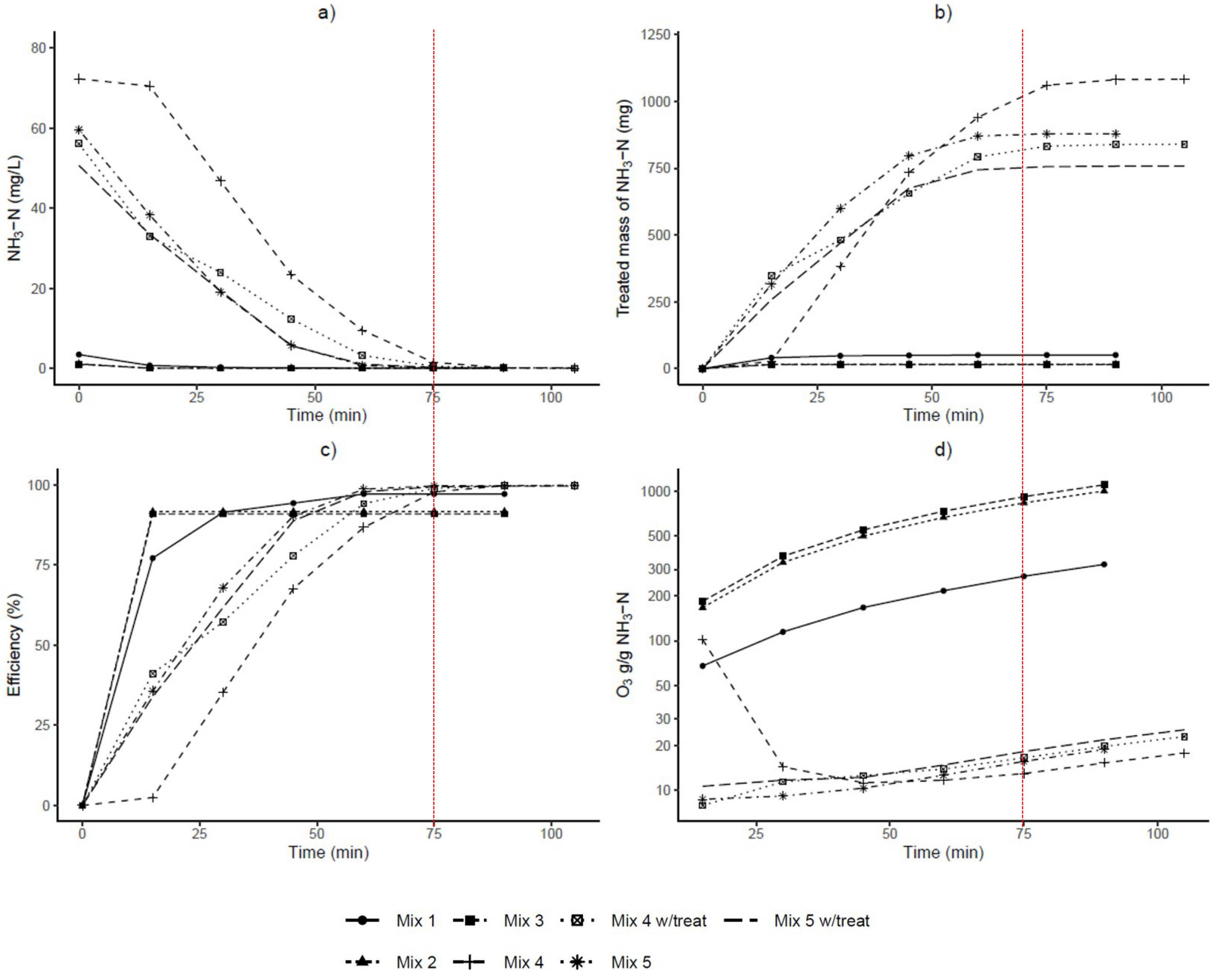
Daphnia magna bioassays

(Ryskie et al., 2023)

3b

Microbubbles O_3: mixed effluents

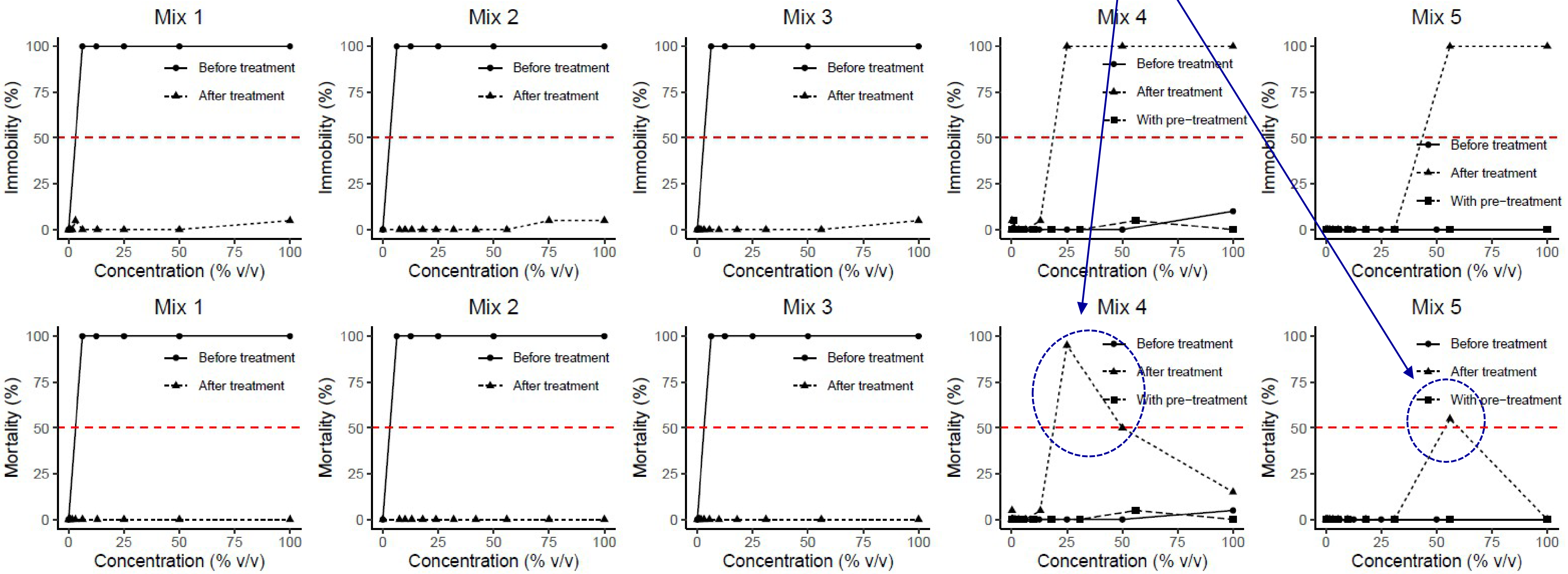
- Findings
  - Optimal residence time: **75 min**
  - Better efficiency at **higher concentrations**



3b

Microbubbles O_3: mixed effluents

Abnormal toxicity results
Possible presence of metal oxide nanoparticles
The neonates swelled & lost limbs



(Ryskie et al., 2023)

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

3b

Microbubbles O_3: mixed effluents

- Presence of metal oxide nanoparticles: may entail color development
- Toxicity at 50% dilution
- Lower hardness when the sample is diluted
- Ozonation without metal pretreatment slightly increases metal treatment efficiency but generates toxicity

→ **SO, metal pretreatment step is necessary**

(Ryskie et al., 2021)

RIME UQAT-POLYTECHNIQUE Research Institute of Mines and Environment

Passive treatment (biochemical) of mine drainage

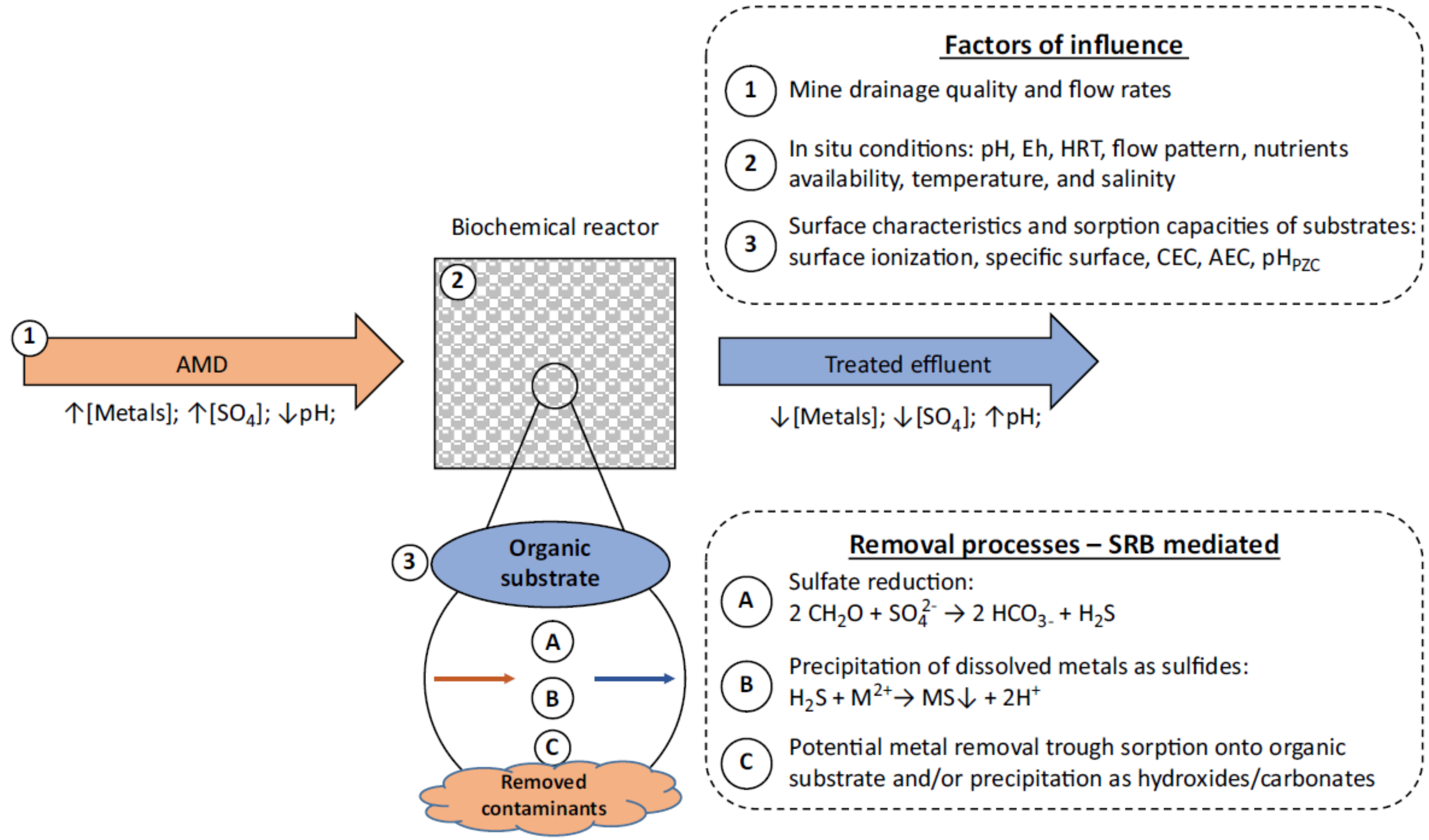


FIGURE 11.5 Scheme of a passive biochemical system for the treatment of AMD.

(Neculita et al., 2021)

Toxicity of a synthetic AMD, before vs after biochemical treatment

Table 2. Acute toxicity on rainbow trout (*Oncorhynchus mykiss*) and water flea (*Daphnia magna*) with unmodified samples from passive bioreactors[a]

Organism	Test	Sample	LC50 (%, v/v)
O. mykiss	1	10-d HRT effluent	>100
D. magna		AMD	9 (7–11)
	1	7.3-d HRT effluent	27 (22–33)
		10-d HRT effluent	44 (33–58)
	2	7.3-d HRT effluent	23 (19–29)
		10-d HRT effluent	62 (52–73)

[a] Toxicity is expressed as the 48-h median lethal concentration (LC50), with 95% confidence intervals given in parentheses. AMD = acid mine drainage; HRT = hydraulic retention time.

Table 4. Survival of cladoceran *Daphnia magna* when exposed to modified samples during toxicity identification evaluation[a]

Test	Sample	Treatment	Survival[b] (%)
1	10-d HRT effluent	Control	40 ± 26
		+ 0.238 mM EDTA	43 ± 31
		+ 0.238 mM EDTA + 1 h of aeration at pH 9.3	100 ± 0
	7.3-d HRT effluent	Control	0 ± 0
		+ 0.238 mM EDTA	0 ± 0
		+ 0.238 mM EDTA + 1 h of aeration at pH 9.3	100 ± 0
2	10-d HRT effluent	Control	23 ± 15
		+ 2 h of aeration	100 ± 0
	7.3-d HRT effluent	Control	0 ± 0
		+ 2 h aeration	0 ± 0
3	10-d HRT effluent	Control	7 ± 12
		+ 10 mg/L of NH_4^+	7 ± 12
		10 mg/L of NH_4^+ + 1 h of aeration	33 ± 42
4	Iron-only effluent[c]	Control	92 ± 1
		+ 0.238 mM EDTA	35 ± 18

[a] EDTA = ethylenediaminetetraacetic acid; HRT = hydraulic retention time.
[b] Survival refers to the proportion (%) surviving at 48 h and is presented as the mean ± standard deviation (n = 3).
[c] Reconstituted hard water plus 100 mg/L or iron.

Table 3. Sublethal toxicity on *Pseudokirchneriella* and *Lemna minor* with unmodified samples from passive bioreactors[a]

Organism	Test	Sample	IC25 (%, v/v)	IC50 (%, v/v)
P. subcapitata		AMD	1.2 (0.8–2.2)	5.3 (1.5–20.9)
	1	10-d HRT effluent	17 (12–20)	24.2 (22.6–NA)
		7.3-d HRT effluent	0.8 (0.7–1.0)	7.3 (NA–10.0)
L. minor	2	10-d HRT effluent	Frond count: 66 (52–74)	Frond count: 90.5 (82.2–99.5)
			Total dry weight: 82 (70–104)	Total dry weight: >100 (NA–NA)

[a] Toxicity is expressed as the 25 and 50% inhibition concentrations (IC25 and IC50, respectively), with 95% confidence intervals given in parentheses. AMD = acid mine drainage; HRT = hydraulic retention time; NA = not available.

(Neculita et al., 2008)

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

Toxicity of a synthetic AMD, before vs after biochemical treatment

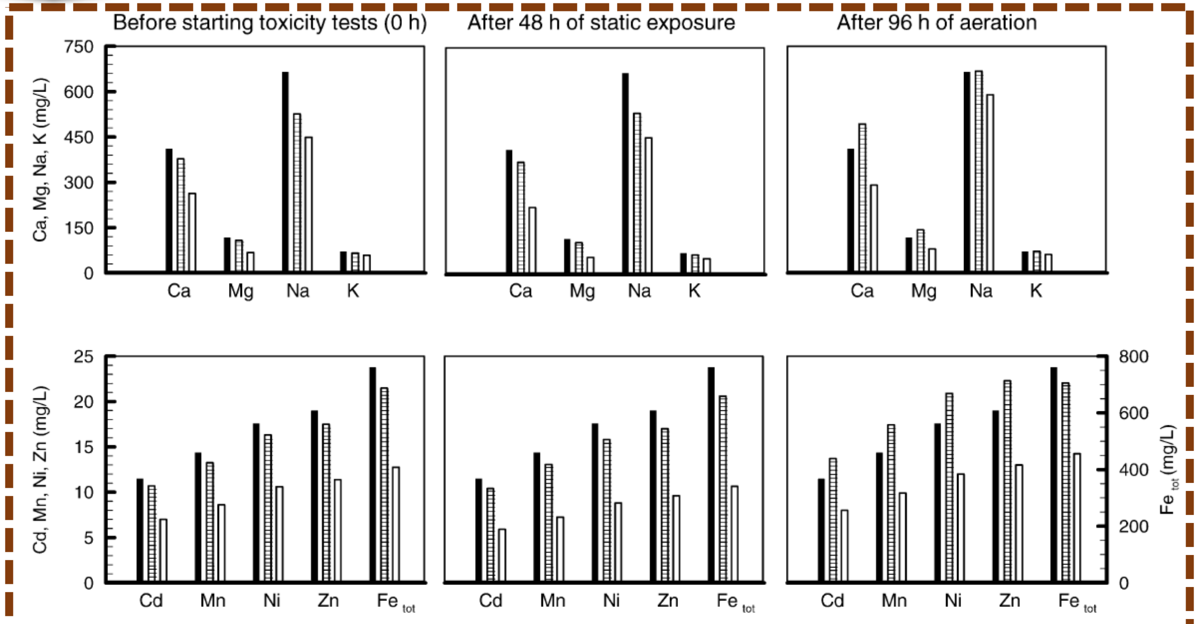


Fig. 1. Metal partitioning in highly contaminated acid mine drainage. ■ = total recoverable (unfiltered); ▤ = less-than-0.45-µm fraction; □ = less-than-1-kDa fraction.

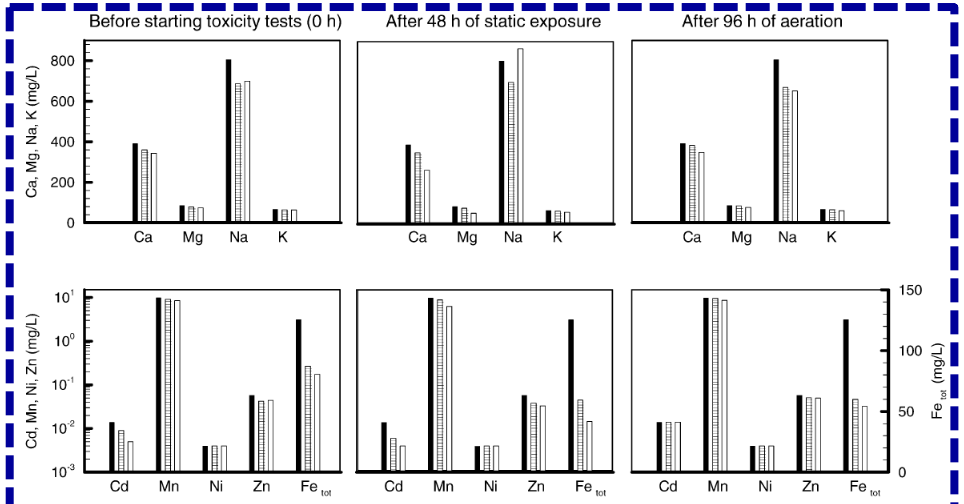


Fig. 2. Metal partitioning in treated effluent from bioreactors operated at a 10-d hydraulic retention time. ■ = total recoverable (unfiltered); ▤ = less-than-0.45-µm fraction; □ = less-than-1-kDa fraction.

10-d HRT

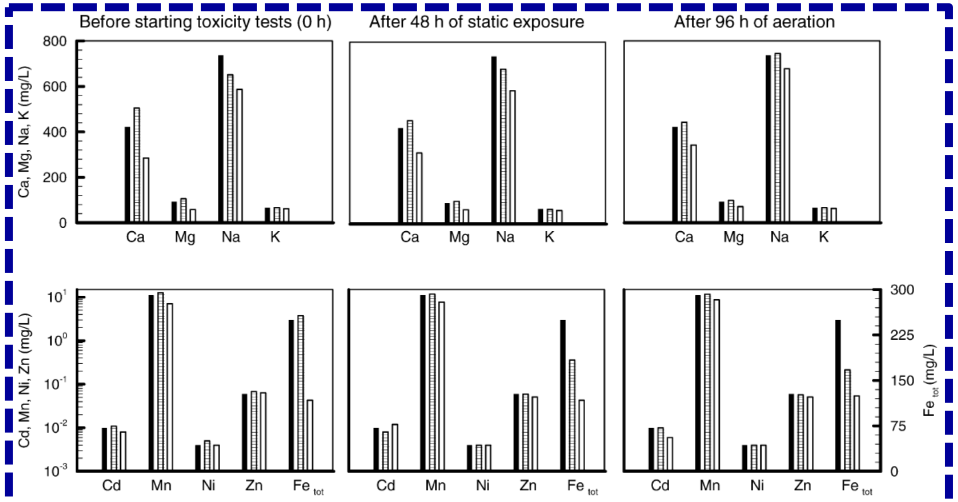


Fig. 3. Metal partitioning in treated effluent from bioreactors operated at a 7.3-d hydraulic retention time. ■ = total recoverable (unfiltered); ▤ = less-than-0.45-µm fraction; □ = less-than-1-kDa fraction.

7.3-d HRT

- Findings
  - Longer HRT: **lower aquatic toxicity**
  - BUT more hydraulic issues

(Neculita et al., 2008)

Concluding remarks

- Microbubble O_3 limits the creation of residual salinity in treated water and its aquatic toxicity during the treatment of oxidizable compounds in cold mine water
- Electro-Fenton process shows great promise in the effective treatment of thiosalts and the elimination of aquatic toxicity in cold mine water
- Treatment of contaminants of emerging interest requires adapted processes

Related ongoing & upcoming research

Scientific knowledge for informed new practical applications

- **Advanced oxidation of N- and S-based contaminants**: Is salinity role beneficial or detrimental? Is the source of thiosalts (sulfides vs collectors) of influence on toxicity? (4 MSc + 1 PDF)

Outline

- Introduction
  - Personal presentation
  - RIME – UQAT: Who we are, what we do
- Mine water: contaminants and treatment processes
  - Examples: active vs passive treatment, synthetic vs real effluents, lab vs field-scale
- Concluding remarks
- Potential collaboration opportunities

FYI: Collaborative research opportunities

- **NSERC (Natural Science & Engineering Research Council of Canada)**
  - Alliance International (Catalysts & Collaboration) grants

    (https://www.nserc-crsng.gc.ca/innovate-innover/AllianceInternational-AllianceInternational/index_eng.asp)

    - **Catalysts ($25k): supporting exploratory research activities; initiating exchanges for Canadian personnel where appropriate**
    - **Collaboration grants (up to $100k/year, up to 3 years)**
      - Alliance International Catalyst grants were launched in December 2021 to support collaborations between Canadian University researchers and international university researchers. These grants have supported collaborations with academic colleagues in over 50 different countries. The funding opportunity has seen significant demand and NSERC has awarded grants above the target of 100 Catalyst grants per year. To ensure the continued impact and relevance of this funding opportunity, NSERC is pausing the intake of Catalyst grants as of October 16, 2024 at 8:00 pm (ET) until further notice to review and refine the objectives and optimize processes. Applications received by October 16, 2024 will be processed but applicants should expect a delay in funding decisions. Regular application limits still apply (one (1) Catalyst application in a 12-month period). Award decisions will be subject to the availability of funds and may include a random selection process. NSERC will communicate when the funding opportunity re-opens.

FYI: Collaborative research opportunities

- **NSERC (Natural Science & Engineering Research Council of Canada)**
  - Discovery grants

    (https://www.nserc-crsng.gc.ca/professors-professeurs/grants-subs/dgigp-psigp_eng.asp)

    - **Renewable every 5 years, on merits of excellence, variable amount**
      - promoting and maintaining a diversified base of high-quality research capability in the natural sciences and engineering in Canadian universities
      - fostering research excellence
      - providing a stimulating environment for research training

References

1. Biggar, K.W., Sego, D.C., Donahue, R., Johnson, M. (2003) Colomac Mine Tailings Lake Spray Freezing Research Project Report. Report submitted to Public Works and Government Services Canada, Environmental Services Division Prairie and Northern Regions. Dated, 30p.
2. Bogart, S.J., Woodman, S., Steinkey, D., Meays, C., Pyle, G.G. (2016) Rapid changes in water hardness and alkalinity: Calcite formation is lethal to *Daphnia magna*. *Science of the Total Environment* 559: 182-191.
3. CANMET (2009) Evaluating the potential for thiosalts to contribute to toxicity in mine effluents. Report MMSL 06-053, 101p.
4. Dama-Fakir, P., Toerien, A. (2009). Evaporation rates on brine produced during membrane treatment of mine water. International Mine Water Association, 5p.
5. **Dubuc, J. (2022) Performance evaluation of electro-Fenton for thiosalts treatment in mine effluents. MSc thesis (English), RIME, UQAT, 174p** (https://publications.polymtl.ca/10311/)
6. Dubuc, J., Coudert, L., Lefebvre, O., Neculita, C.M. (2022) Electro-Fenton treatment of contaminated mine water to decrease thiosalts toxicity to *Daphnia magna*. *Science of the Total Environment* 835: 155323.
7. **Foudhaili, T. (2019) Traitement de la salinité sulfatée et de la toxicité associée des effluents miniers au moyen de l'électrocoagulation. PhD thesis, RIME, UQAT, 244p** (https://publications.polymtl.ca/3999/)
8. Foudhaili, T., Jaidi, R., Neculita, C.M., Rosa, E., Triffault-Bouchet, G., Veilleux, E., Coudert, L., Lefebvre, O. (2020) Effect of the electrocoagulation process on the toxicity of gold mine effluents: A comparative assessment of *Daphnia magna* and *Daphnia pulex*. *Science of the Total Environment* 708: 134739.
9. Kuyucak, N., Yaschyshyn, D. (2007) Managing thiosalts in mill effluents: studies conducted at the Kidd Metallurgical Site. Mining and the Environment Conference, Sudbury, ON, 10p.
10. Miranda-Trevino, J.C., Pappoe, M., Hawboldt, K., Bottaro, C. (2013) The importance of thiosalts speciation: review of analytical methods, kinetics, and treatment. CREST, 43: 2013-2070.
11. Neculita, C.M., Zagury, G.J., Bussière, B. (2021) Passive treatment of acid mine drainage at the reclamation stage. In: Hard Rock Mine Reclamation: From Prediction to Management of Acid Mine Drainage. Bussière, B., Guittonny, M. (Eds.), CRC Press, pp. 271-296.
12. **Neculita, C.M. (2008) Traitement biologique passif du drainage minier acide : sources de carbone, mécanismes d'enlèvement des métaux et écotoxicité. PhD thesis (French & English), Mineral Engineering, Polytechnique Montreal, 244p** (https://publications.polymtl.ca/8117/)
13. Neculita, C.M., Vigneault, B., Zagury, G.J. (2008) Toxicity and metal speciation in acid mine drainage treated by passive bioreactors. *Environmental Toxicology and Chemistry* 27(8): 1659-1667.
14. **Ryskie, S. (2023) Caractérisation et traitement des contaminants émergents dans les effluents miniers. PhD thesis (French & English), RIME, UQAT, 203p** (https://publications.polymtl.ca/53398/)
15. **Ryskie, S. (2017) Traitement de l'azote ammoniacal dans les effluents miniers contaminés au moyen de procédés d'oxydation avancée. MSc thesis (French), RIME, UQAT, 129p** (https://publications.polymtl.ca/2486/)
16. Ryskie, S., Bélanger, E., Neculita, C.M., Couture, P., Rosa, E. (2023) Influence of ozone microbubble enhanced oxidation on mine effluent mixes and *Daphnia magna* toxicity. *Chemosphere* 329:138559.
17. Ryskie, S., Gonzalez-Merchan, C., Neculita, C.M., Genty, T. (2020) Efficiency of ozone microbubbles for ammonia removal from mine effluents. Minerals Engineering 145: 106071.
18. Sanchez-Andrea, I., Sanz, J.L., Bijmans, M.F.M., Stams, A.J.M. (2014) Sulfate reduction at low pH to remediate acid mine drainage. Journal of Hazardous Materials, 269: 98-109.
19. Sánchez-Andrea, I, Stams, A.J.M., Weijma, J., Gonzalez Contreras, P., Dijkman, H., Rozendal, R.A., Johnson, D.B. (2016) A case in support of implementing innovative bio-processes in the metal mining industry. FEMS Microbiology Letters, 363.

RIME
UQAT-POLYTECHNIQUE
Research Institute of Mines and Environment

Děkuju!

RIME

UQAT-POLYTECHNIQUE

Research Institute of Mines and Environment

Thank you!

Merci!

UQAT Université du Québec en Abitibi-Témiscamingue

Polytechnique Montréal

Chaires de recherche du Canada / Canada Research Chairs

Canada

CRSNG NSERC

Fonds de recherche sur la nature et les technologies Québec

Ressources naturelles et Forêts Québec

Fondation UQAT

Agnico Eagle

IAMGOLD Corporation

Mine Canadian Malartic

mitacs

Mine Raglan une compagnie Glencore

Newmont Goldcorp

RioTinto