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Taking into account final mining wastes in LCA: How to quantify the impacts of tailings?

S. Muller¹, A. Lassin¹, F.Lai¹, S. Guignot¹

LCM 2019

3rd September 2019

Session: Metals industry in a sustainable world – chances and challenges

1: BRGM

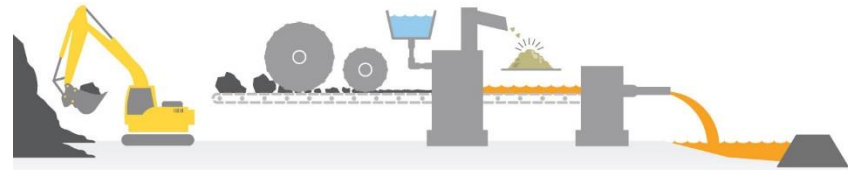


Géosciences pour une Terre durable

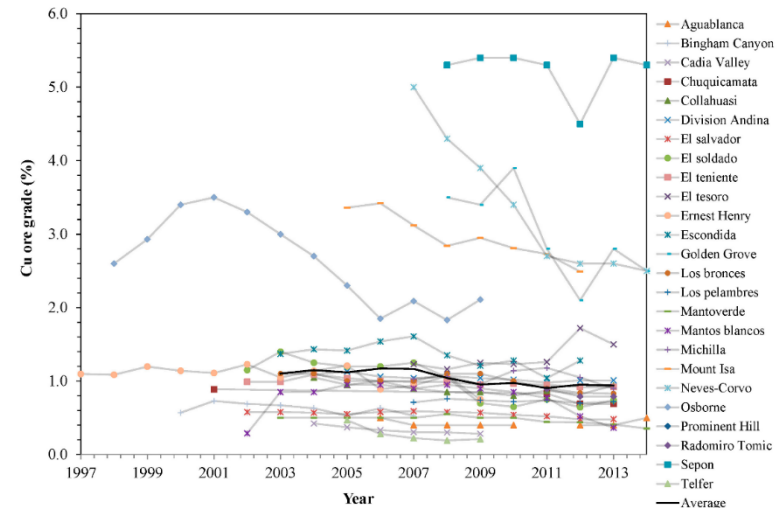
brgm

Context and objectives: tailings generation

- Tailings: ground rock + process water that are generated in a mine processing plant
- In 2014: the EU generated more than 700 million tons of waste in the mining and quarrying sector
- This figure might increase
 - From 2003 to 2013: combined weighted decrease of copper ore grades was 25%
- Environmental impacts of tailings
 - Long term emissions
 - Associated risk



<https://www.wsj.com/articles/brazils-samarco-disaster-mining-dams-grow-to-colossal-heights-and-so-do-the-risks-1459782411>



Calvo et al., 2016

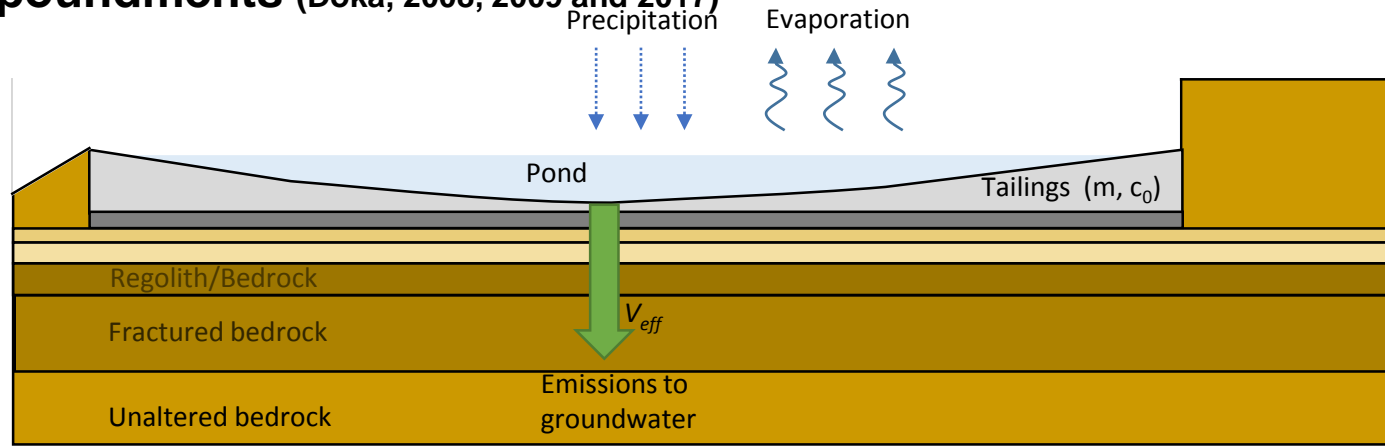


<https://watchers.news/2019/01/26/tailings-dam-collapse-brumadinho-minas-gerais-brazil/>

Tailings considerations in LCA

- Few LCA studies focus specifically on tailings management
 - Have access to **site-specific data**
 - Leaching obtained by standard tests (Song et al., 2017) or lab experiments (Reid et al. 2009)
 - Tailings management contribute the most to **human toxicity** and **marine ecotoxicity** when include in metal production (Song et al., 2017)
 - Tailings impacts contribution highly depends on **temporal perspective** (Beylot and Villeneuve, 2017)
- When looking at theecoinvent database
 - All metal production datasets model tailings based on the same unit processes
 - Only uncertainty factors differ to take into account the context of the dataset
 - Distinction between sulfidic and non sulfidic tailings

Developed by Gabor Doka for landfills and adapted for tailings impoundments (Doka, 2008, 2009 and 2017)

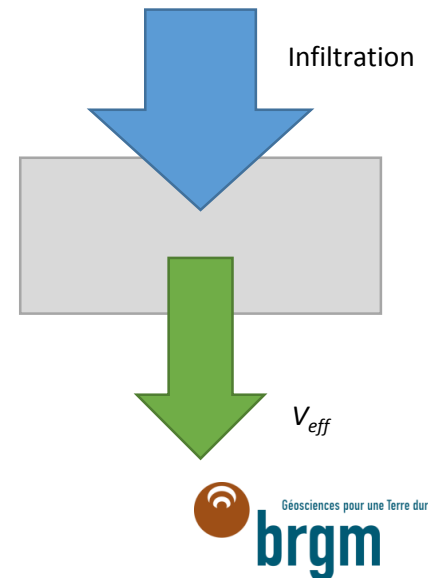


Expression of transfert coefficients following a first order kinetics equation:

$$TK(t) = TK_{\infty} \left[1 - \exp \left(- \frac{V_{eff} * c_0}{m * TK_{\infty}} * t \right) \right]$$

with TK_{∞} : fraction of the observed element (in the solid) that can be emitted (100% by default)

and V_{eff} : Effective leachate volume (depends on climatic conditions, tailings height and density)



Developed by Gabor Doka for landfills and adapted for tailings impoundments (Doka, 2008, 2009 and 2017)

- Generic transfert coefficients determined for each element based on literature data
- Development of an « average » tailings, with:
 - an average initial tailings composition
 - an average initial leaching concentration
 - average tailings and meteorological characteristics
 - the assumption that all metals are leached on an infinite time frame
- Huge uncertainty factors are associated to the generic transfer coefficients
- Developed based on a first order kinetics that do not consider all physical and chemical interactions occurring in the tailings and in the surroundings

A tool to assess long-term tailings emissions

Reactive transport modeling aims at understanding the distribution in space and time of chemical reactions occurring in a specific environment

Depends on mass transport, heat transport and geochemical reactions

Development of databases and softwares

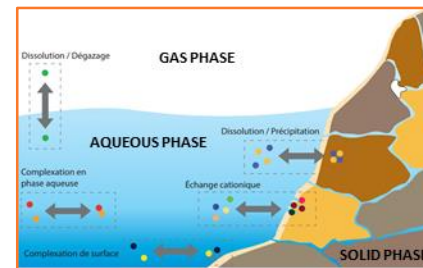
Thermodynamics (mass action laws):
 $AB \leftrightarrow A^+ + B^-$ with $K = [A^+][B^-]/[AB]$

Kinetics:
 $dm_{AB}/dt = k e^{-E/RT} (1 - [A^+][B^-]/K)$

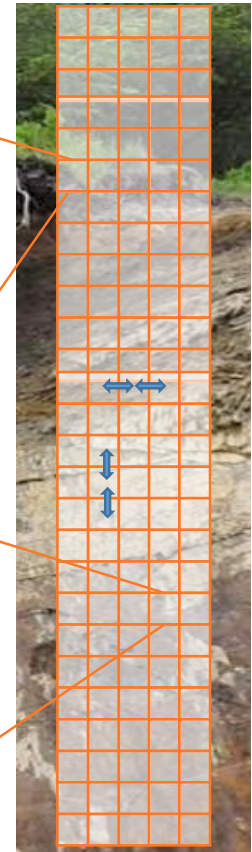
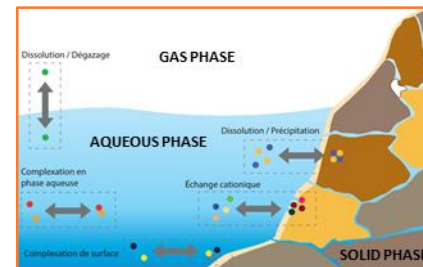
K (aqueous species, minerals, gases)
k, E (minerals)

Databases

Fluid flows & mass transport



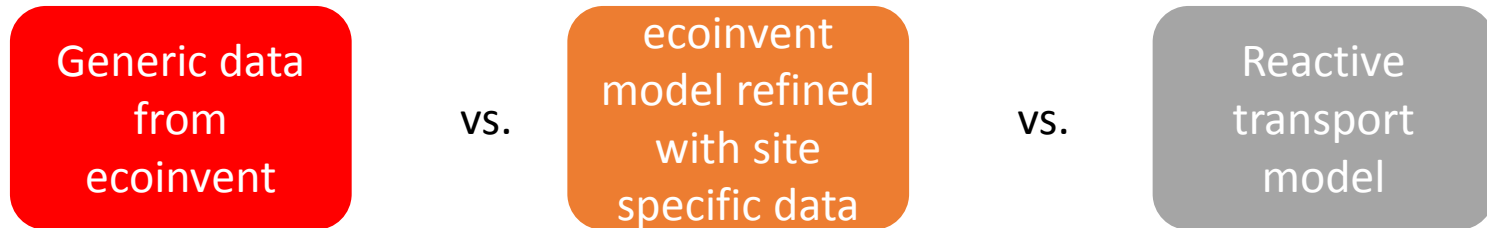
Chemical interactions



Case study: Presentation and specific data acquisition

- Emissions resulting from the treatment of 1 kg of sulfidic tailings on a 100 years timeframe
 - resulting from the exploitation of a copper-nickel ore body in Europe

- Comparison between:

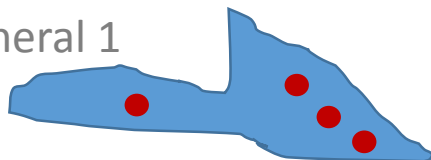


- Site specific data obtained from:
 - The mine operator
 - Climatic conditions, hydraulic properties
 - Sampling campaigns on the mine site
 - Tailings composition, water composition

Original tailings composition

Element	Symbol	mass (g_element / kg_tailings)
Sulfur	S ●	5.24
Copper	Cu	5.20
Silicon	Si	197.11
Iron	Fe	159.14
Calcium	Ca	91.11
Aluminium	Al	12.34
Potassium	K	4.29
Magnesium	Mg	87.72
Sodium	Na	0.60

Mineral 1



Mineral 2



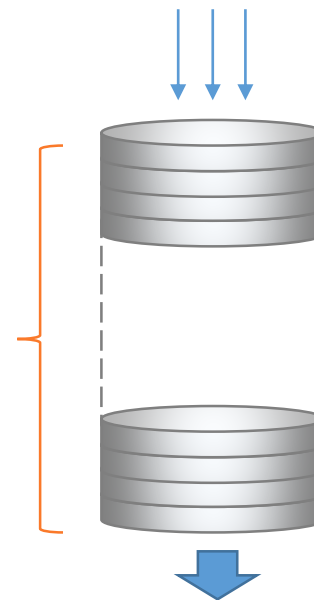
1D column of tailings

- To estimate the flows of chemical compounds at the outlet of the tailings
- Geochemical calculation code = **PhreeqC** with **Thermoddem**
(Thermodynamic and kinetic database: <http://thermoddem.brgm.fr/>)

Conceptual model

Simulation over a period of 100 years
(1200 time steps)

100 cells
Total length ~ 2m



Input

Rainwater:

- net infiltration: 10^{-8} m/s
- O₂, CO₂, pH

In every cell:

- Tailings mineralogy
- Groundwater chemistry
- Porosity

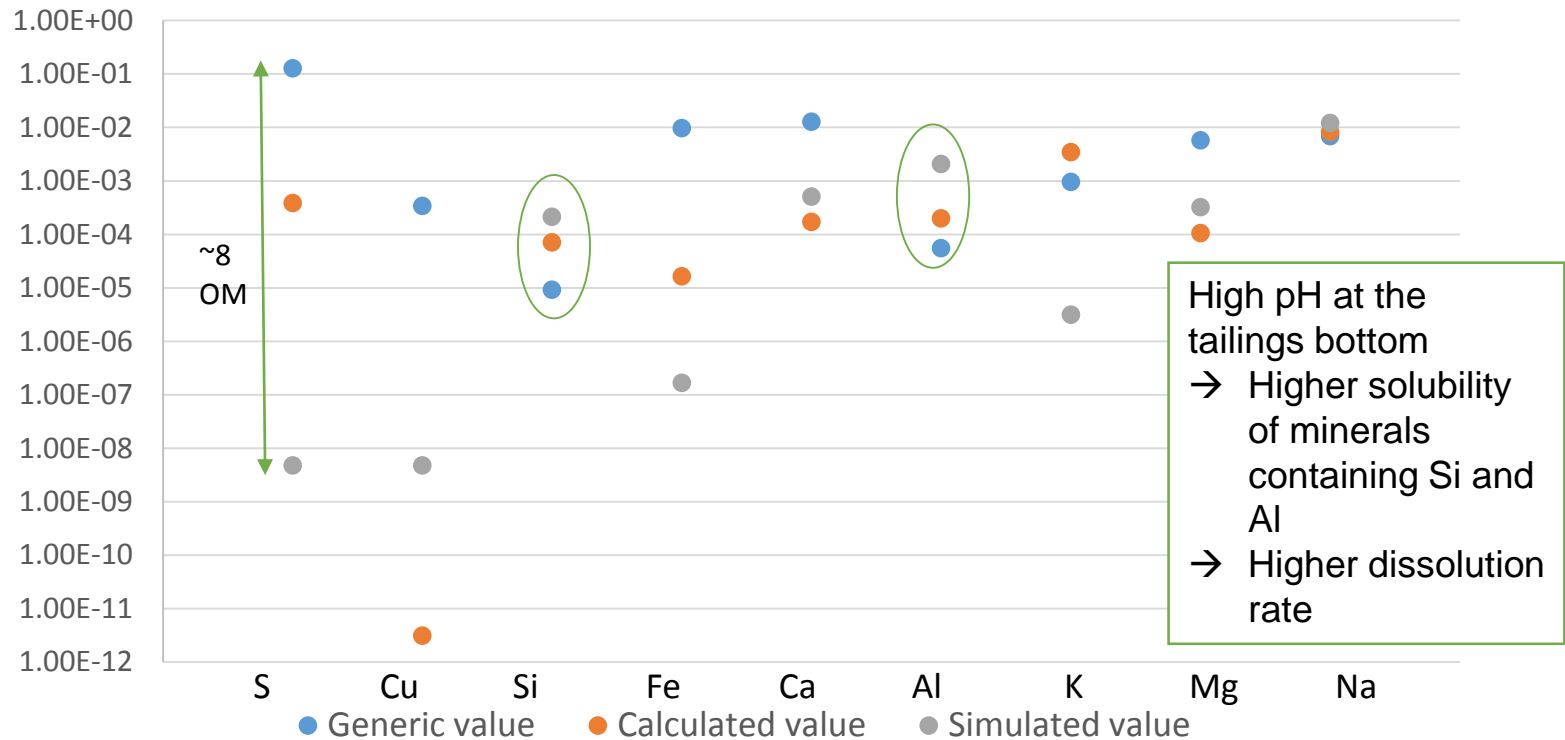
Output:

- Aqueous concentrations
- Mineralogical evolution

PhreeqC: Parkhurst and Appelo (2013)
Thermoddem: Blanc et al. (2012)

Resulting transfert coefficients – 100 years timeframe

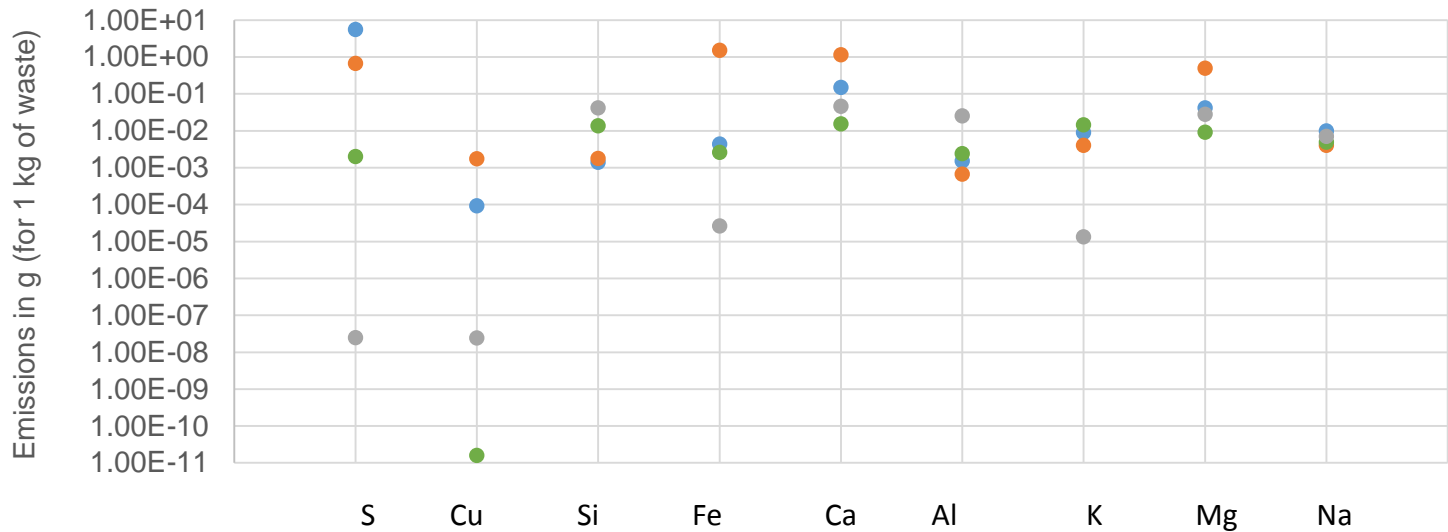
TK(100) - Leaching fraction after 100 years



- Overall, generic data overestimate the simulated leached fraction
- Differences between calculated and simulated values can be explained by the consideration of kinetics and thermodynamics
- Differences between generic and calculated data come from site specific considerations

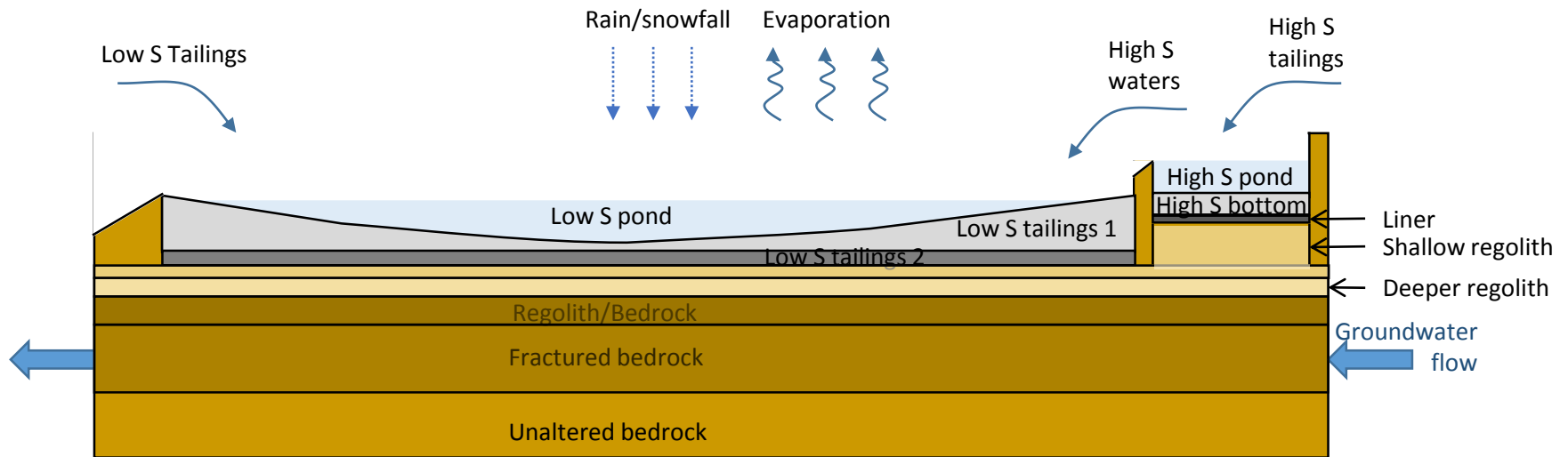
Differences that have an impact on resulting emissions

Emissions on a 100 years timeframe : $m_e * TK(100)$



- Generic value, as in ecoinvent
- Generic transfer coefficients, specific waste composition
- Calculated transfer coefficients, specific waste composition
- Simulated value

For a more realistic estimation of the emissions



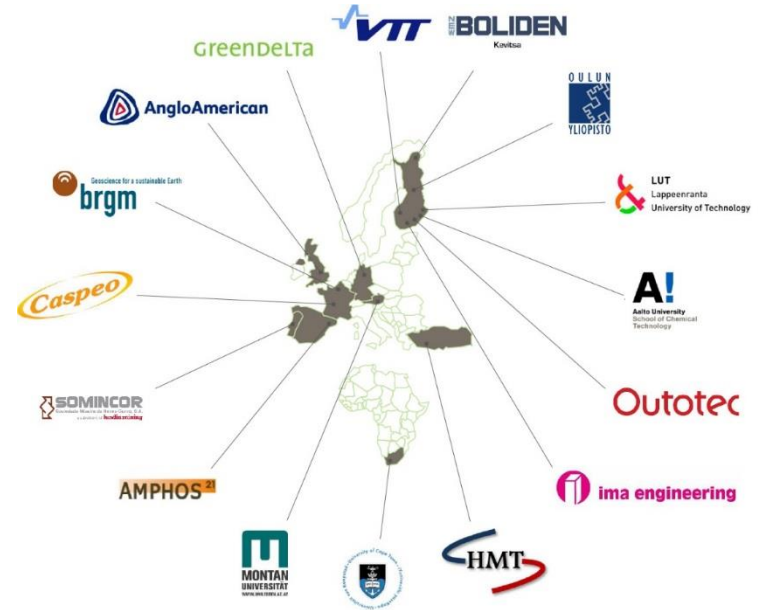
And then:

- Consideration of a **longer temporal perspective**
- Resulting emissions and **associated impacts compared** to the whole life cycle of metals production

- Tailings emissions depend on:
 - Tailings composition
 - Characteristics of the surroundings (climatic conditions, water and soil properties, groundwater flow,....)
 - Generic values may overestimate the emissions especially when considering a specific temporal perspective
- Reactive transport modelling can provide more reliable results....
 - By accounting for the influence of the chemical reactivity of the elements
- ... But rely on on-site specific data
 - Hydraulic properties
 - Tailings composition and tailings pond geometry
 - Climatic conditions,...

- If emissions are site-specific, so are characterization factors
 - Generic and regional characterization in USEtox might differ by some orders of magnitude
 - A “groundwater” compartment is missing in USEtox
 - Only few metal species are characterized (Cu, Al and Fe)
- How these potential emissions compare themselves to existing legal limits (e.g. drinking water limits)?
- These are emissions when the mine closure is well managed, risks considerations are not taken into account here

- Integrated Mineral Technologies for More Sustainable Raw Material Supply
- Addresses H2020 issue “Sustainable selective low impact mining”
- 3 years: 1.6.2017 – 31.5.2020
- 7.9 M€ budget
- 16 partners



Project’s ambition: to develop and obtain a new paradigm proof of concept at mines sites to:

- recycle water
- value tailings
- improve environmental and economic results to enable future sustainable mineral supply in Europe.

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<https://doi.org/10.3390/resources5040036>.

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Thank you for your attention

s.muller@brgm.fr

a.lassin@brgm.fr

1: BRGM



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