Conferencia

Toma de decisiones para el cierre: marcos, incertidumbre y costo

Decision Making for Closure – Frameworks, Uncertainty, and Cost

27 Marzo 2023

UNIVERSIDAD EAFIT | Escuela de Ciencias Aplicadas e Ingeniería

Lanzamiento
Jornada Técnica de Relaves Mineros

srk consulting

Presentation

- My Background
- Mining Life Cycle
- Cost Estimates
- Uncertainty
- Decisions
- Conclusion

- Mi pasado
- Mining Life Cycle
- Coste Estimado
- Incertidumbre
- Decisiones
- Conclusiones

Mi Pasado
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LinkedIn

B.S. Civil Engineering (University of Colorado, Boulder, USA)

M.S. Environmental Science and Engineering
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Professional Engineer (Arizona, Colorado, New Mexico and Texas)

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Managing Practice Leader, SRK Consulting (North America)

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EARTH • ENERGY • ENVIRONMENT

Adjunct Lecturer, Business and Economics

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2023

Mi Pasado
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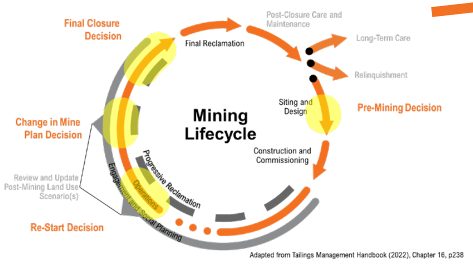
30+ years…

- Project Sponsor for Integrated Mine Closure of the BHP San Manuel Mine and Plant Sites (1999 to 2008)
- Project Sponsor for Site-Wide Closure of Globe-Miami Arizona Legacy Assets (2015 to Present)
- Uranium Tailings Closure Planning and Implementation, Asset Retirement Obligations, Closure Cost Estimates (Class 5, 4 and 3)

1 Mining Life Cycle

Momento de las decisiones relacionadas con el cierre
Timing of Closure-Related Decisions

Concepto de Tiempo y Toma de Decisiones
Concept of Time and Decision-Making

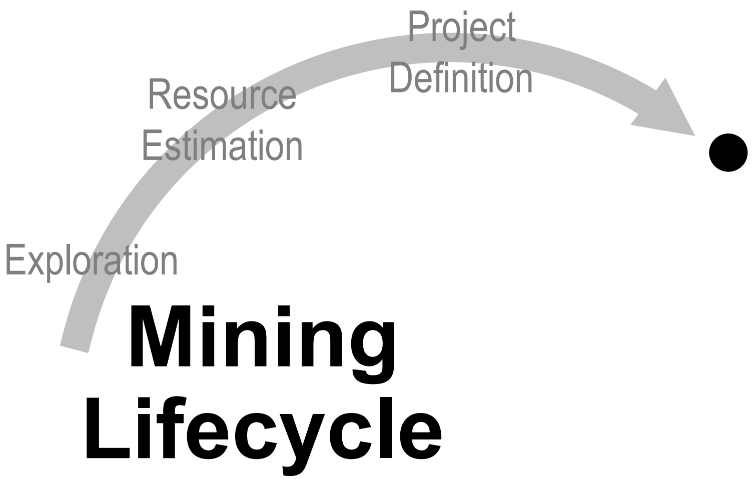


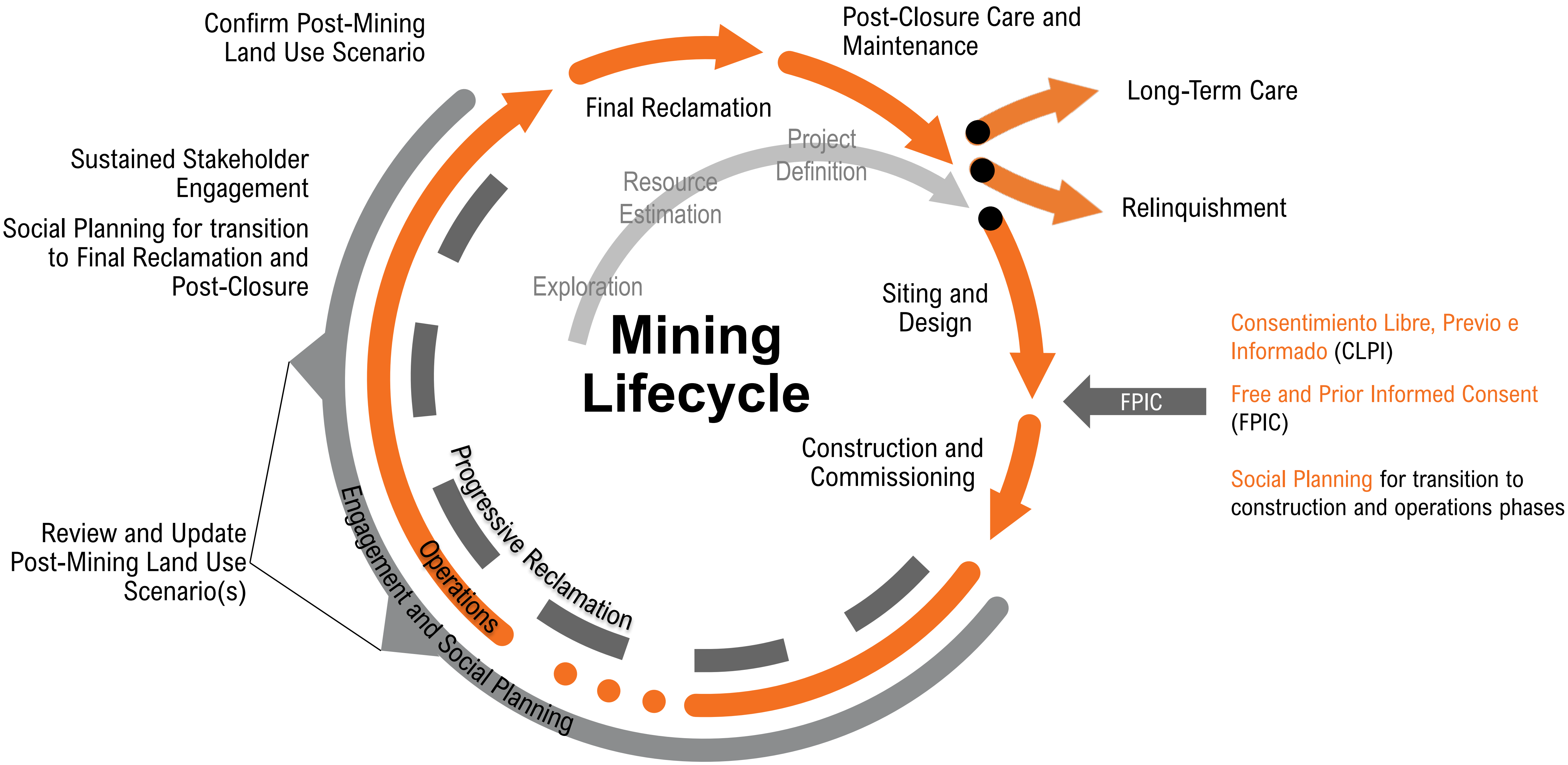
Perpetual Care and Maintenance
Cuidado y mantenimiento perpetuos

Mine Life – Decades
Vida de la mina - Décadas

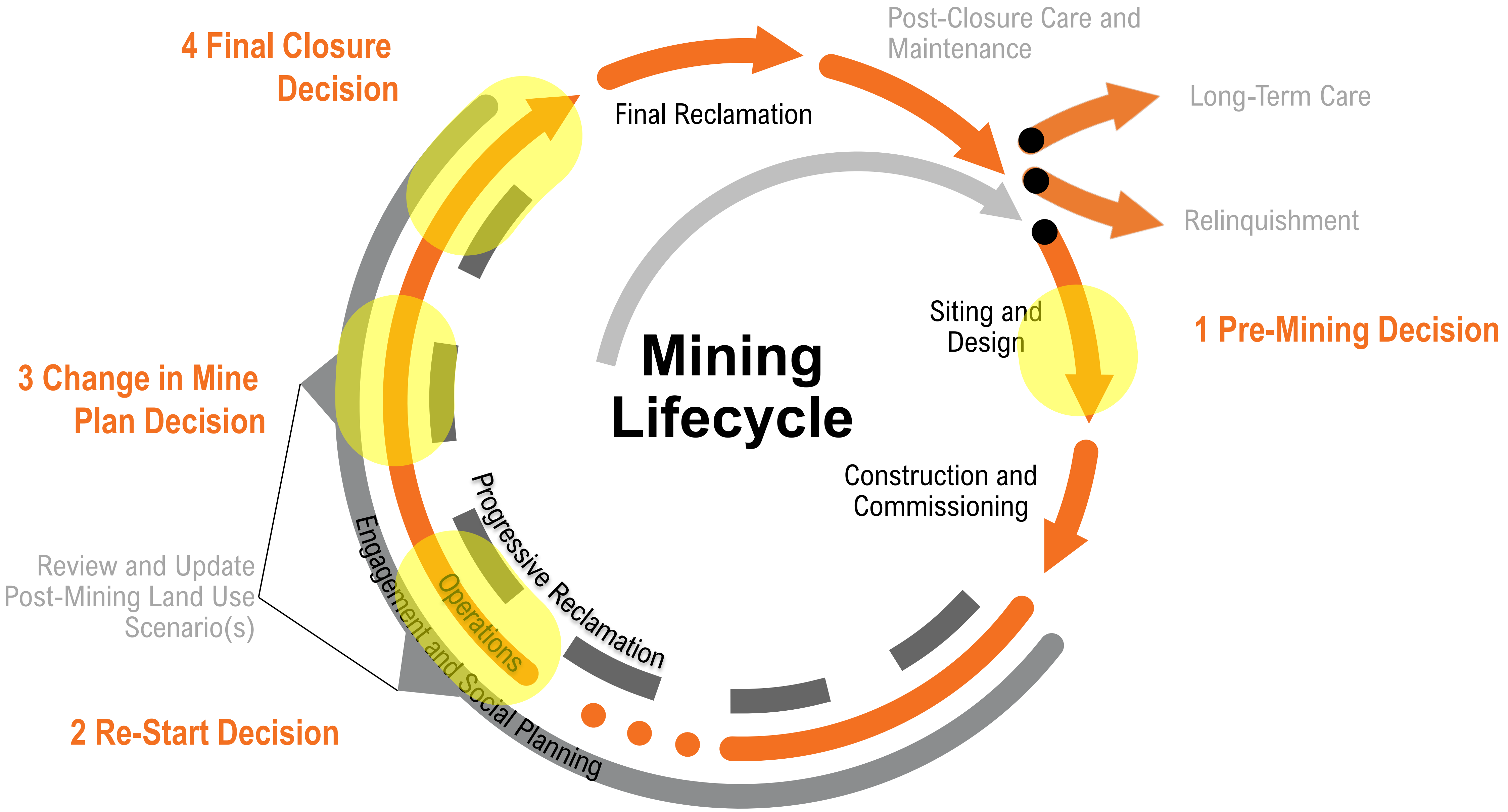
Post-Closure – Centuries
Post-Cierre - Siglos

Mining Lifecycle


Project
Definition
Resource
Estimation
Exploration
Mining
Lifecycle



Adapted from Tailings Management Handbook (2022), Chapter 16, p238



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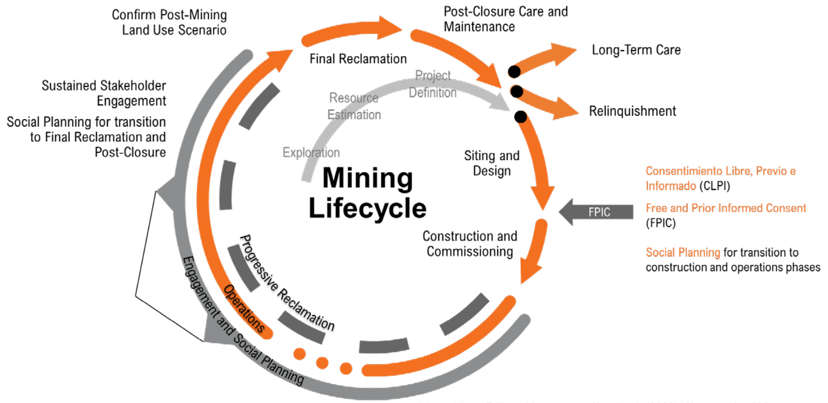
Pasado a Presente
Past to Present



Adapted from Tailings Management Handbook (2022), Chapter 16, p238

Legacy Site
Operated and Closed **Prior to** Modern Era of Mining and Environmental Regulation

Present

Long-Term Producer
Operated **Prior to and During** Modern Era of Mining and Environmental Regulation

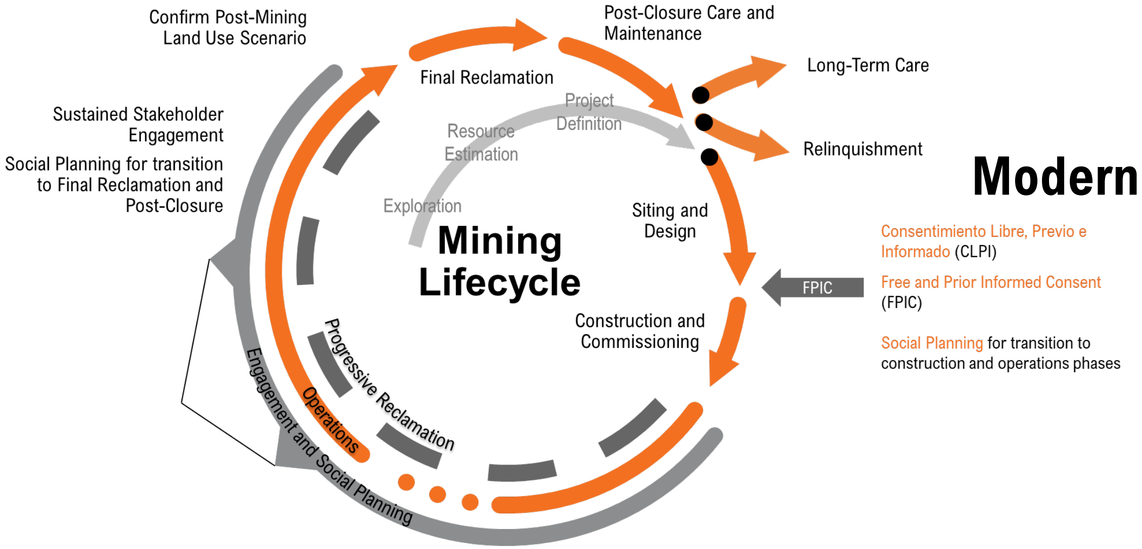
Contemporary Producer
Planned and Operated **During** Modern Era of Mining and Environmental Regulation

Future Producer
Planned and Operated **During Future** Era of Mining and Environmental Regulation

Pasado a Presente
Past to Present

Legacy Mine

Modern and Future Operations (?)



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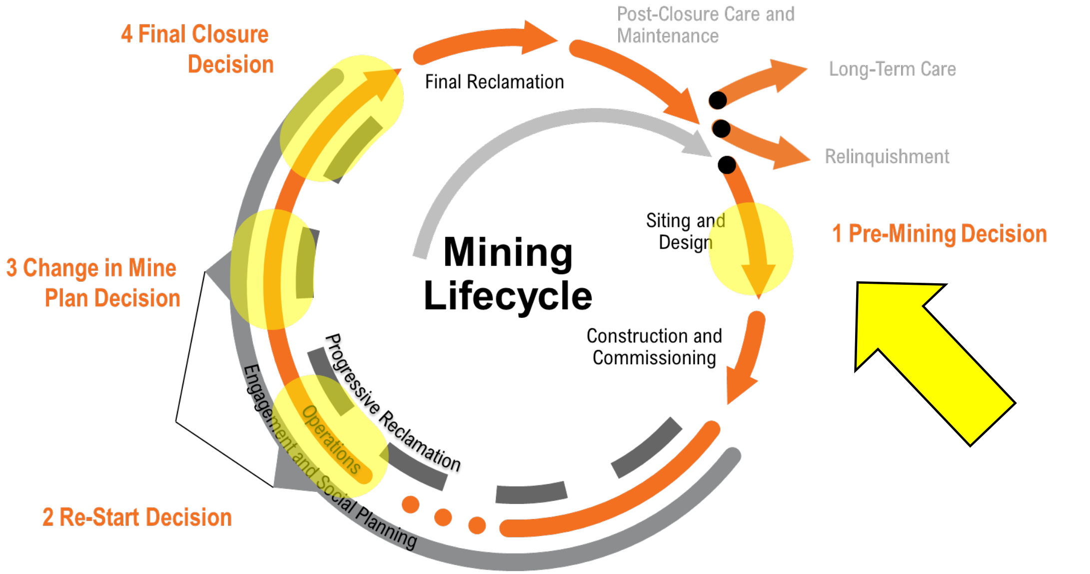
Existing Long-Term Operations

Decision Point
Pre-Mining (start with the Mineral Resource)

Example Inputs to **Pre-Mining** Closure Planning (Trade-Offs):

- Mining Method
- Metallurgical Process
- Mine Waste Management
- Water Balance
- Stakeholder Engagement
- Environmental Impact
- Post-Mining Land Use
- **Project Economics***



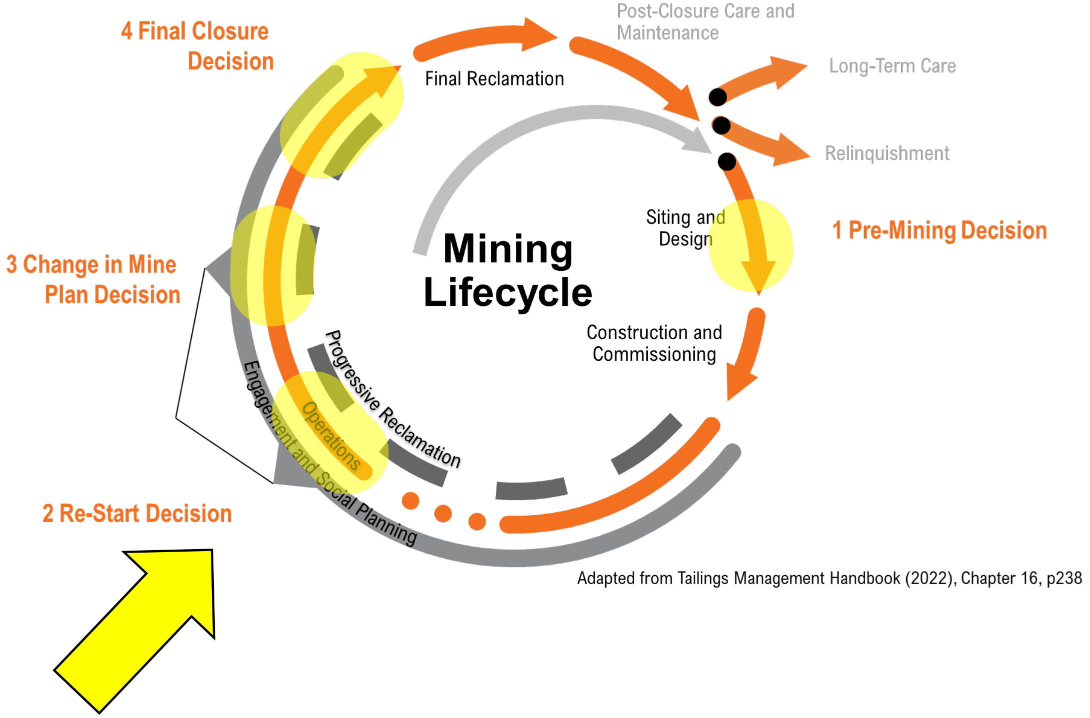
Adapted from Tailings Management Handbook (2022), Chapter 16, p238

* NPV vs. Life Cycle Accounting

Decision Point
Re-Start Mining

Example Inputs to **Re-Start** Closure Planning:

- Mining Method (Change?)
- Metallurgical Process (Change?)
- Mine Waste Management (Change?)
- Water Balance (Update)
- Stakeholder Engagement (Re-Establish?)
- Environmental Impact (Re-Assess)
- Post-Mining Land Use (Re-Assess)
- Project Economics

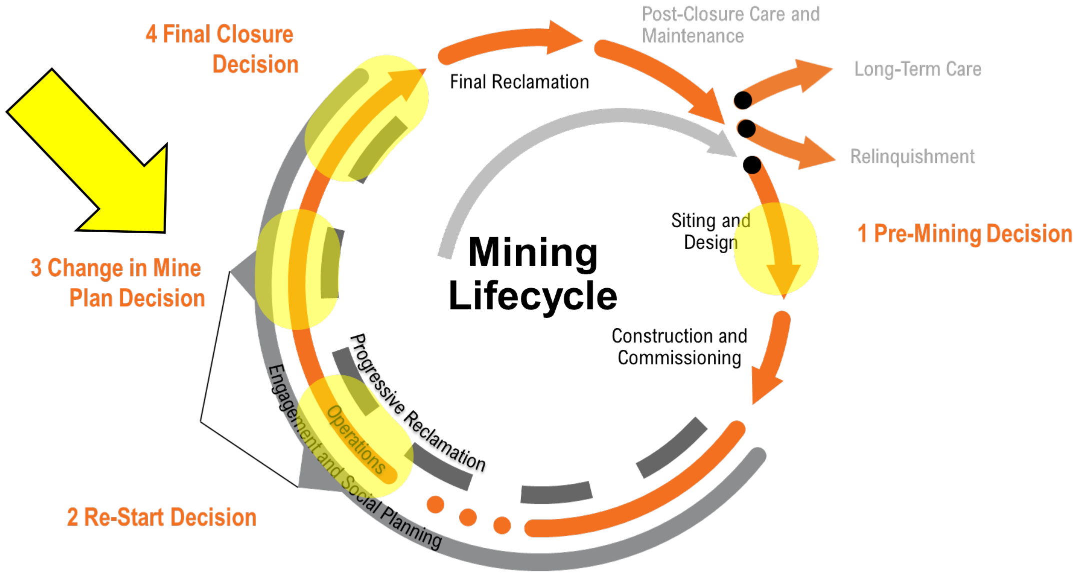


Adapted from Tailings Management Handbook (2022), Chapter 16, p238

Decision Point
Change in Mine Plan

Example Inputs to **Change in Mine Plan** Closure Planning:

- Mining Method (New?)
- Metallurgical Process (New?)
- Mine Waste Management (**New?**)
- Water Balance (Update)
- Stakeholder Engagement (**Maintain**)
- Environmental Impact (Re-Assess)
- Post-Mining Land Use (Re-Assess)
- Project Economics

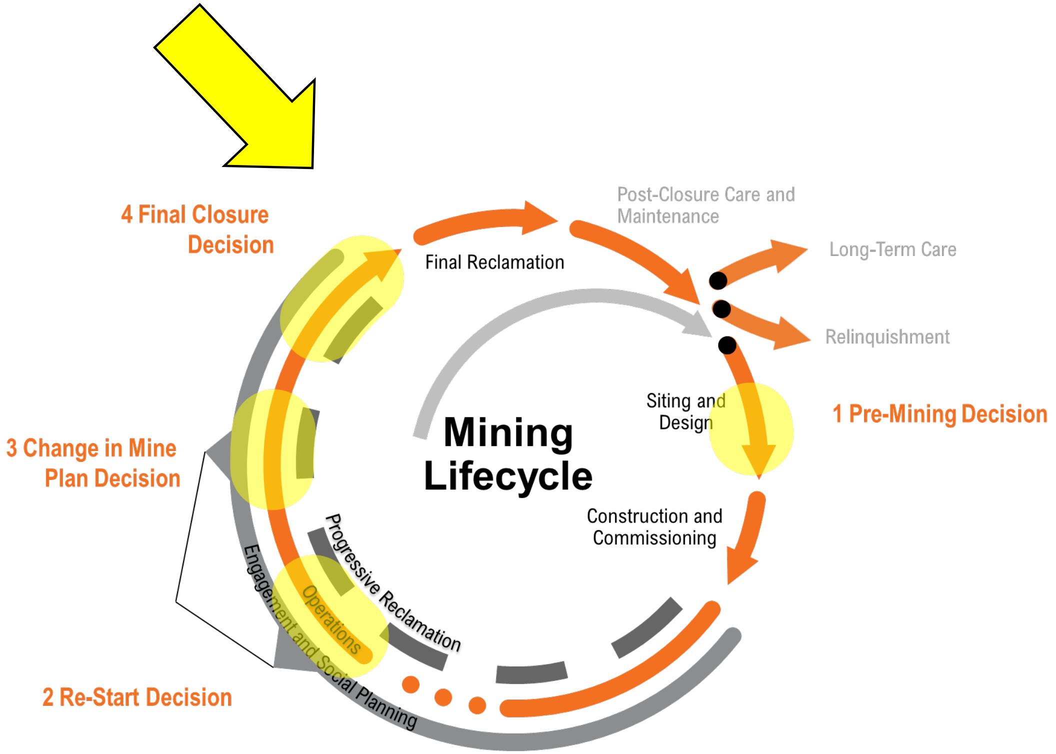


Adapted from Tailings Management Handbook (2022), Chapter 16, p238

Decision Points
Final Closure

Example Inputs to **Final** Closure Planning:

- Mining Method (Inert rock/stockpiles?)
- Metallurgical Process (De-pyritize?)
- Mine Waste Management (**Outslope?**)
- Water Balance (Update)
- Stakeholder Engagement (Priority)
- Environmental Impact (Assess)
- Post-Mining Land Use (Assess)
- Project Economics

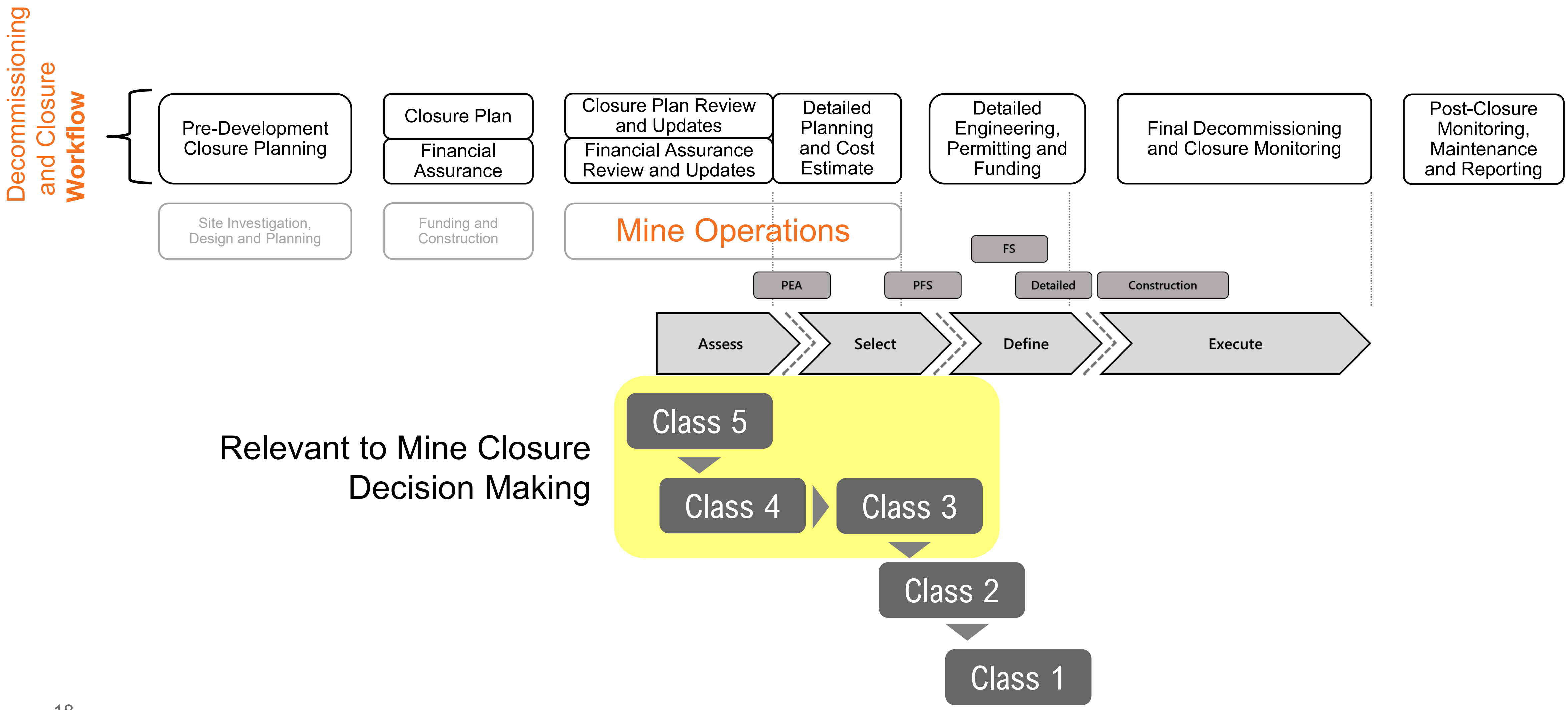


Adapted from Tailings Management Handbook (2022), Chapter 16, p238

2 Cost Estimates

Papel de las estimaciones de costos en las decisiones de cierre
Role of Cost Estimates in Closure Decisions

Example of Cost Estimate Class and Frond End Loaded (FEL) in Mine Closure



https://www.costengineering.eu/Downloads/articles/AACE_CLASSIFICATION_SYSTEM.pdf

Cost Estimate Classification

Widely accepted industry guidelines

- Association for the Advancement of Cost Engineering
- Independent Project Analysis

ESTIMATE CLASS	*Primary Characteristic* LEVEL OF PROJECT DEFINITION Expressed as % of complete definition	*Secondary Characteristic* END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE Typical variation in low and high ranges [a]	PREPARATION EFFORT Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Increasing detail/effort

Specialist

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

Cost Estimate Class cross-referenced with FEL and Mining

Generic study classification guide.

Terminology used in this handbook		Scoping study – Phase 1	Prefeasibility study – Phase 2	Feasibility study – Phase 3
Front end loading		FEL 1	FEL 2	FEL 3
Different titles that may be used to describe this level of study	Conceptual	Concept	Preliminary feasibility	Final feasibility
	Opportunity assessment	Order of magnitude (OOM)		Basic engineering
		Identification phase	Selection phase	Definition phase
	Screening	Scoping[a]		'Bankable' feasibility
	Scoping (see footnote)			Definitive feasibility
		Capacity factor	Equipment factor	Forced detail
		Preliminary evaluation	Intermediate economic study	
Estimate type (AACE)		Class 5	Class 4	Class 3
Expected accuracy range of capital cost	±35% to ±100% Typically ±50%	±30% to ±35%	±20% to ±25%	±10% to ±15%
Expected estimate contingency range	30% to 75%	20% to 35%	15% to 25%	10% to 15%
Level of definition (% of complete engineering (see Table 4.5)	Minimal, generally based on other operations, or in-house 'database'	1 - 2% Basic general layouts	10 - 15% Preliminary take-offs	15 - 25% Detailed drawings and take-offs
Typical estimating methodologies (but refer Table 4.5 for detail by line item)	Capacity factored Parametric models, judgement or analogy Stochastic estimating methods, including cost-capacity curves, and various factors	Equipment factored or parametric models. Some 'first principles' estimating related to early scope definition	Semi-detailed unit costs, and more deterministic estimating methods Preliminary MTOs (Some) budget pricing	More detailed unit costs and MTOs Budget prices and vendor quotes Higher degree of deterministic estimating methods Line items, and forced detail where definition is lacking

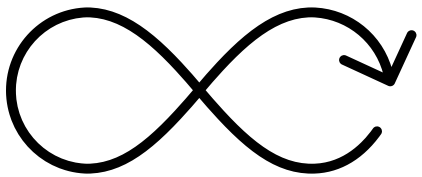
Chapter 1, Table 1.1. The Australasian Institute of Mining and Metallurgy (AusIMM), Cost Estimation Handbook (Second Edition). 2012

Note focus on capital cost estimates

What about **post-closure** costs? Perpetuity?

Post-Closure Cost Components

- Active water management (seepage, draindown), if applicable
- Stormwater management
- Cover and hydrotechnical installations inspection and maintenance
- Risk register review and update



Useful Reference for Class 5 and 4 Cost Estimates

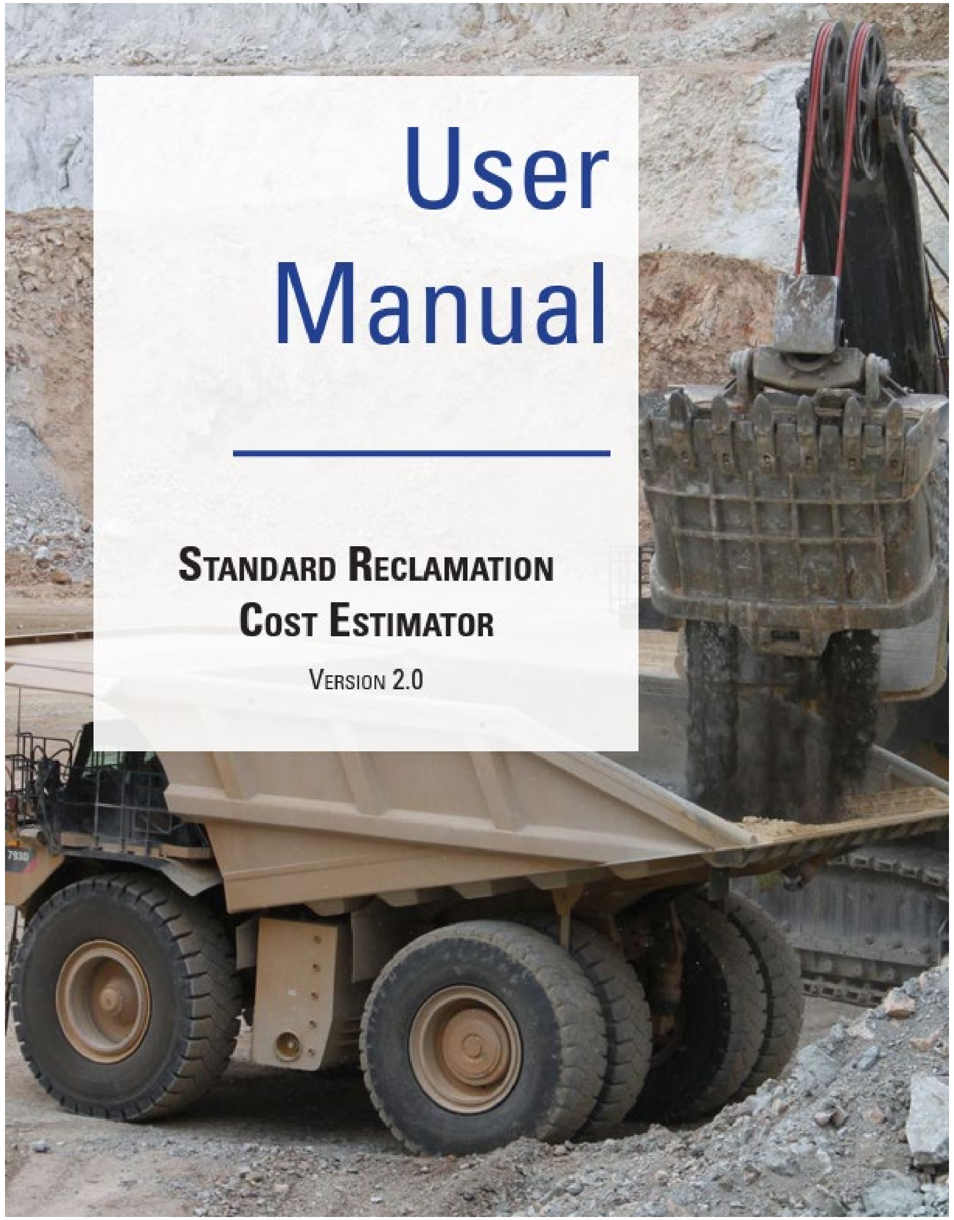
Standard Reclamation Cost Estimator, Version 2.0, available at https://nvbond.org/manuals/

NEW

SRCE 2.0 User Manual

Updated user manual.

Format: pdf (6.5MB)
Last update: 25 November 2019



3 Uncertainty

Incertidumbre y Decisiones de Cierre
Uncertainty and Closure Decisions

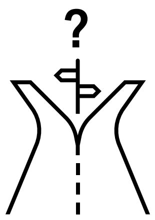
Uncertainty and Closure Decisions
Why and How

Uncertainty matters in terms of

- Conceptualization of the physical system
- Data gaps in site characterization

Conceptual models and site-specific data are components of your knowledge base

To advance the closure planning process, you must assess how uncertainty could change your decisions



Uncertainty and Closure Decisions Examples

Should decisions wait until you address the data gap(s)?

If the record of surface water runoff for the facility or surface water run-on from upstream catchments is sporadic or non-existent, data collection must capture seasonality and wet/dry years.

Field trials of cover systems can become critical path activities for planning (no short cuts)

Water quality interpretation (fingerprinting) in groundwater systems can reduce uncertainty associated with lack of long-term data

Geochemical predictions, weathering impacts on rock strength, hydrogeologic testing, erosion monitoring and modeling, etc.

Uncertainty and Closure Decisions
Role of the Knowledge Base

- Have proper baseline and pre-mine data been collected? Is the data sufficient for evaluating closure needs? Does the data include proper documented QA/QC information
- Are the tools and/or methodologies in place to obtain additional information?
- Are relevant corporate standards incorporated?
- Have commitments and legal obligations of the company to relevant stakeholders been captures, as well as their expectations?
- Are appropriate data management protocols in place to ensure that data from activities such as ongoing monitoring and field trials are incorporated?

*If **NOT**, what is the impact on a closure plan decision…*

Excerpt from Section 3, Page 16, ICMM 2022, "Integrated Mine Closure, Good Practice Guide, 2nd Edition". Link

4 Decision Analysis

Métodos y Discusión
Methods and Discussion

Closure Risk Assessment Informs Closure Decisions

Fundamentally connected. **Throughout** the Mining Life Cycle.

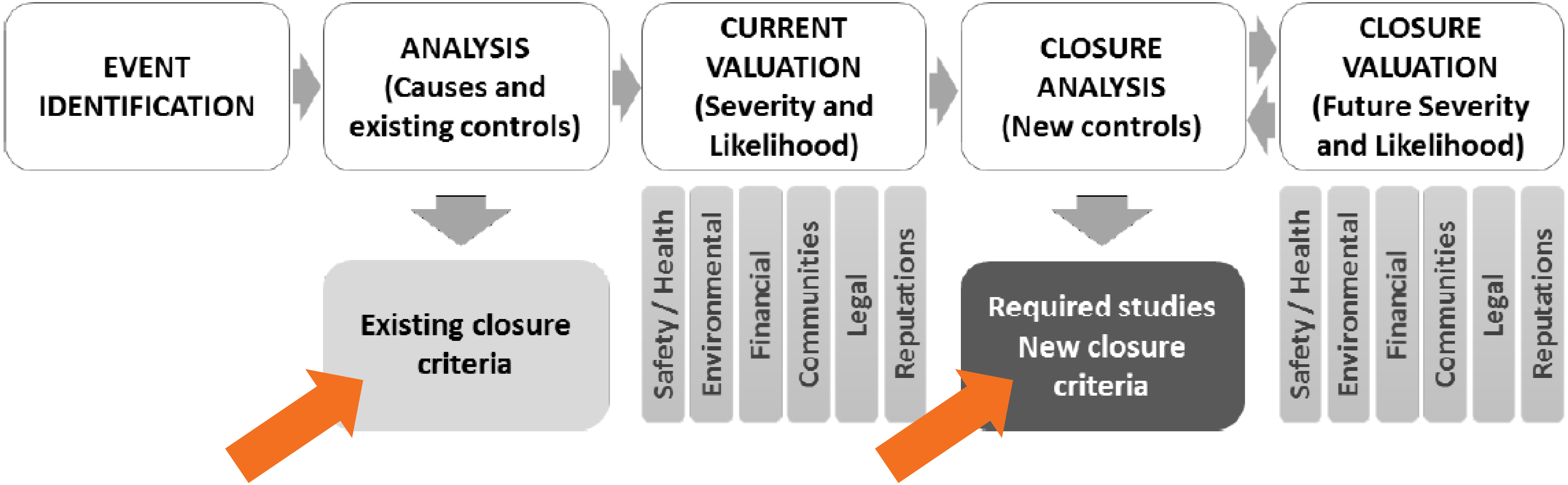


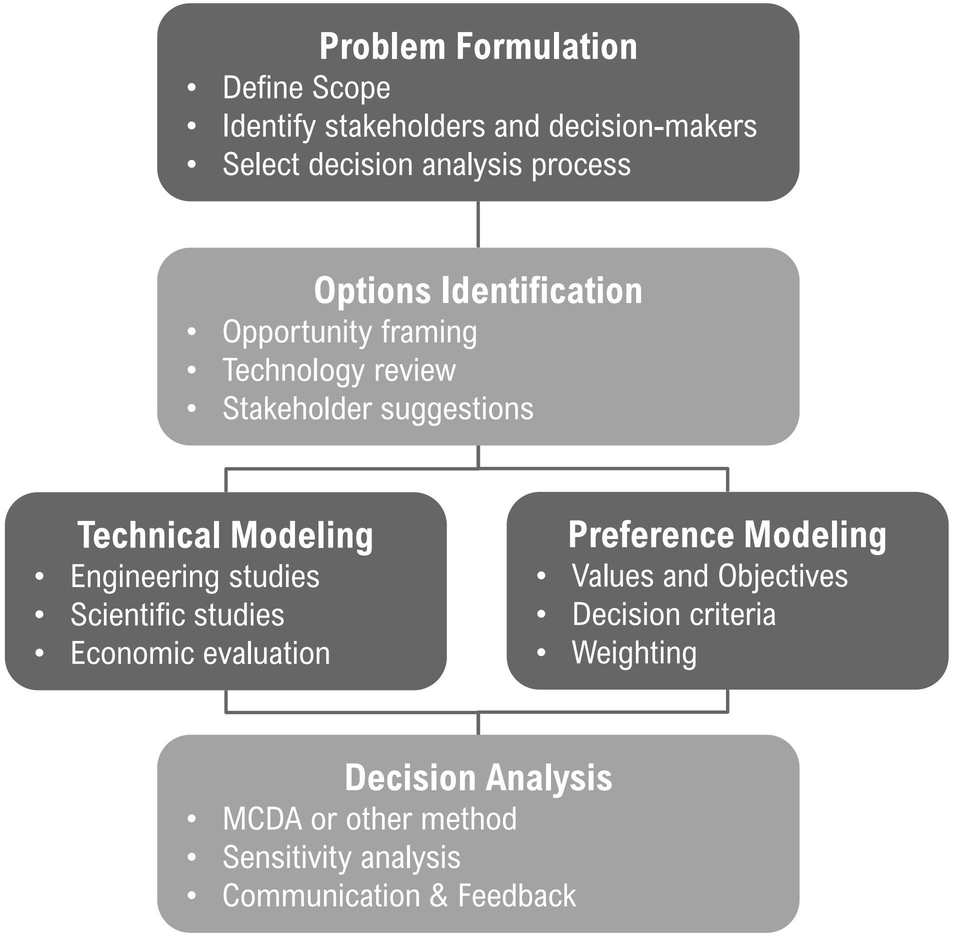
Figure 3 from Ricaurte J (2019), "Classifying closure scenarios through integrated planning at the Cerrojon mine in Colombia" Mine Closure.

Decision Analysis Context (CIM BC22)

Understand the overall context

- What decision are we making?
- Who is involved in the decision?
- What options are being considered?
- What are the evaluation factors?
- What are the required levels of option definition, preference transparency, and decision defensibility?

Only then you are ready to choose appropriate decision analysis method



Slide 5 from CIM ESRS Webinar Series (2022) “Lessons Learned from Tailings Decision Analysis”, April 13.

Decision-Making about Decision-Making (CIM BC22)

Slide 13 from CIM ESRS Webinar Series (2022) “Lessons Learned from Tailings Decision Analysis”, April 13.

Method	Strengths	Weaknesses
Cost-benefit analysis	Simple. Easily convertible to financial decisions	Requires all considerations to be converted to monetary terms. Unable to reflect different perspectives
Pair-wise comparison	Simple. Allows consideration of many decision criteria	Results are inconclusive unless one method clearly dominates the other. Unable to reflect different perspectives.
Conventional Multi-Criteria Decision Analysis (MCDA)	Rigorous theoretical basis. Allows consideration of many decision criteria	Does not account for uncertainty in science, engineering and economic assessments
MCDA with uncertainty	Allows consideration of many decision criteria. Includes uncertainty in science, engineering and economic assessments	Rapidly becomes complex if there are too many uncertainties involved.
Multi-party MCDA	Rigorous theoretical basis. Allows consideration of many decision criteria by many interested parties	Difficult to organize multiple stakeholders and to communicate clearly. Can be conflicts between parties. Rigorous treatment of uncertainty is onerous.
Internal MCDA	Rigorous theoretical basis. Most efficient way to incorporate expected assessment by external interested parties	Does not directly consult external interested parties, and therefore runs risks of error and future opposition by interested parties.
Non-quantitative MCDA	Allows consideration of many decision criteria by many interested parties, using their own language	Need careful development of objectives that can be expressed in non-quantitative terms. Non-quantitative results are not readily amenable to sensitivity analysis.

Decision-Making about Decision-Making (CIM BC22)

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Table Notes:

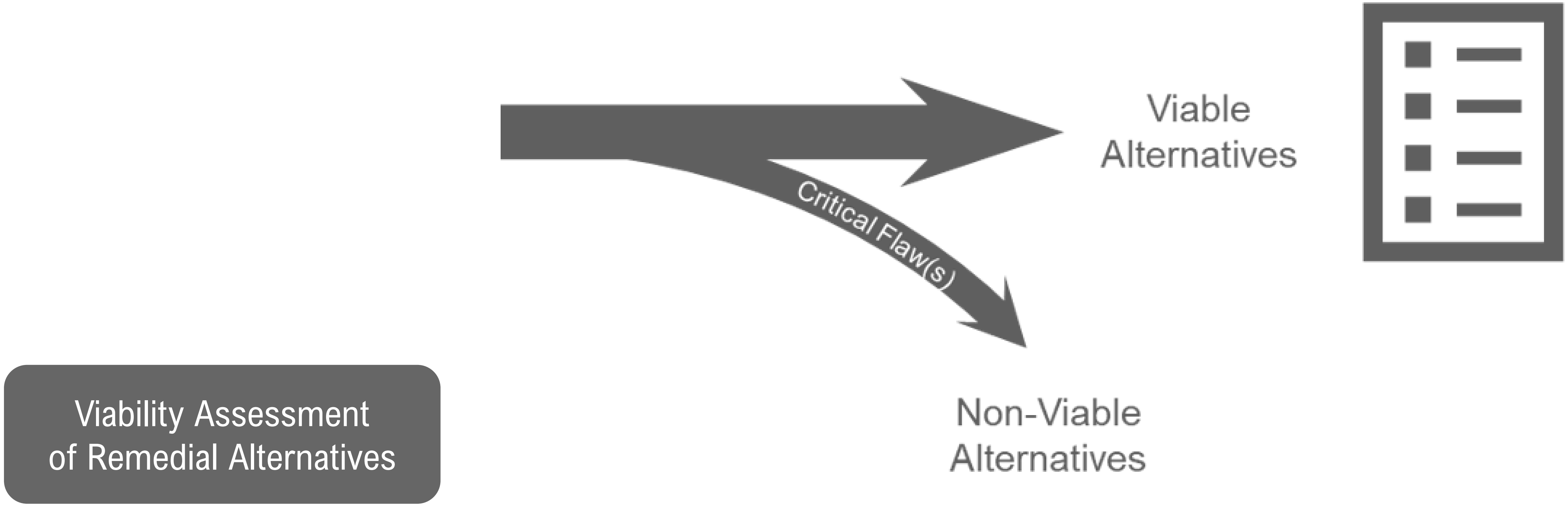
Every row in this table should include the caveat "if executed correctly"

The most important point is understanding the weaknesses of each method. This will require more than just learning how to turn the crank…you may need to immerse yourself in some wonky decision analysis literature.

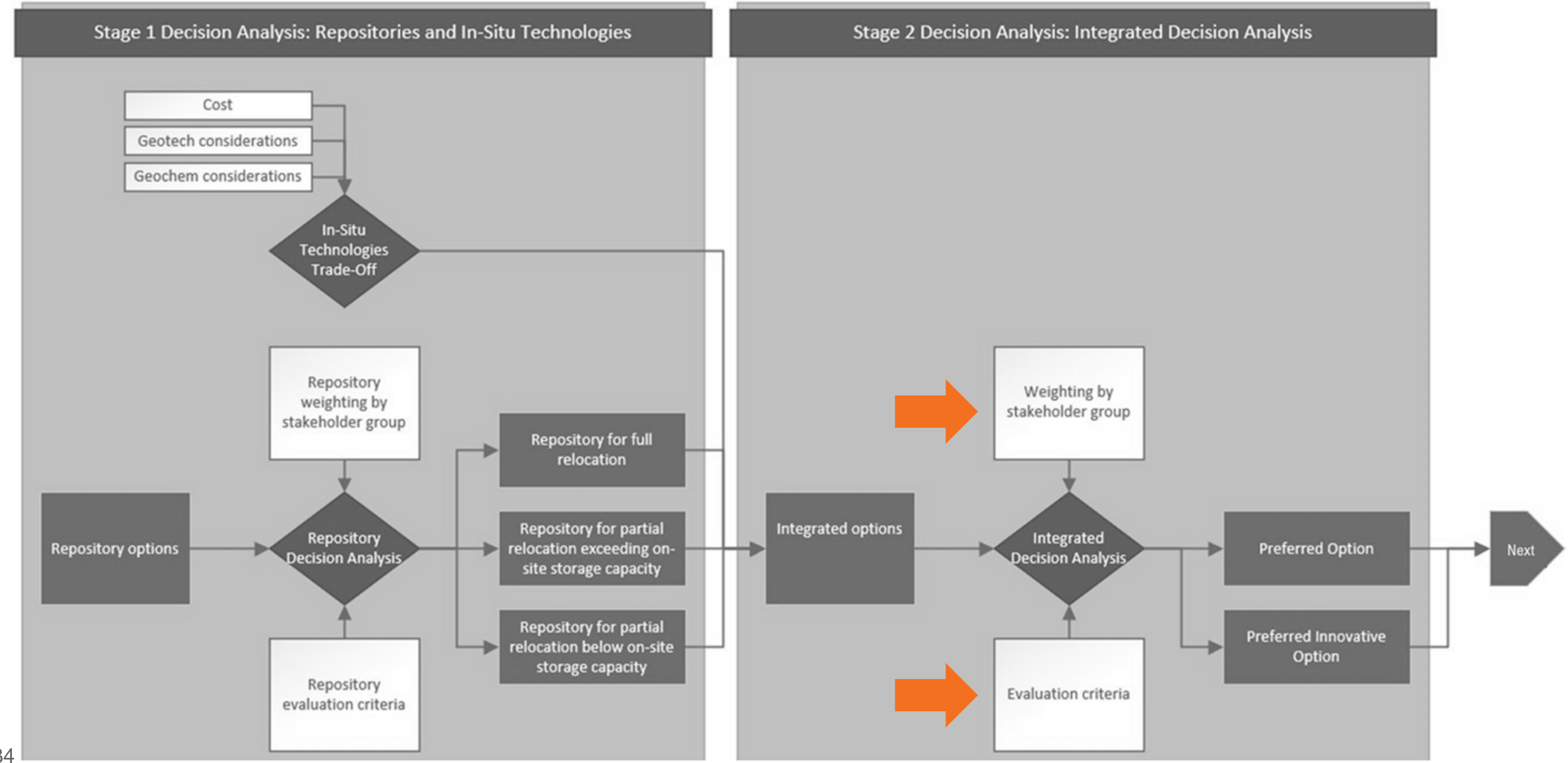
People tend to have favorite references specific to their technical fields. For a good introduction to above methods, consider Decision Behaviour Analysis and Support by Simon French, John Maule, and Nadia Papamichai, published by Cambridge University Press, 2009

Closure Risk Assessment Informs Closure Decisions

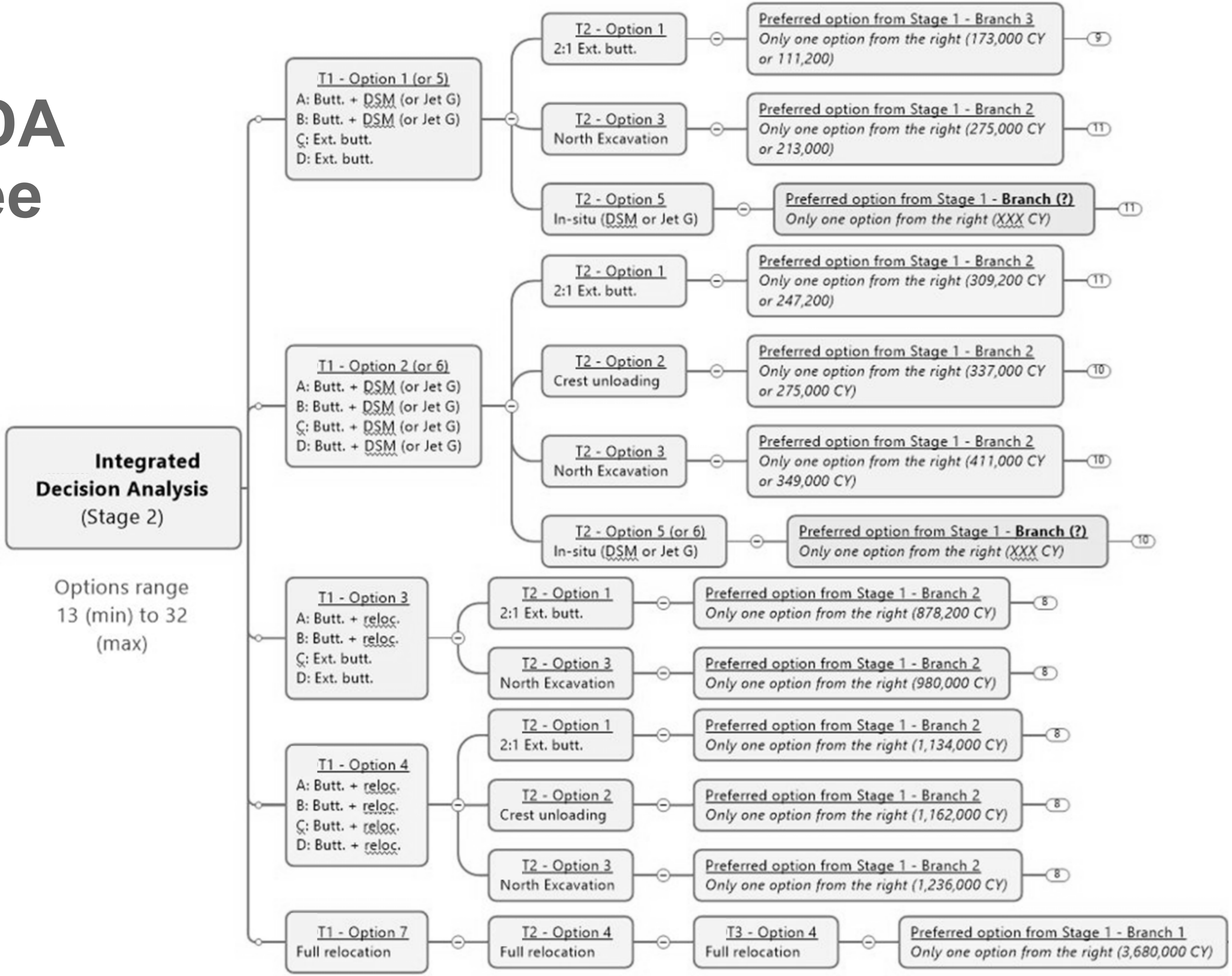
Review closure alternatives for critical flaws (e.g., technical uncertainty, significant cost relative to other alternatives that offer similar risk reduction)



Example of Two-Stage Multi-Criteria Decision Analysis (MCDA)



Stage 2 MCDA Decision Tree

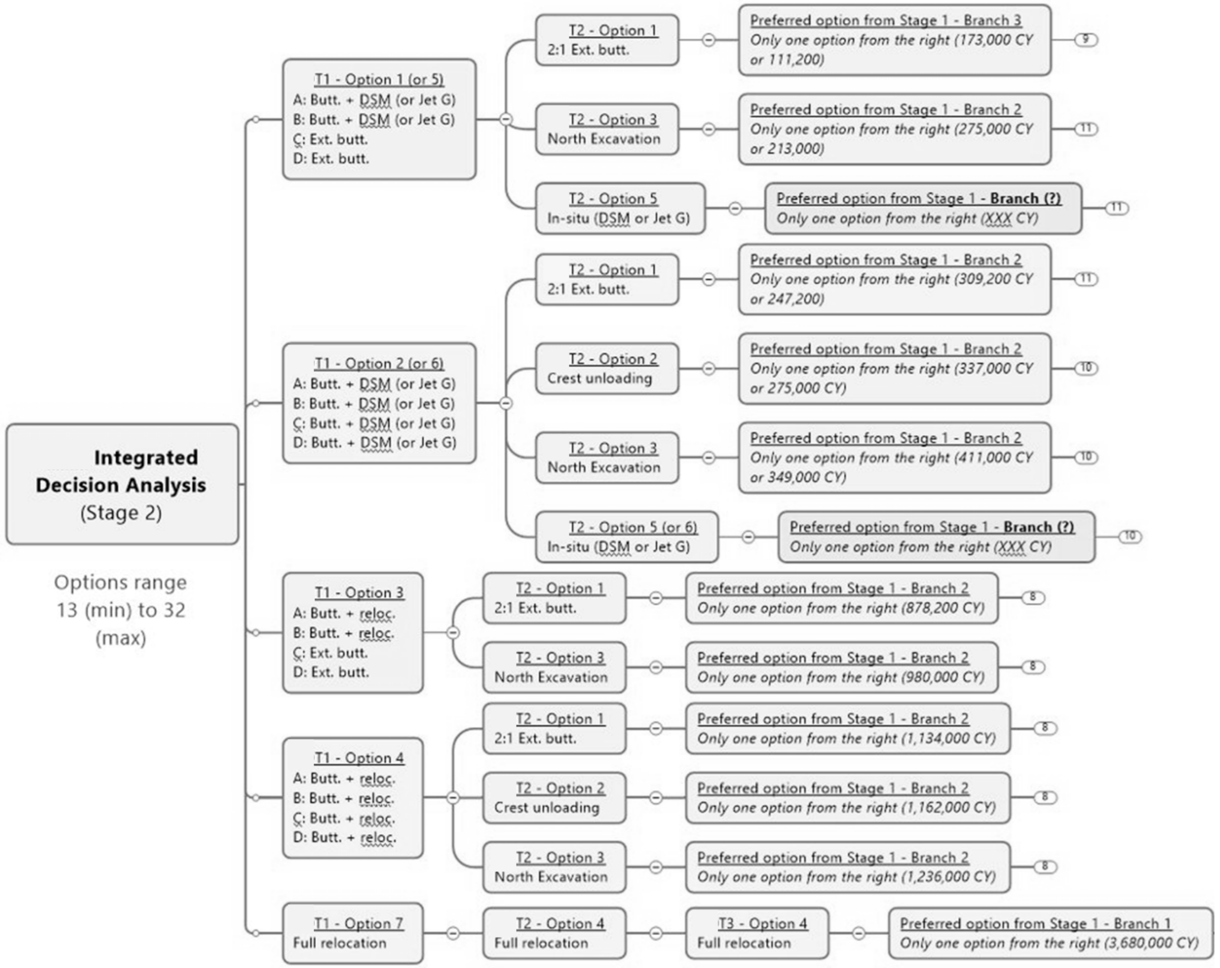


Viable Alternatives

Achieve closure objectives, including risk reduction and stakeholder engagement

Integrate different combinations of engineering controls

Represent different scenarios of high/low initial capital vs. long-term cost

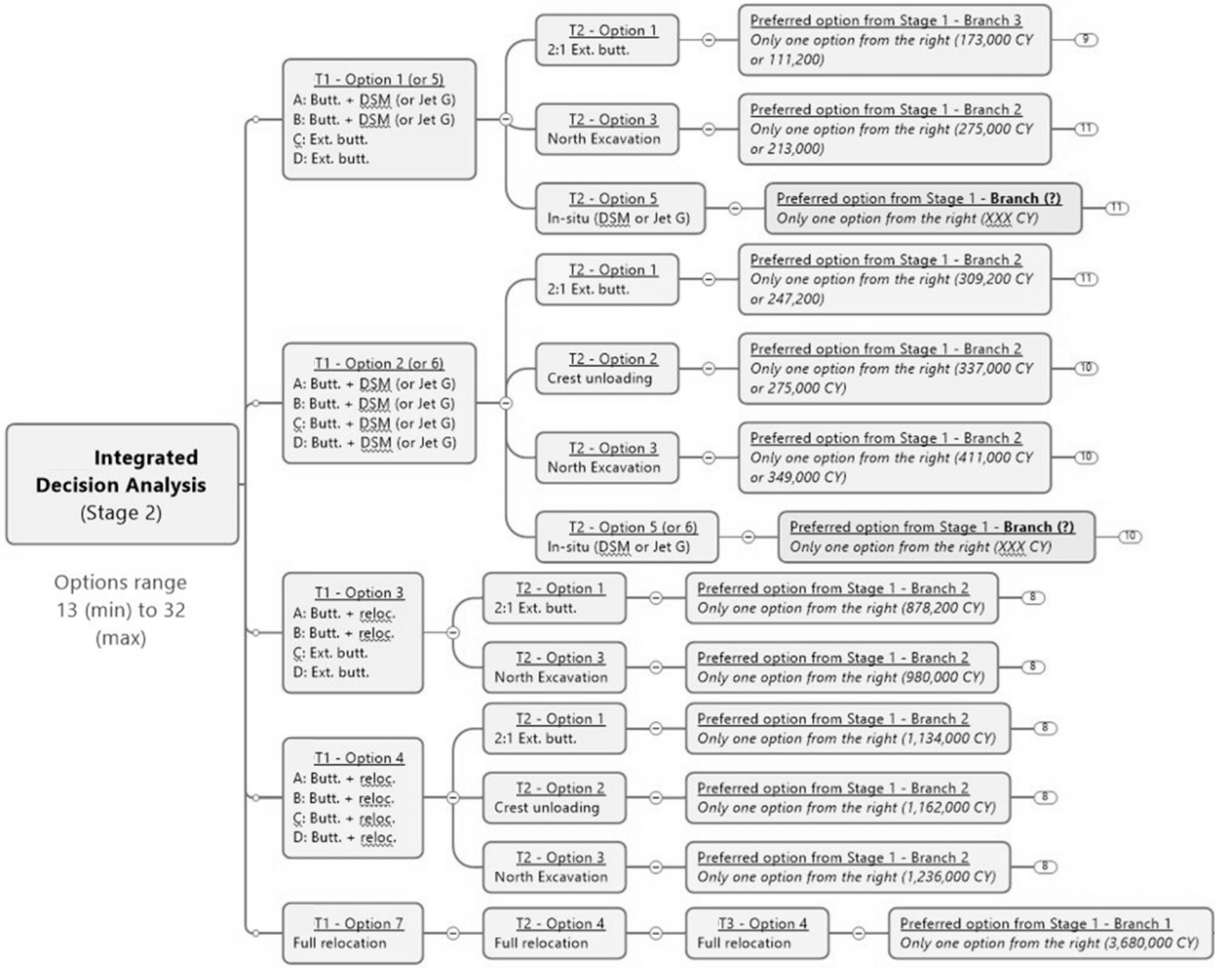


Evaluation Criteria

Criterion should have potential to meaningfully differentiate between remedial alternatives (e.g., increase or decrease in land disturbance)

Criterion should have a unique basis for evaluation (e.g., avoid using the same parameter to inform more than one criterion)

Consider each criterion as a "trade-off" between alternatives



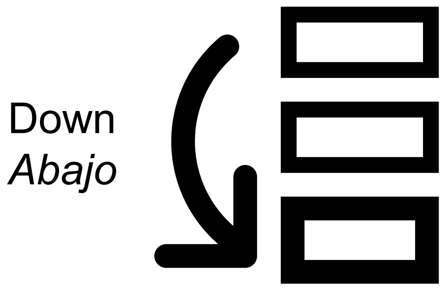
Weighting Factors

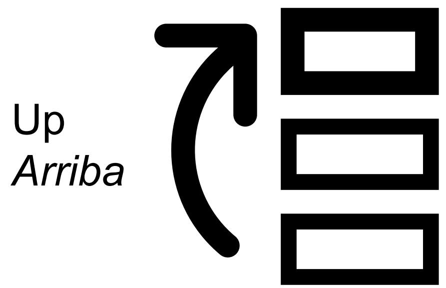
Assign relative importance of each criterion

Opportunity to engage multiple internal and external stakeholder perspectives

Workshop method varies

Informs the sensitivity analysis



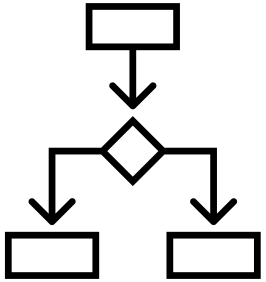


Decision Analysis and Uncertainty

Complete analysis on base case inputs and identify recommended base case alternative

Assess

- Sensitivity of recommendation to different combinations of weighting factors
- Sensitivity of recommendation to criterion scores (testing error/uncertainty of inputs)
- Improvement of base case alternative by incorporating elements of other alternatives
- If non-cost criteria outcome changes the recommended base case

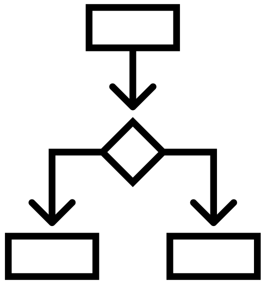


Decision Analysis and Uncertainty

Complete analysis on base case inputs and identify recommended base case alternative

Assess

Robustness of recommended base case alternative – compare final “scores” – does recommendation change on weighting factor, criterion scores, and/or cost?

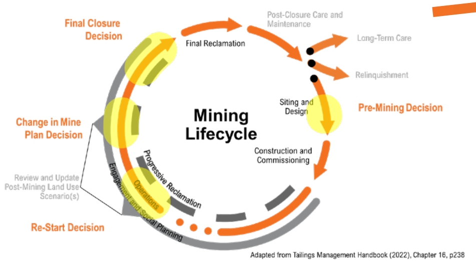


5 Conclusions

Conclusiones
Conclusions

Improve our decisions for closure
Mejorar nuestras decisiones de cierre

Remember the **LONG-TERM** aspect of the decisions we make today
*Recuerde el aspecto **A LARGO PLAZO** de las decisiones que tomamos hoy.*



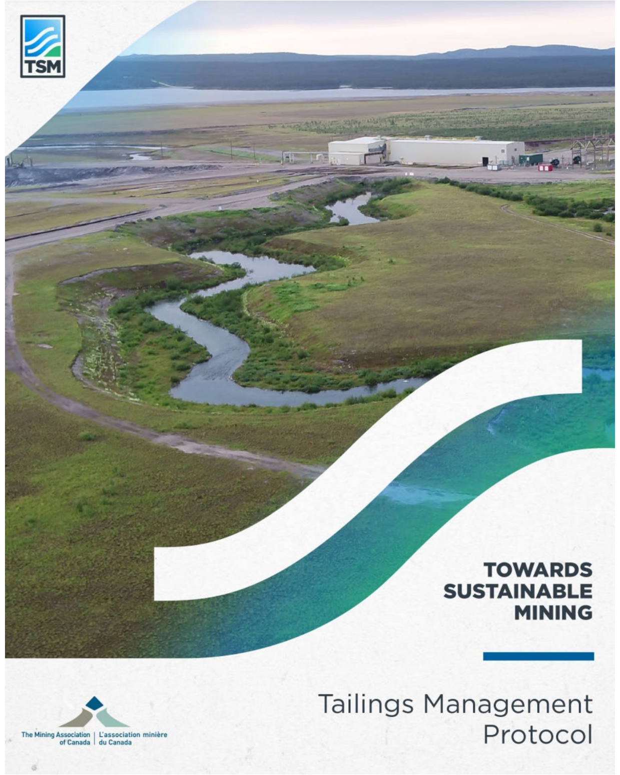
Perpetual Care and Maintenance
Cuidado y mantenimiento perpetuos

Mine Life – **Decades**
*Vida de la mina - **Décadas***

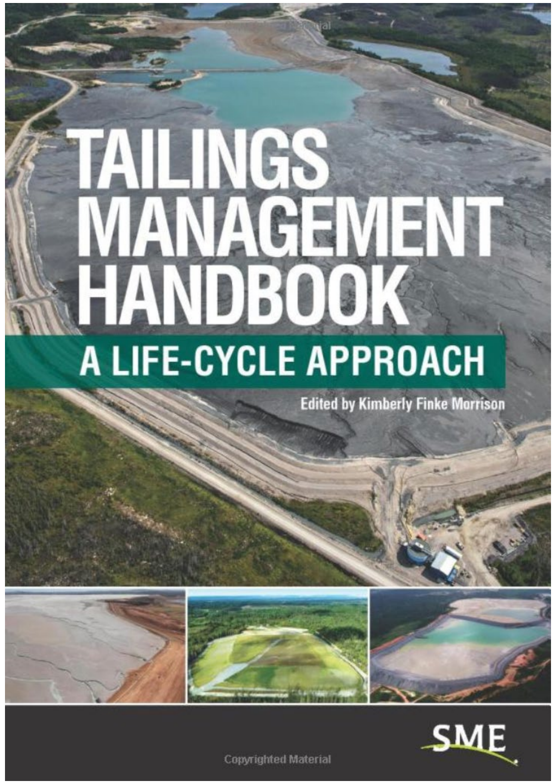
Post-Closure – **Centuries**
*Post-Cierre - **Siglos***

Useful References

https://www.icmm.com/website/publications/pdfs/environmental-stewardship/2019/guidance_integrated-mine-closure.pdf



https://mining.ca/towards-sustainable-mining/protocols-frameworks/tailings-management-protocol/



Part II Life-Cycle Planning, Chapter 16 Closure Planning and Landform Design, 2022

Useful Links – Conference Papers

TAILINGS AND MINE WASTE

https://tailingsandminewaste.com/past-tmw-conferences/

MineClosure

30 Celebrating 30 years of geomechanical excellence

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS

CSIRO | The University of Western Australia | Joint Venture

https://papers.acg.uwa.edu.au/f/mineclosure

APRIL 2018 MMSA MINE SUMMIT

April 2018 MMSA Mine Summit Flyer

April 2018 MMSA Mine Summit Proceedings

NOVEMBER 7TH 2018 MINE SUMMIT

November 2018 Mine Summit Flyer

November 2018 Mine Summit Agenda

November 2018 Mines Summit Speaker Bios

November 2018 Mine Summit Presentations

November 2018 Summit Photos

November 2018 Summit Attendees

2017 MINE SUMMIT

2017 Mine Summit Flyer

2017 Mine Summit Agenda

2017 Mine Summit Speaker Bios

2017 Mine Summit Facilitator Bios

2017 Mine Summit Attendees

2017 Mine Summit Summary

2017 Mine Summit Interactive Agenda

2016 MINE SUMMIT

2016 Mine Summit Info

2016 Mine Summit Flyer

2016 Mine Summit Agenda

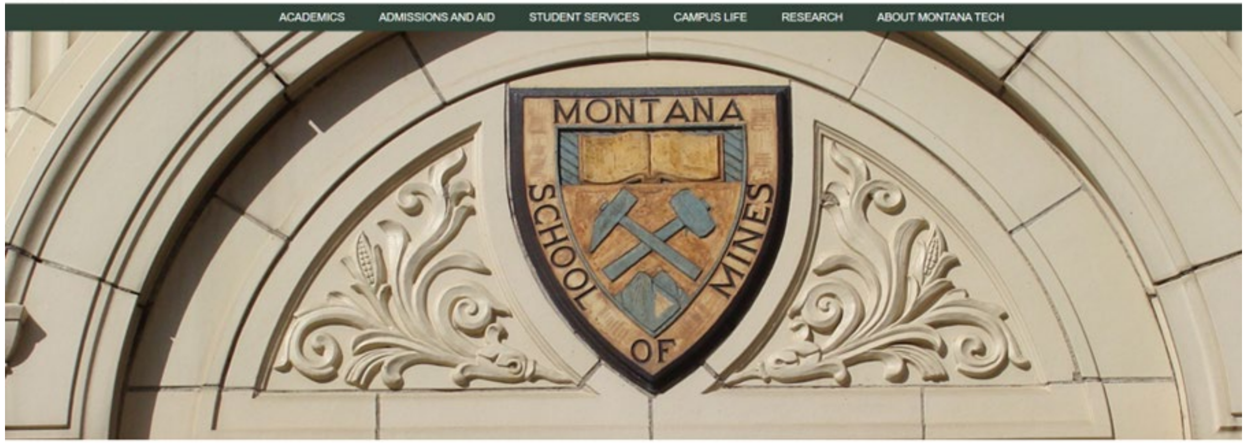
2016 Mine Summit Bios

2016 Mine Summit Attendees

https://mining.mines.edu/mine-summit/

https://www.mtech.edu/mwtp/index.html

MONTANA
TECHNOLOGICAL UNIVERSITY



Mine Design, Operations & Closure Conference

Gracias

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