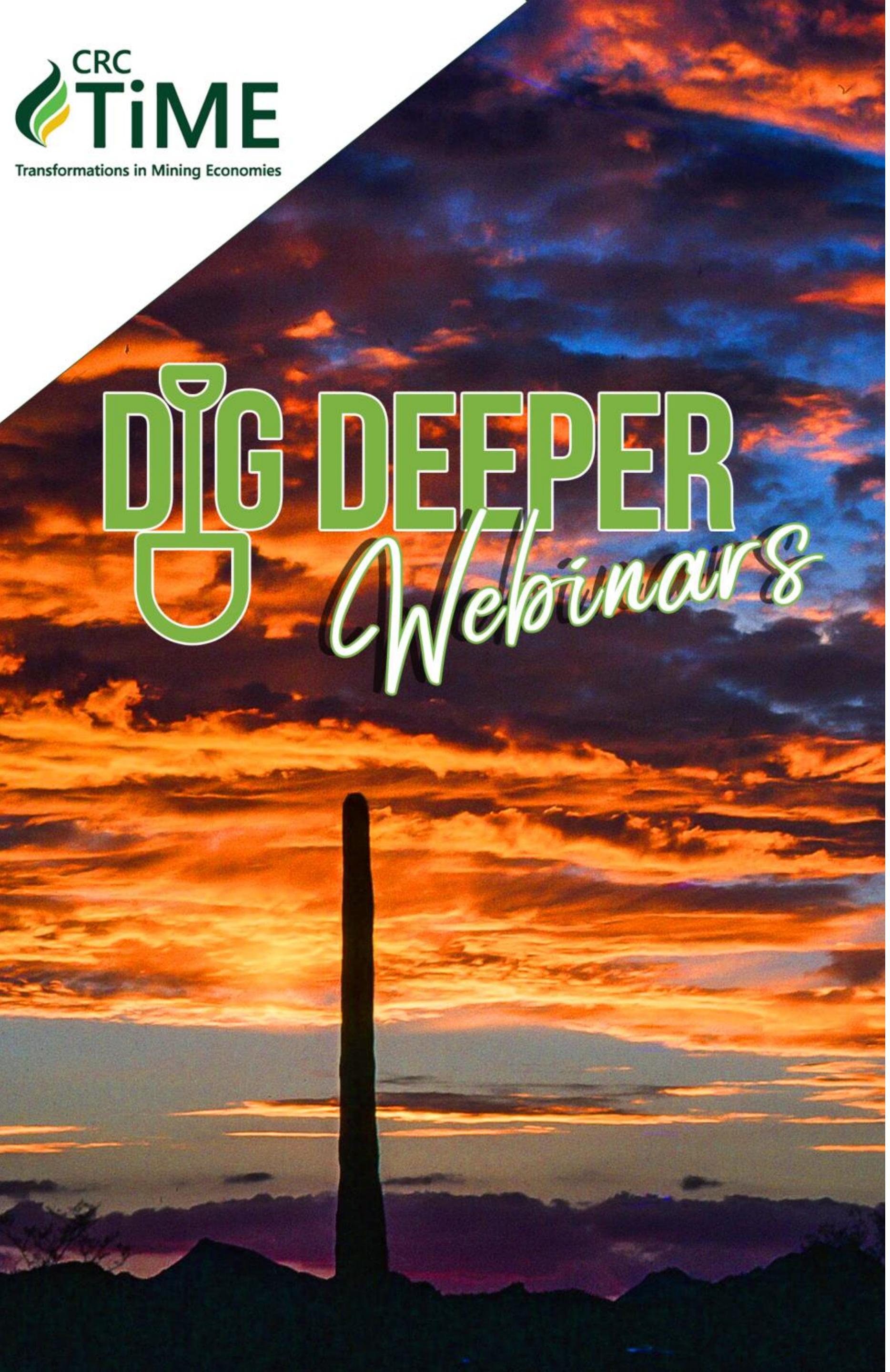

COMPARATIVE CLOSURE: ASSESSING THE BIOPHYSICAL CLOSURE CHALLENGES OF DIFFERENT MINING METHODS

PROJECT 3.7| DR EWAN SELLERS | 8 JULY 2022

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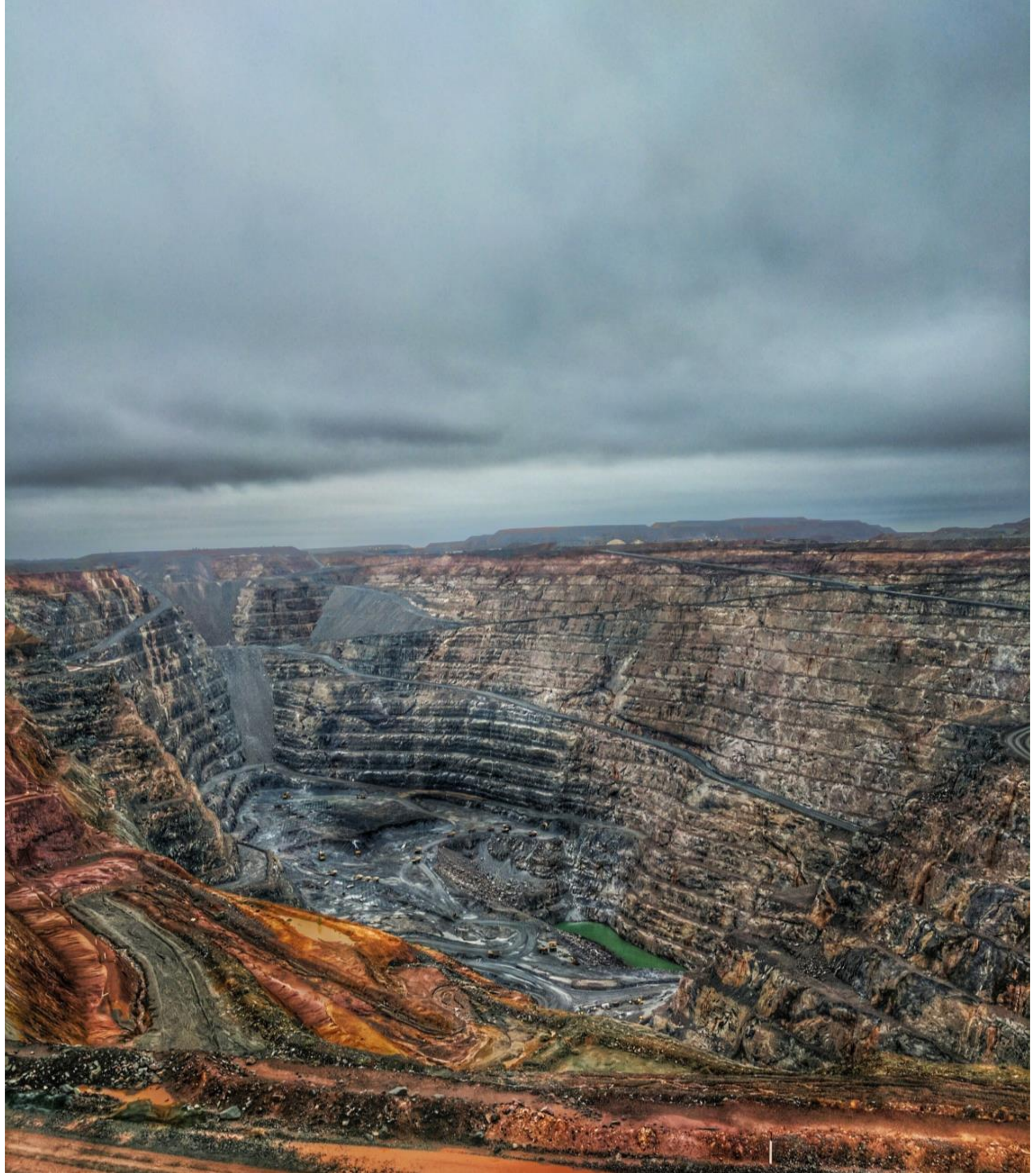


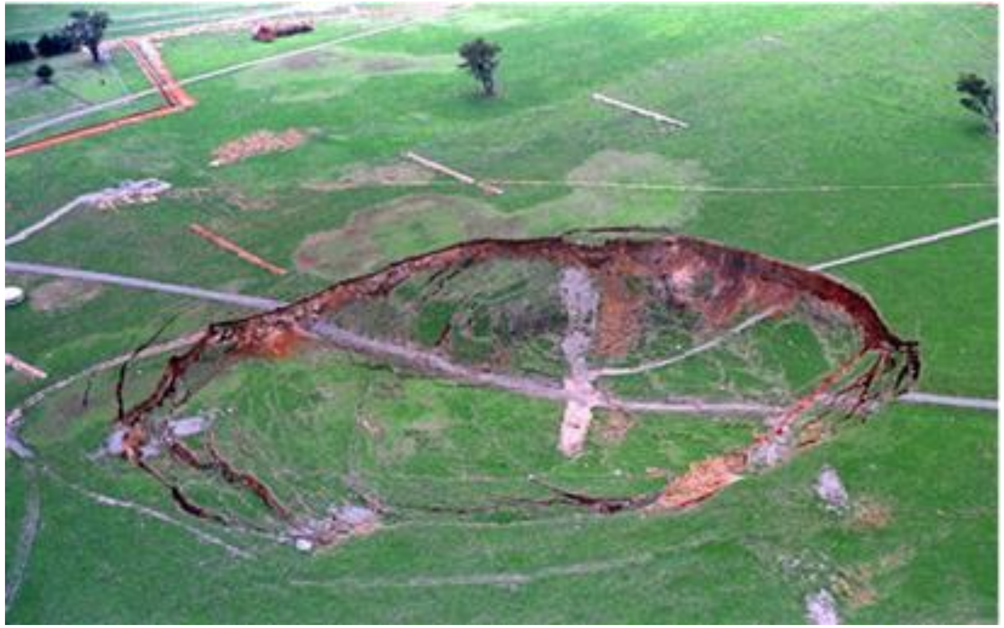
Photo by Matthew de Livera on unsplash.com

The Problem: How does the mining method influence biophysical closure outcomes?

- Conventional mining methods lead to large open pits, underground voids and large tailings footprints which are difficult to manage for any potential post-mining land use.
- New methods support a business case for closure that transforms the industry towards new approaches. How do they modify and alter, preferably reduce, the closure issues relative to conventional mining methods

CRC TiME
Transformations in Mining Economies

Issues for closure and post mining use



https://upload.wikimedia.org/wikipedia/commons/f/f7/Ug-mining-greek.svg

Fathi Salmi et al., 2017

The Research Process

Understand
- Review of methods and biophysical issues

Explore
- Simplify categories
- use Rock Engineering risk rating system

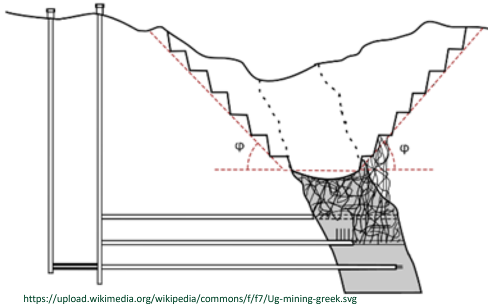
Question
- Survey of external parties

Analyse
- **Prioritized risks for different methods**
- **Identified unknowns**

CRC TiME
Transformations in Mining Economies

Categorization of Mining Methods

- Conventional methods
- Surface
  - Open Pit
  - Strip mining
- Underground
  - Caving
  - Longwall
  - Room and Pillar
  - Stope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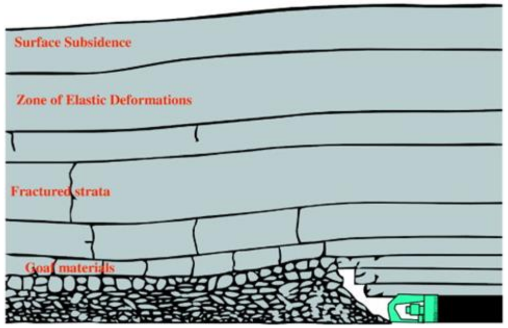
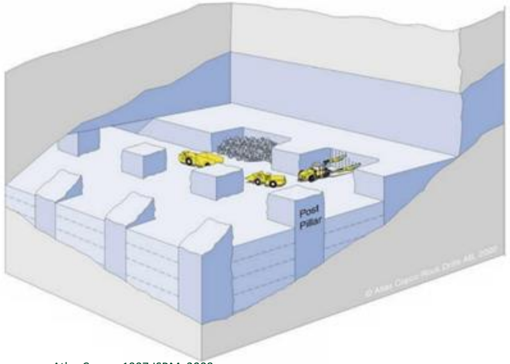
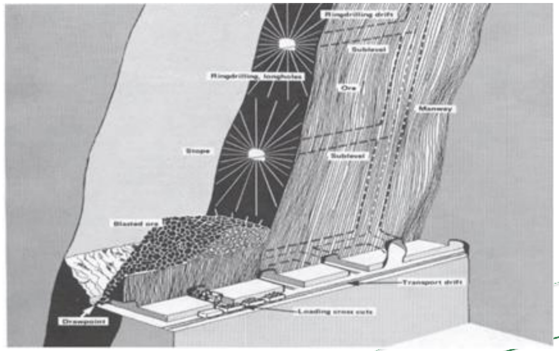


Fathi Salmi et al., 2017



Atlas Copco, 1997,ISRM, 2008


Atlas Copco, 1997,ISRM, 2008

Transformations in Mining Economies

Why change?

Deposits

smaller, deeper, distributed

lower grades

geography

Sustainability

Water, energy, etc

Environmental impact – tailings

Right to mine – social, community

Finances

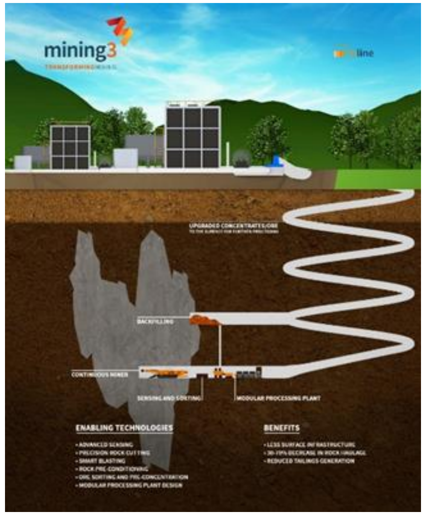
Returns?

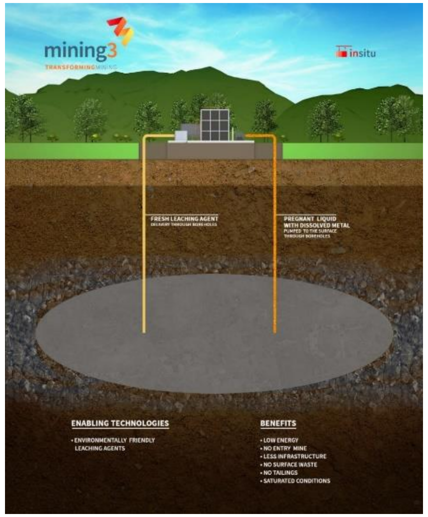
Strings attached (ESG)

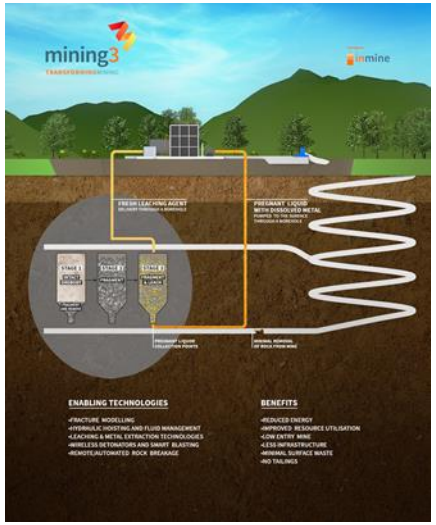
-> Availability

Categorization of Mining Methods

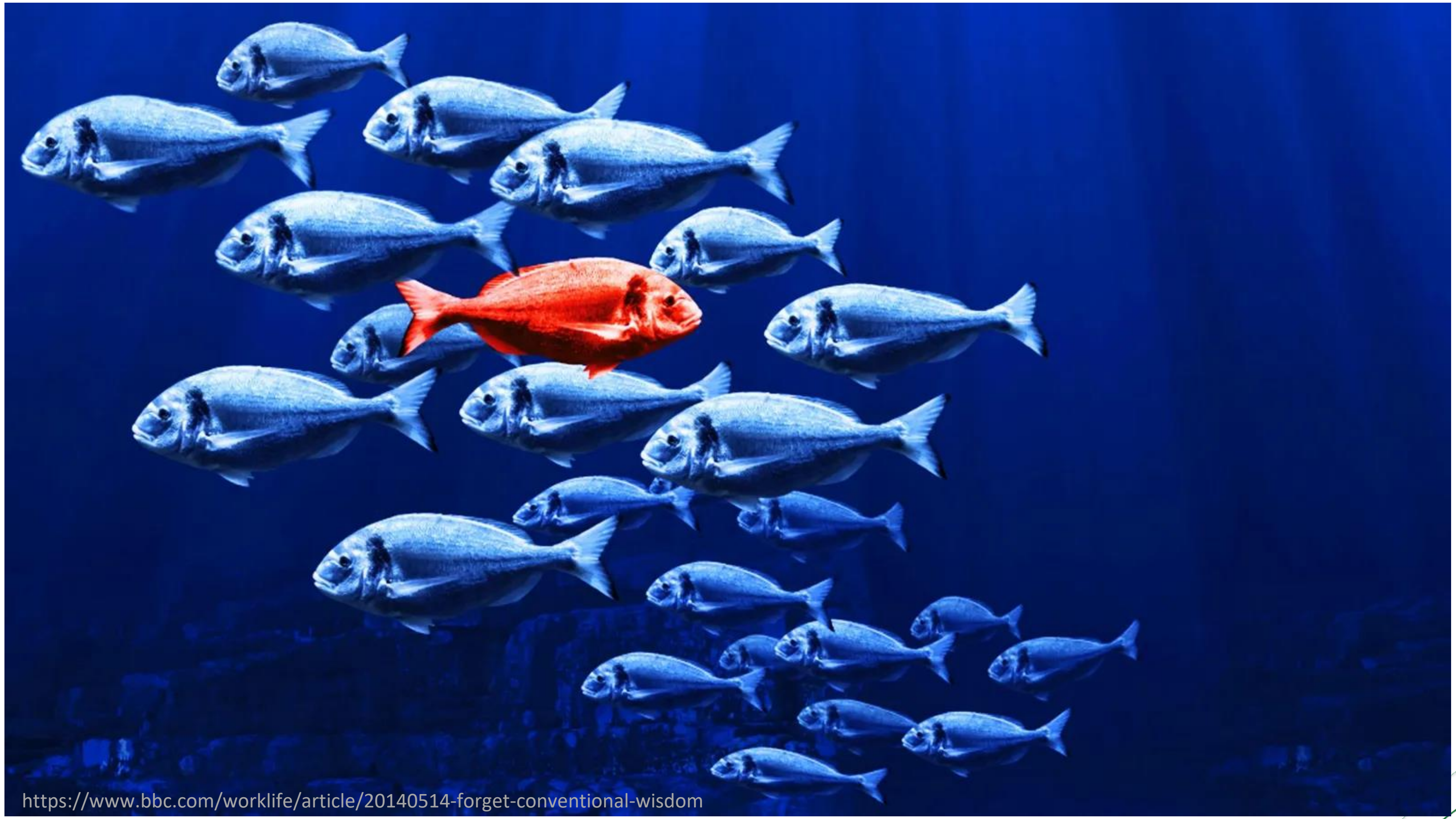
- Novel, In-Place methods:
- In-Line
  - Selective mining with local processing and underground separation
- In-Situ
  - Drilling into permeable strata and pumping fluids to extract minerals
- In-Mine
  - In hard impermeable rock, blasting silos and leaching minerals







The challenge of change



Is closure really easier?

What is biophysical?

Type of alteration	Description
Topography and landform	• Temporary changes to the existing topography • Permanent changes include open-pit void, waste rock dumps,and tailings storage facilities.
Flora and vegetation	• Clearing for the mine, waste rock dumps, processing plant, tailings storage facility, and associated infrastructure.
Fauna	• Primary impact = direct destruction of habitats through land clearing and earthmoving activities. • Secondary impacts = varying degrees of disturbance beyond the immediate point where mining is taking places - roads, powerlines, pipelines, infrastructure, feral animals, and general workforce activities.
Surface water hydrology and groundwater	• Interrupt some of the natural drainage paths. • Deprivation of water to drainage systems downstream • Localized ‘shadowing’ effects on some vegetation which may be reliant on intermittent flows.
Soil and water contamination	• Chemical reactions in waste rock and tailings detrimental to plant growth = contamination of both surface and groundwater. • Mining chemical may cause atmospheric, soil, or water contamination and could potentially pose ongoing risks to human health and the environment. **Bell et al. (2006)**

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Transformations in Mining Economies

How are biophysical closure issues considered?

- Technical criteria mainly
- Limited consideration of Biophysical

	Criteria (Bogdanovic, 2012)
1	Ore thickness
2	dip
3	Ore strength
4	Fracturing
5	Shape
6	Amount of development
7	Excavation efficiency
8	Ore dilution
9	Excavation costs
10	Work safety
11	***Surface preservation***

How do we know if novel methods have less impact?

- Novel methods don't have a history
- Literature review
- Experts survey?

Rock Engineering System redefined

- Developed by Hudson (1992)
- Experts can contribute to rank and prioritise risks

Impact Rating	
0	No Impact
1	Low Impact
2	Medium Impact
3	Strong Impact
4	Critical Impact

	SM1	SM2	UM1	UM2	UM3	UM4	IM1	IM2	IM3	Sum
P1	4	4	1	1	3	3	0	0	0	16
P2	0	0	2	2	4	4	0	0	0	12
P3	4	4	0	0	0	0	0	0	0	8
P4	4	4	2	2	2	2	1	1	1	19
P5	4	4	3	3	3	3	2	1	2	25
P6	4	4	2	2	2	2	1	0	1	18
P7	2	2	3	3	4	4	4	4	4	30
P8	4	4	2	2	2	2	1	1	1	19
P9	4	4	3	3	3	3	2	2	2	26
P10	4	4	2	2	2	2	1	1	1	19
P11	4	4	2	2	3	3	1	1	1	21
P12	4	4	2	2	3	3	1	1	1	21
P13	4	4	2	2	3	3	1	0	1	20
P14	4	4	2	2	3	3	1	0	1	20
P15	4	4	4	4	4	4	2	1	2	29
P16	4	4	2	2	3	3	1	1	1	21
Sum	58	58	34	34	44	44	19	14	19	

CRC TiME Transformations in Mining Economies

Relative Biophysical Risk

Row Labels	InLine	InMine	InSitu	Open cast	Open pit	UG Cave	UG Longwall	UG Room & Pillar	UG Stope
Affecting_the_rate_of_erosion_and_weathering	0.7	0.7	0.7	3.0	3.1	2.8	1.6	1.1	1.3
Air_pollution_and_dust_problems	0.7	0.7	0.7	3.0	2.9	1.3	0.9	0.9	0.9
Biological_effects	1.0	1.0	1.0	2.8	2.5	1.5	1.3	1.0	1.0
Capital_costs	2.3	2.5	2.3	3.2	3.3	3.0	3.0	3.0	3.0
Effect_on_surface_and_subsurface_aquifers	2.7	2.7	2.7	3.3	3.3	2.5	2.5	2.4	2.4
Effects_on_animals	1.0	1.0	1.0	2.7	2.5	1.5	1.1	1.0	1.0
Effects_on_indigenous_land_use	1.7	1.7	1.7	3.1	3.3	2.3	1.8	1.4	1.4
Effects_on_vegetation	1.2	1.2	1.2	3.1	2.6	1.6	1.4	1.0	1.0
Emissions	1.1	1.4	1.3	3.3	3.3	1.8	1.5	1.5	1.5
Hazards_and_effects_on_humans	2.2	2.2	2.2	2.2	2.1	2.0	1.8	1.5	1.6
Operating_costs	1.8	2.0	1.8	3.2	3.1	2.6	3.0	2.8	2.8
Ore_loss_&_not_recovered	2.2	1.8	2.0	2.3	2.0	1.6	2.0	3.0	2.0
Rehabilitation_costs	2.0	2.0	2.2	3.3	2.7	3.0	2.0	1.6	2.2
Size_of_tailing_and_tailing_issues	1.0	1.0	1.0	3.2	3.6	2.1	1.9	1.8	2.1
Size_of_waste/spoil_dumps	1.0	1.0	1.0	3.0	3.4	1.8	1.6	1.4	1.9
Slope_instability_issues_and_triggering_landslides	1.2	1.2	1.0	2.6	2.7	1.9	1.3	0.9	1.0
SocioEconomic_issues	2.0	2.0	2.0	2.6	2.5	2.0	2.0	2.0	2.0
Soil_pollution	0.7	0.7	0.7	2.2	1.9	0.9	0.8	0.8	0.8
Surface_subsidence_and_sinkholes	2.5	2.2	2.3	1.1	1.2	3.1	2.5	1.3	1.5
Water_Pollution:_Acid_rock_drainage	2.5	2.8	2.8	3.3	3.4	2.9	2.6	2.4	2.8
Water_Pollution:_Heavy_metal_contamination				3.1	3.3	2.4	2.3	2.3	2.4
Water_use	2.3	2.5	2.7	3.5	3.6	1.8	2.2	1.8	2.0

CRC TiME
Transformations in Mining Economies

Final rankings

Rank	Biophysical impact	Mining Method
1	Water Pollution: Heavy metal contamination	Open pit
2	Water Pollution: Acid rock drainage	Open cast
3	Effect on surface and subsurface aquifers	UG Cave
4	Capital costs	UG Longwall
5	Size of tailing and tailing issues	InMine
6	Water use	UG Stope
7	Surface subsidence and sinkholes	InSitu
8	Effects on indigenous land use	UG Room & Pillar
9	Operating costs	InLine
10	Socio Economic issues	
11	Size of waste/spoil dumps	
12	Affecting the rate of erosion and weathering	
13	Hazards and effects on humans	
14	Rehabilitation costs	
15	Emissions	
16	Effects on vegetation	
17	Slope instability issues and triggering landslides	
18	Effects on animals	
19	Air pollution and dust problems	
20	Biological effects	
21	Ore loss & not recovered	
22	Soil pollution	

Caveat: Based on a small sample of opinions.

Unknown-Unknowns?

% of people not responding

Row Labels	InLine	InMine	InSitu	Open	Open pit	UG Cave	UG	UG Room	UG Stope
Affecting_the_rate_of_erosion_and_weathering	30%	30%	30%	10%	0%	20%	20%	20%	20%
Air_pollution_and_dust_problems	40%	40%	40%	10%	0%	20%	20%	20%	20%
Biological_effects	40%	40%	40%	10%	0%	20%	20%	20%	20%
Capital_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Effect_on_surface_and_subsurface_aquifers	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_animals	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_indigenous_land_use	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_vegetation	40%	40%	40%	10%	0%	20%	20%	20%	20%
Emissions	30%	30%	30%	40%	30%	40%	40%	40%	40%
Hazards_and_effects_on_humans	40%	40%	40%	10%	0%	20%	20%	20%	20%
Operating_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Ore_loss_&_not_recovered	40%	40%	40%	40%	30%	50%	50%	50%	50%
Rehabilitation_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Size_of_tailing_and_tailing_issues	40%	40%	40%	10%	0%	20%	20%	20%	20%
Size_of_waste/spoil_dumps	40%	40%	40%	10%	0%	20%	20%	20%	20%
Slope_instability_issues_and_triggering_landslides	40%	40%	40%	10%	0%	20%	20%	20%	20%
SocioEconomic_issues	40%	40%	40%	10%	0%	20%	20%	20%	20%
Soil_pollution	40%	40%	40%	10%	0%	20%	20%	20%	20%
Surface_subsidence_and_sinkholes	40%	40%	40%	10%	0%	20%	20%	20%	20%
Water_Pollution:_Acid_rock_drainage	40%	40%	40%	10%	0%	20%	20%	20%	20%
Water_Pollution:_Heavy_metal_contamination				10%	0%	20%	20%	20%	20%
Water_use	40%	40%	40%	40%	30%	50%	50%	50%	50%

Unknown-Unknowns?

% of people not responding

Row Labels	InLine	InMine	InSitu	Open	Open pit	UG Cave	UG	UG Room	UG Stope
Affecting_the_rate_of_erosion_and_weathering	30%	30%	30%	10%	0%	20%	20%	20%	20%
Air_pollution_and_dust_problems	40%	40%	40%	10%	0%	20%	20%	20%	20%
Biological_effects	40%	40%	40%	10%	0%	20%	20%	20%	20%
Capital_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Effect_on_surface_and_subsurface_aquifers	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_animals	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_indigenous_land_use	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_vegetation	40%	40%	40%	10%	0%	20%	20%	20%	20%
Emissions	30%	30%	30%	40%	30%	40%	40%	40%	40%
Hazards_and_effects_on_humans	40%	40%	40%	10%	0%	20%	20%	20%	20%
Operating_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Ore_loss_&_not_recovered	40%	40%	40%	40%	30%	50%	50%	50%	50%
Rehabilitation_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Size_of_tailing_and_tailing_issues	40%	40%	40%	10%	0%	20%	20%	20%	20%
Size_of_waste/spoil_dumps	40%	40%	40%	10%	0%	20%	20%	20%	20%
Slope_instability_issues_and_triggering_landslides	40%	40%	40%	10%	0%	20%	20%	20%	20%
SocioEconomic_issues	40%	40%	40%	10%	0%	20%	20%	20%	20%
Soil_pollution	40%	40%	40%	10%	0%	20%	20%	20%	20%
Surface_subsidence_and_sinkholes	40%	40%	40%	10%	0%	20%	20%	20%	20%
Water_Pollution:_Acid_rock_drainage	40%	40%	40%	10%	0%	20%	20%	20%	20%
Water_Pollution:_Heavy_metal_contamination				10%	0%	20%	20%	20%	20%
Water_use	40%	40%	40%	40%	30%	50%	50%	50%	50%

Low knowledge of UG methods?

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Transformations in Mining Economies

Unknown-Unknowns?

% of people not responding

Lack of confidence in understanding new methods?

Row Labels	InLine	InMine	InSitu	Open	Open pit	UG Cave	UG	UG Room	UG Stope
Affecting_the_rate_of_erosion_and_weathering	30%	30%	30%	10%	0%	20%	20%	20%	20%
Air_pollution_and_dust_problems	40%	40%	40%	10%	0%	20%	20%	20%	20%
Biological_effects	40%	40%	40%	10%	0%	20%	20%	20%	20%
Capital_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Effect_on_surface_and_subsurface_aquifers	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_animals	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_indigenous_land_use	40%	40%	40%	10%	0%	20%	20%	20%	20%
Effects_on_vegetation	40%	40%	40%	10%	0%	20%	20%	20%	20%
Emissions	30%	30%	30%	40%	30%	40%	40%	40%	40%
Hazards_and_effects_on_humans	40%	40%	40%	10%	0%	20%	20%	20%	20%
Operating_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Ore_loss_&_not_recovered	40%	40%	40%	40%	30%	50%	50%	50%	50%
Rehabilitation_costs	40%	40%	40%	40%	30%	50%	50%	50%	50%
Size_of_tailing_and_tailing_issues	40%	40%	40%	10%	0%	20%	20%	20%	20%
Size_of_waste/spoil_dumps	40%	40%	40%	10%	0%	20%	20%	20%	20%
Slope_instability_issues_and_triggering_landslides	40%	40%	40%	10%	0%	20%	20%	20%	20%
SocioEconomic_issues	40%	40%	40%	10%	0%	20%	20%	20%	20%
Soil_pollution	40%	40%	40%	10%	0%	20%	20%	20%	20%
Surface_subsidence_and_sinkholes	40%	40%	40%	10%	0%	20%	20%	20%	20%
Water_Pollution:_Acid_rock_drainage	40%	40%	40%	10%	0%	20%	20%	20%	20%
Water_Pollution:_Heavy_metal_contamination				10%	0%	20%	20%	20%	20%
Water_use	40%	40%	40%	40%	30%	50%	50%	50%	50%

Implications

- Experts considered high impact scores for in-place mining for:
  - water pollution, soil and air pollution,
  - subsurface aquifers,
  - subsidence and ground movements, and water consumption,
- Expert opinions are dependent on their experience and are not transferable across mining methods
- The main implication for CRC TiME is that the issues arising, and future mitigation options, for closure have already been entrenched by the selection of the mine design at pre-feasibility or feasibility stages. This is dependent on techno-economic considerations with minimal biophysical input
  - Further research needed into the connection of biophysical impacts into mine design for closure outcomes
- The lack of answers in the survey for the novel mining methods, emphasises that there is a need for :
  - Further research needed into the novel methods and their implications over Life of Mine
  - Pilot scale testing
  - Communication of the methods, impacts and opportunities to a wider range of the community and stakeholders in mining and closure

How can Industry use these Findings?

- Miners – better planning for closure, more reserve
- METS – new technologies
- Indigenous – potential for less impact
- Regional development – different jobs, more opportunities
- Government - reduce closure liabilities
- Research – increase understanding and systems

THANK YOU

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www.crctime.com.au

CRC TiME
Transformations in Mining Economies