Forward Looking Industry Initiatives Aimed at Managing or Reducing Tailings Risk

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BC MEND ML/ARD 31st Annual Workshop

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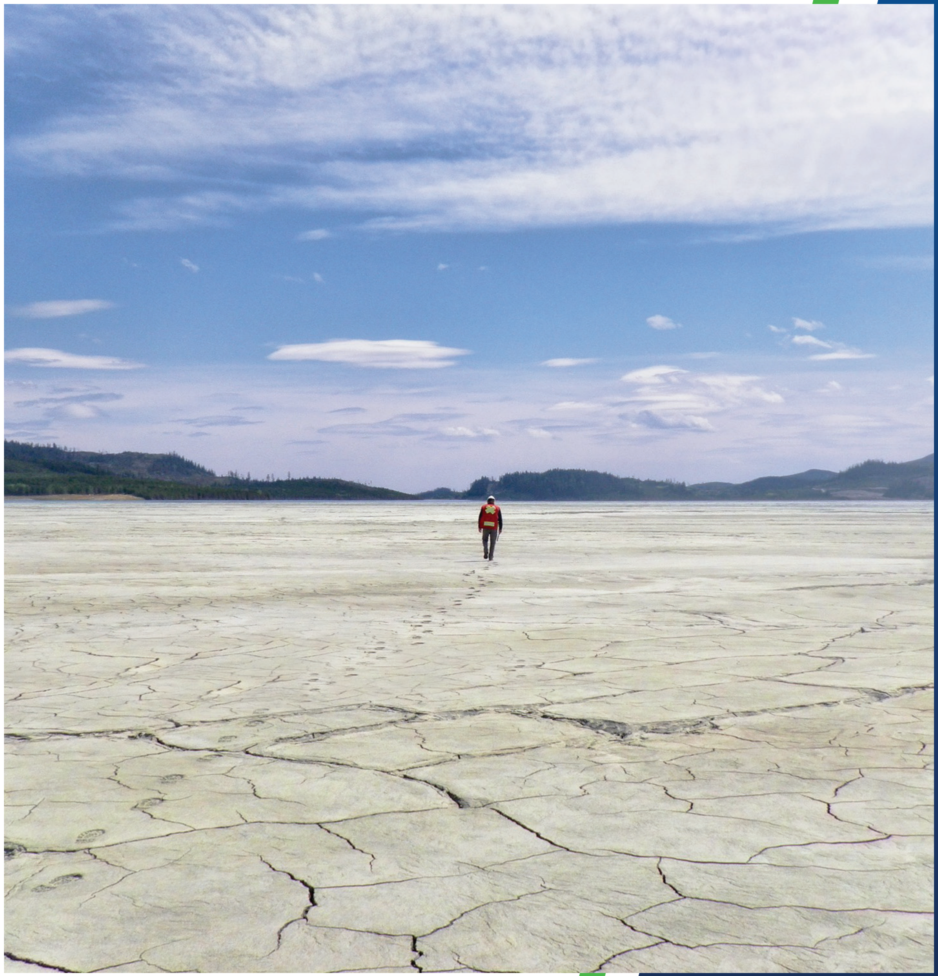

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Outline

- Context Setting
- Current State of Practice
  - Site Characterization
  - Decision Analysis
  - Performance Based Design
- The Future of Tailings Facility Engineering

Context Setting

The Challenge

- Cleaner energies and technologies are increasing metals demand
- Grades of ore bodies are declining
- Leads to more tailings (annual growth of mining/tailings about 3%)
- Leads to bigger tailings facilities and repurposing old facilities
- All mines are different, no one combination of tailings technology and management strategy is "best" for all cases!
- **How do we manage and reduce risk as TSFs are getting larger?**

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Context Setting

What is Tailings Facility Engineering?

Knowledge Areas

- Tailings milling and processing
- Design of tailings storage facilities
- Closure design
- Geotechnical engineering
- Hydrogeological engineering
- Hydrotechnical engineering
- Geology
- Geochemistry
- Environmental protection
- Construction
- Operations
- Surveillance
- Risk Assessment
- Governance

Not just geotechnical engineering anymore!

Technical Inputs

- Engineering and scientific studies
- Field work (drilling, construction)
- Lab analyses (testing and interpretation)
- Modelling (simple to advanced)

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What do we mean by tailings facility engineering?

It is all the ologies

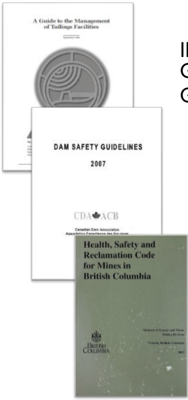
Governance is out of scope for this talk

There are a number of players that support the world of Tailings Facility Engineering. CDA… This slide gives you an indication of some of the players.

You will see in this presentation how we believe many of these organizations can support the future of tailings facility engineering.

Context Setting

Guides Supporting Tailings Facility Engineering



- 2010 – INAP GARD Guide
- 2011 – ICOLD Bulletin 139: Improving Tailings Dam Safety
- 2011 – MAC Tailings Management Guide, OMS Guide
- 2013 – ICOLD Bulletin 153: Sustainable Design and Post-Closure Performance of Tailings Dams
- 2013 – **EC Guidelines for the assessment of alternatives for mine waste disposal**
- 2014 – CDA Mining Dams Bulletin
- 2014 – De-Licensing of Oilsands Tailings Dams
- 2016 – **EGBC Site Characterization Guidelines**
- 2017 – **MEND Study of Tailings Management Technologies**

CDA – Canadian Dam Association
EGBC – Engineers and Geoscientists BC
EC – Environment Canada
ICOLD – International Commission on Large Dams
INAP - International Network for Acid Prevention
MAC - Mining Association of Canada
MEND – Mine Environment Neutral Drainage

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Global Acid Rock Drainage (GARD) Guide.
As a Canadian, in the early 2000's I had paper copies of 3 things on my desk MAC, CDA, and FEMA
Note that I have not listed failures here.

Context Setting

Guides Supporting Tailings Facility Engineering

2018
- **Dr. Morgenstern's de Mello lecture on Performance Based Risk Informed Safe Design**
- CDA Mining Dams Bulletin Update

2019
- ICMM Integrated Mine Closure Good Practice Guide

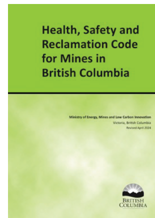
2020
- CDA Tailings Dam Breach Guidance
- Global Industry Standard on Tailings Management

2021
- ICMM Good Practice Guide on Tailings Management
- Establishment of Landform Design Institute
- Establishment of CDA/USSD Joint Working Group on EOR
- MAC Tailings Management Guide, OMS Guide Updates

2022
- **ICOLD Bulletin 194: Tailings Dam Safety Guideline**
- SME Tailings Management Handbook
- Assessment Tool for Landforms in Oilsands

2023

2024
- SME Tailings Case Studies



MOMENTUM

ICMM – International Council on Mining and Metals
SME – Society for Mining, Metallurgy, and Exploration
USSD – US Society on Dams

Becoming more international in the last 6 years.

Add integration of standards with compliance to either MAC TSM or GISTM in 2024

Tailings Facility Engineering - Current State of Practice

Risk-informed Approach to Tailings Management

- Risk Assessment (Likelihood x Consequence)
- **Site Characterization**
- **Decision Analysis**
- Understanding and managing uncertainty
- **Performance-based design**
- Surveillance
- Adaptation

Figure 8: Framework for a risk-informed approach for tailings management

Tailings Facility Engineering - Current State of Practice

Site Characterization

- Site characterization sets the basis of design (MAC 2011):
  - “basis of design addresses conditions imposed by the site, requirements of the project, and regulations; and
  - design criteria are standards set by engineering practice and/or regulation, in accordance with the basis of design.”
- The ground conditions at any site are a product of its total geological and geomorphological history.
  - We call this total geological history, it includes stratigraphy, the structure, the former and current geomorphological processes and the past and present climatic conditions (Fookes 1997).

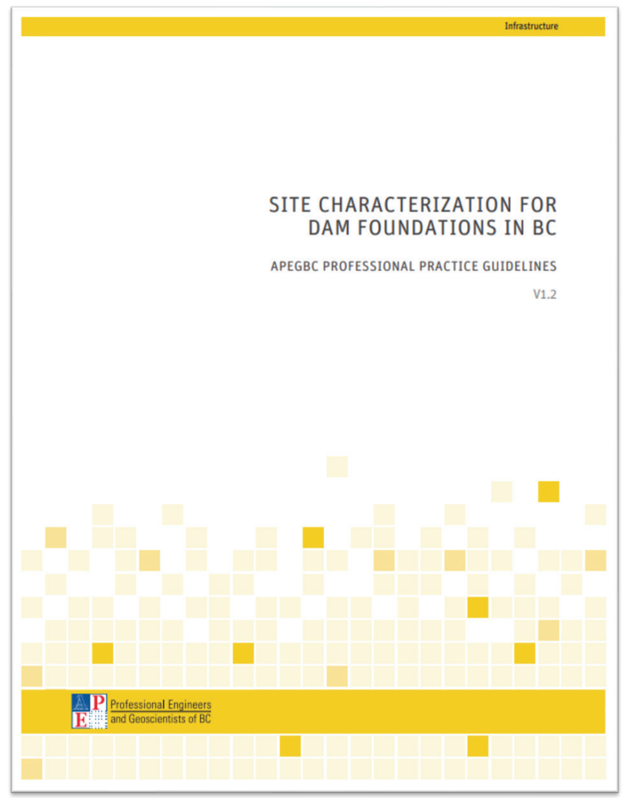
Mining Association of Canada (MAC). 2011. Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water Management Facilities.
Fookes, P. G. (1997). The First Glossop Lecture. 'Geology for Engineers: the Geological Model, Prediction and Performance'. Quart. Jl. Engrg. Geol., 30, 293-431.

Designers usually have a broad vision in mind e.g. is the site a flat desert; has it been glaci
seismic. Need experienced team

Tailings Facility Engineering - Current State of Practice

Site Characterization Guidelines

- Provide direction on good practice for site characterization and on the level of detail required.
- The guidelines are intended to lead to a common level of expectation for professionals, owners, regulatory authorities, First Nations, and other stakeholders.
- A Site Characterization Assurance Statement is required at the feasibility and detailed design stages of a project.



Engineers and Geoscientists BC. 2016. Site Characterization for Dams in BC – Professional Practice Guideline. V. 1.2.

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10

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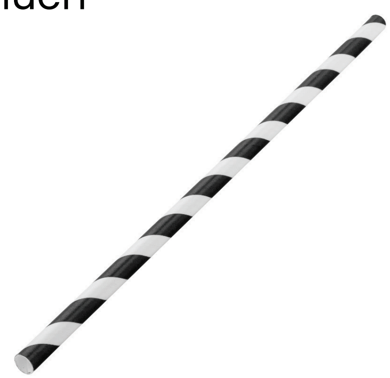
Site Characterization

- The question to ask is why is this soil/rock here?
  - Fast flowing water? – alluvial gravels
  - Slow moving water or flooding? – overbank silts
- A conceptual model of why the terrain looks like it does helps us understand what could be between the sparsely spaced drill holes.
  - Think of a drill hole as a straw in a layer cake, how much of the geology do we really see from a drill hole



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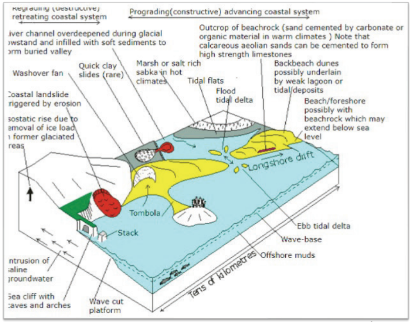
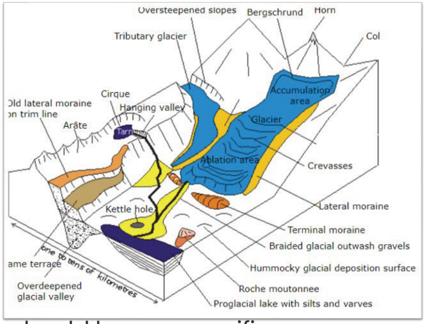
Tailings Facility Engineering - Current State of Practice

Geomorphological Models

- Coastal Model



- Glacial Model



Once we have a model, each drill hole should have a specific purpose to <u>reduce uncertainty</u>, not just to see what we find.

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https://environment.uwe.ac.uk/geocal/totalgeology/

Ask why things are where they are.

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Tailings Alternatives Assessment

- Decision making process for evaluating numerous alternatives and selecting preferred tailings management strategy
- Consider alternative site locations, and different tailings technologies
- Typically uses a multi-criteria decision analysis framework

Where we want to be?

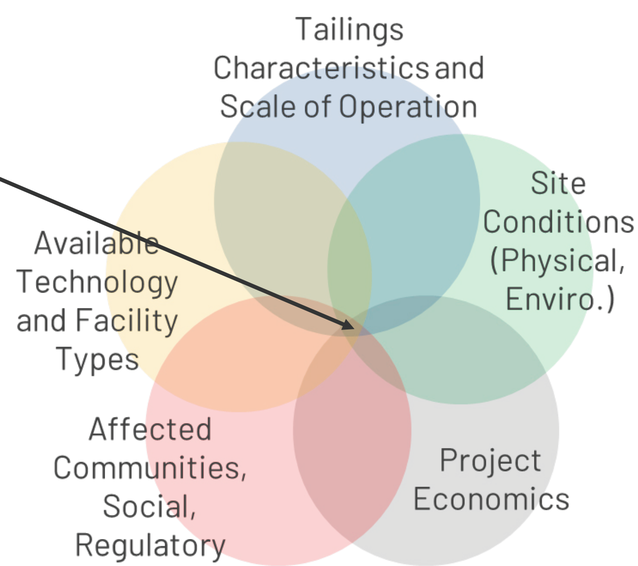
Balancing objectives with the ultimate goal of ***reducing risk***

Acknowledging that **"one size does not fit all"**

Sustainable Design Paradigm:

"resilient structures that are physically, chemically, ecologically, and socially stable"

ICOLD. 2019. Bulletin 181: Tailings Dam Design Technology Update.



Tailings Facility Engineering - Current State of Practice

Typical Steps in a Multi-Criteria Decision Analysis

1. Decision Context
- Decision statement (overall study purpose and objective)
- Confirm battery limits/ design criteria/ design assumptions
- Confirm team

2. Develop Evaluation Criteria
- Identify Critical Flaws, which are policy Objectives (MUST HAVES) (used to screen alternatives)
- Identify strategic Objectives (WANTS) (used in the MAA for evaluating TSF alternatives).
- Develop MAA ledger

3. Identify TSF Alternatives
- Identify possible locations within study area
- Identify range of technologies
- Screen potential alternatives with Critical Flaws (MUST HAVES)
- Develop list of TSF alternatives to progress to MAA

4. Characterize TSF Alternatives
- Characterize remaining TSF alternatives to an appropriate level for comparison. Use MAA ledger to guide characterization details. Sensitivity scoring can be completed for TSF alternatives with high uncertainties.
- Develop high-level comparative cost estimate.

5. Multiple Accounts Analysis (MAA) Preparation and Workshop

- MAA workshop preparation:
  - Complete steps 1 - 4
  - Have team review and provide MAA ledger, scoring criteria and TSF alternatives
  - Have workshop attendees individually Weight the MAA Objectives (how important is this objective? 10 – very important; 0 – not important)
- MAA workshop:
  - Review of above steps (to develop a common understanding)
  - Review MAA ledger Objectives Weighting
  - Review MAA TSF alternatives scoring
  - Develop base case and sensitivities cases
  - Review MAA results
  - Review costing
  - Summarize risks, opportunities and uncertainties
  - Confirm TSF alternatives to be carried forward to next study phase
  - Discuss forward work planning for future study phases

6. Documentation and Future Planning
- Reporting
- Present to Tailings Review Board
- Planning for next stage (site investigations and design)

Tailings Facility Engineering - Current State of Practice

Tailings Multi-criteria Decision Analysis

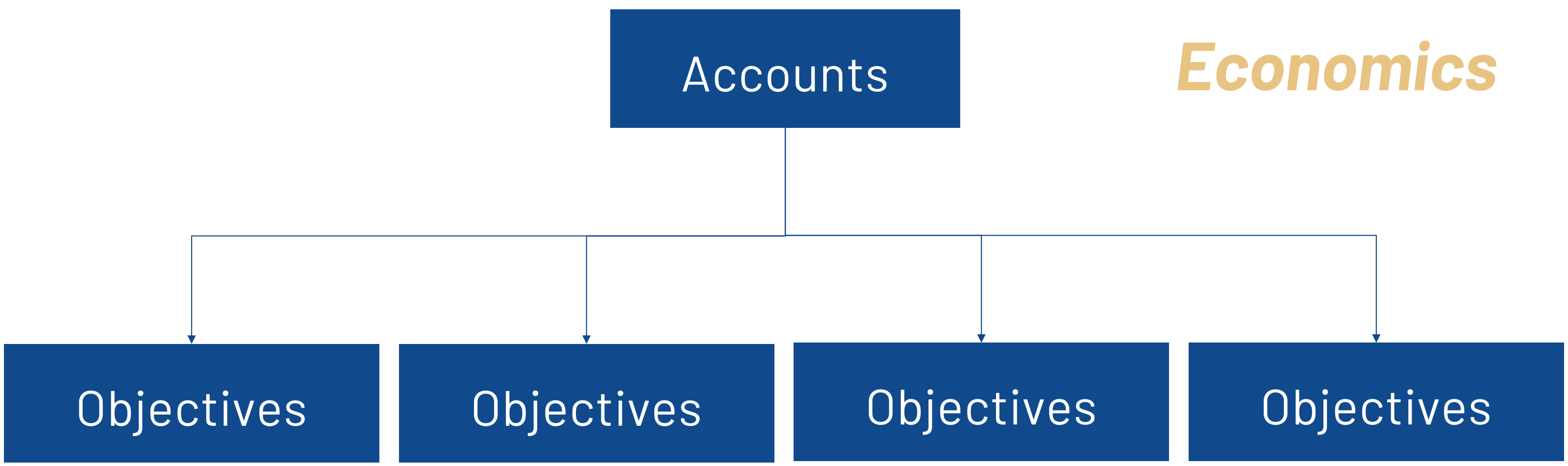
- **Identify Comparison Criteria (Ledger)**
- Characterize Alternatives and Scoring
- Weighting
- Results

Technical

Environmental

Social

Economics



15

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Tailings Multi-criteria Decision Analysis

- **Identify Comparison Criteria (Ledger)**
- Characterize Alternatives and Scoring
- Weighting
- Results

Number	Account	Objective
1	Technical	Maximize ability to meet stability requirements
2		Minimize surface water management complexity
3		Maximize operations and construction simplicity
4	Environmental	Minimize potential for seepage bypass collection
5		Maximize closure landform preference
6		Minimize impacts to critical habitat
7		Minimize disturbance area
8	Social	Minimize public in potential runout zone
9		Minimize impact on cultural resources
10		Minimize visibility at local points of interest
11	Economics	Minimize capital expenditure
12		Minimize operating expenditure

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16

Tailings Facility Engineering - Current State of Practice

Tailings Multi-criteria Decision Analysis

- Identify Comparison Criteria (Ledger)
- **Characterize Alternatives and Scoring**
- **Weighting**
- Results

Objective		Scoring Criteria						Alternative Scores			MAA Scores		
Objective Description	Objective Weighting	1	2	3	4	5	6	Alt. 1	Alt. 2	Alt. 3	Alt. 1	Alt. 2	Alt. 3
Account 1 – Technical													
Minimize/Maximize...	5							3	4	5	15	20	25
Minimize/Maximize...	7							4	2	4	28	14	28
Minimize/Maximize...	8							1	3	5	8	24	40
Account 2 – Environmental		Qualitative or quantitative description developed based on alternative characterization											
Minimize/Maximize...	3							5	4	3	15	12	9
Minimize/Maximize...	6							1	2	4	6	12	24
Minimize/Maximize...	2							3	2	1	6	4	2
Account 3 – Social													
Minimize/Maximize...	9							4	3	3	36	27	27
Minimize/Maximize...	10							2	3	4	20	30	40
										Total MAA Score	134	143	195
										Rank	3	2	1

$$Total\ MAA\ Score = \sum(Objective\ Weighting\ X\ Alternative\ Score)$$

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17

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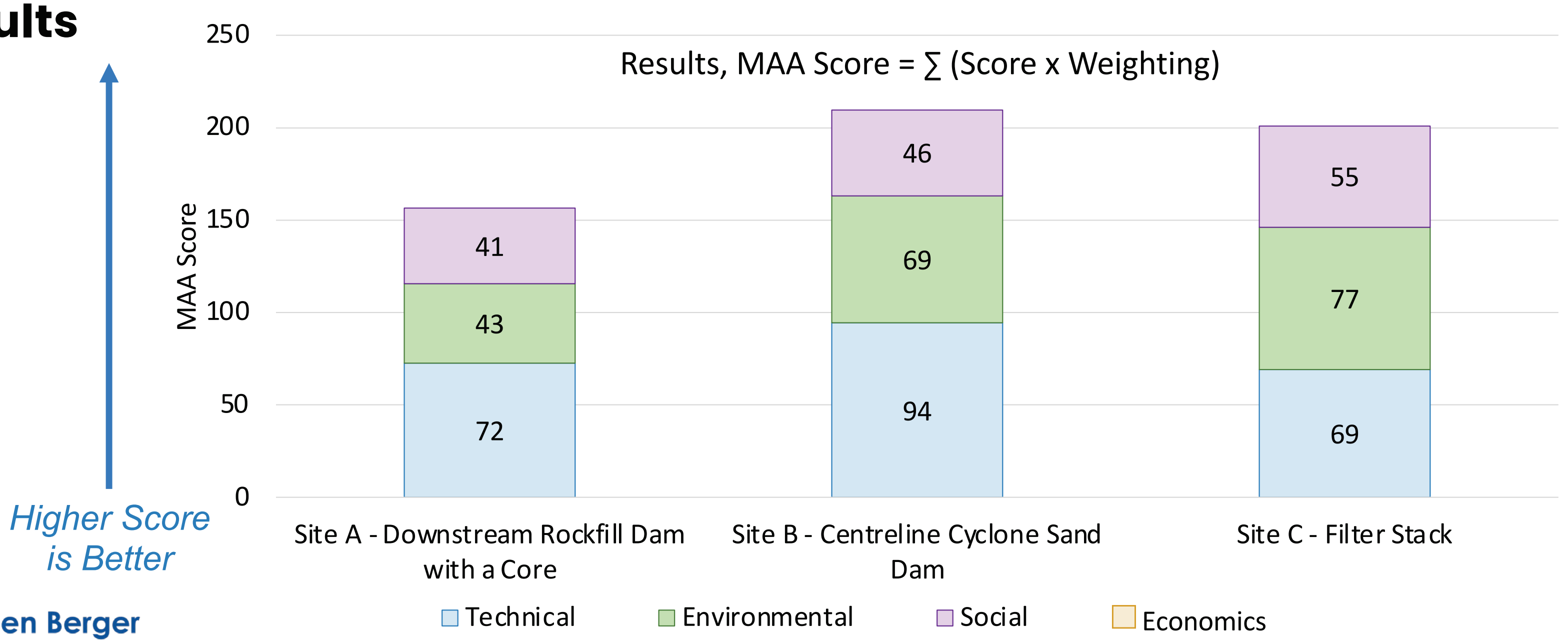
Tailings Multi-criteria Decision Analysis

- Identify Comparison Criteria (Ledger)
- Characterize Alternatives and Scoring
- Weighting
- **Results**



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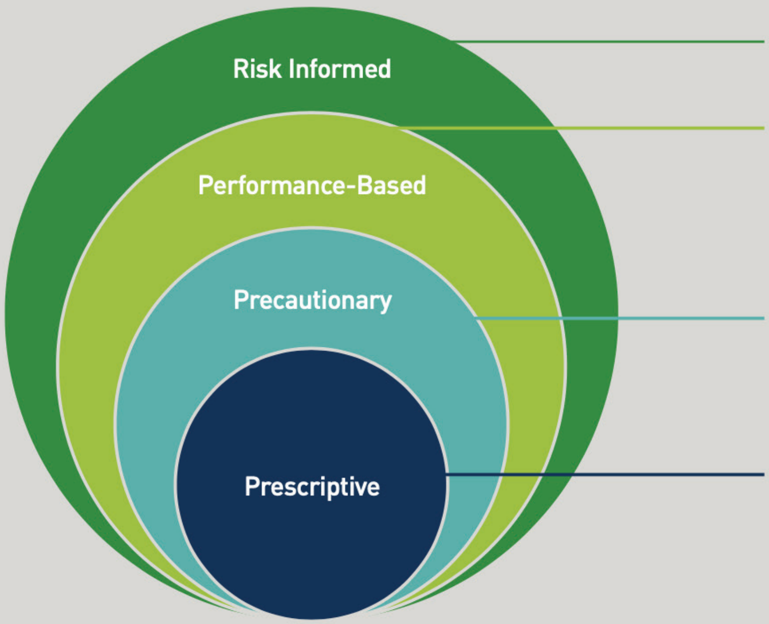
Tailings Facility Engineering - Current State of Practice

Design Approaches



Considers the management of uncertainty and risk in material decisions regardless of approach.

Extends problem interrogation beyond the Precautionary approach, establishing flexible, meaningful and measurable performance objectives throughout Construction, Operations and Closure, and enhances the assessment of safety in a more comprehensive manner.

Extends the Prescriptive approach using the Observational Method to monitor for performance that is indicative of assumed potential failure modes to validate the design basis, and to mitigate if not.

Applies prescribed criteria, such as Factor of Safety, to assess the margin of safety against shear failure but is not able to address complex or dynamic design considerations, such as the risk of brittle failure and the magnitude of seismic deformations.

International Council on Mining & Metals (ICMM). 2021. Tailings Management Good Practice Guide. May.

Tailings Facility Engineering - Current State of Practice

Performance-Based Design

- Extends the Observational Method (Peck 1969)
- Essential elements (for a given failure mode):
  - Identify key performance parameters and associated criteria
  - Develop design
  - Predict performance and modify design to meet performance criteria
  - Monitor performance and compare to predictions (history matching)
  - Optimize the design and construction plan
- **Key aspect ➔ "History Matching"**
- Can apply performance-based design to many failure modes that are considered in design of tailings facilities
- **Key aspect ➔ Prescriptive design when uncertainty is high and move towards performance-based design as uncertainty is reduced**

Peck, RB, 1969. Advantages and Limitations of the Observational Method in Applied Soil Mechanics. Ninth Rankine Lecture, Geotechnique 19, No. 2.

Ability to predict slope stability performance in a reliable and timely manner has improved significantly in recent years
Supported by case studies
Linking to predictions
Becoming more of a reality
History matching
Comprehensive definition and simulation of failure mode and the feedback loop
Need to have possible design modifications developed ahead of time, not "wait and see"

Tailings Facility Engineering - Current State of Practice

Performance-Based Design

- **Establish key parameters that are to be measured/monitored during construction and operation (deformations and pore pressures)**
- Establish allowable criteria for the key parameters
- Establish slope configuration
- Conduct deformation analyses that couple stress-strains-pore pressures
- **Predict key parameters and compare to criteria – accounting for uncertainty**
- Examine stress and deformation conditions to understand keys to system performance, re-assess criteria, if necessary (history matching)
- Modify design as required to meet criteria
- **Measure key parameters and compare to predictions**
- Modify or optimize design

Kafash, et al. 2022. Performance Based Design – How does Performance Based Design Work? Tailings and Mine Waste 2022

- Identify key performance parameters and associated criteria
- Develop design
- Predict performance and modify design to meet performance criteria
- Monitor performance and compare to predictions (history matching)
- Optimize the design and construction plan

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For Point 4 – comment on caution around this point and limitations of current models. Analyses can be used as a general guide to understand the operative mechanisms, not as the sole basis to evaluate performance

At any time, can calculate the residual factor of safety

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Performance-Based Design

- Benefits of deformation analyses for slope stability assessment:
  - Comprehensive understanding of the dam's performance and indications where there could be areas of potential concern
  - Supports monitoring program
  - Improve understanding of the dam during construction and operation and reduce uncertainty on dam behaviour
- **Key aspect → Transparent documentation of risks and uncertainties**

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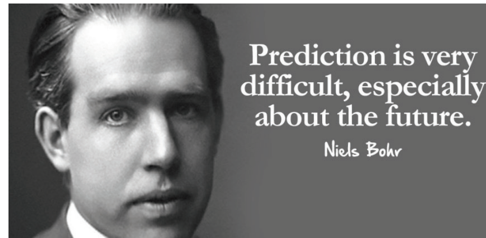
Can build on learnings from static analysis to inform the seismic analysis
Learn as you go...

The Future of Tailings Engineering

Survey: What Could Tailings Facility Engineering Look Like in 2030?

Issued to 240 tailings practitioners around the world (60 responses)

1. Technical:
   a) Tailings technology and deposition strategies
   b) Closure strategies
   c) Characterization of tailings and foundation soils
   d) Design
   e) Surveillance
2. Competency and Capacity:
   a) Guidance documents
   b) Training and development of Tailings Facility Engineers
   c) Regulatory competency and capacity



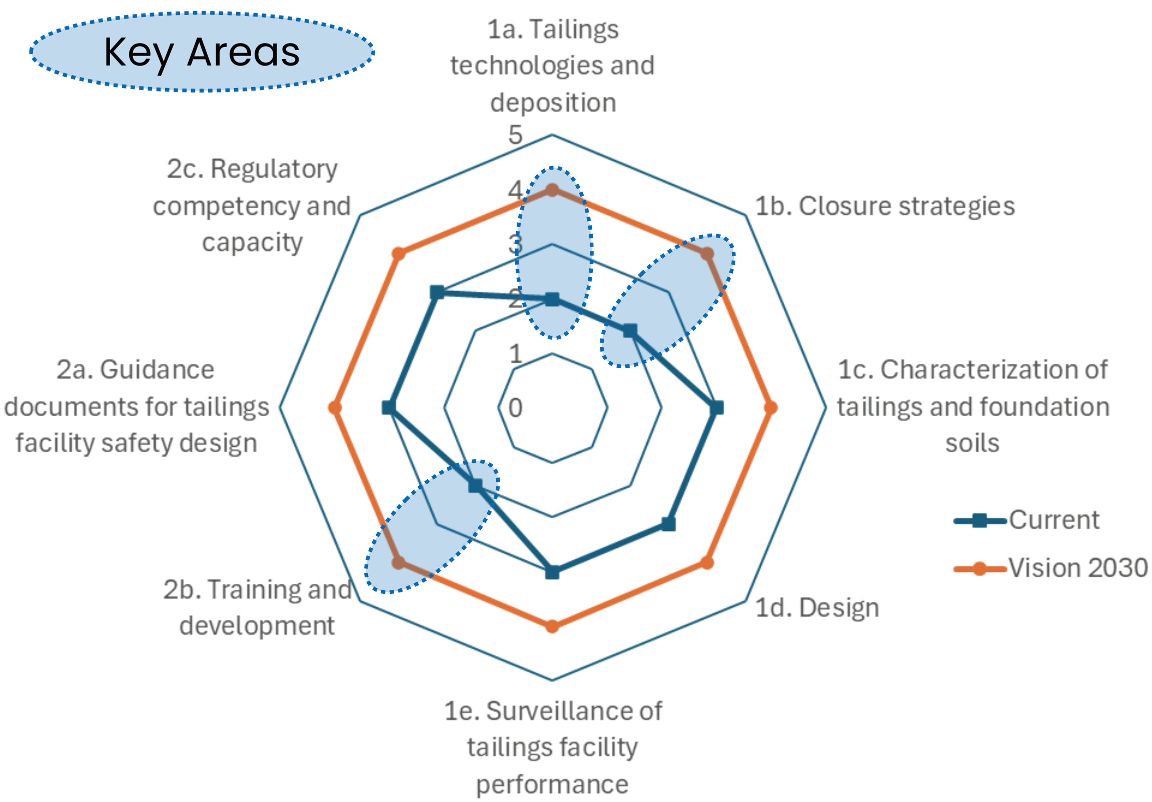
Small, A. et al. 2024. What Could Tailings Facility Engineering Look Like in 2030? Tailings and Mine Waste 2024.

Intended Audience:

- Owners and Operators, Consultants, Academia, Suppliers, Regulators
- Geotechnical, geological, hydrotechnical, hydrogeological, and civil engineers
- Young engineers who are interested in tailings facility engineering, but would like to know where we are headed

The Future of Tailings Engineering

Estimated Situation For Each Topic Based on Questionnaire



0 = not implemented / used / known

1 = implemented in research / regarded as future (pilot test) / known by few

2 = implemented in a few operations / used in a few places / known by few but regarded as an option

3 = implemented in most operations / used in most places / known by many

4 = implemented in many operations / used in many places / known by most

5 = implemented in "all" operations / best possible use / fully known

The Future of Tailings Engineering

2b: Training and Development

- Establish the discipline of Tailings Management Professional (TMP)
  - distinct career path for young engineers, rather than, as so many do now, "just fall into tailings engineering"
  - TMP has general knowledge in areas of tailings facility engineering with a specialty in one or more of those knowledge areas
  - ICOLD forming a working group to develop the scope for the TMP discipline and will work with other organizations (SME, ICMM, CDA) to define it
- More coordinated training
  - Courses like TailENG
  - Graduate programs
  - SME Tailings Training Portal

Colorado State University

THE UNIVERSITY OF BRITISH COLUMBIA
Norman B. Keevil Institute of Mining Engineering
Faculty of Applied Science

UNIVERSITY OF ALBERTA

Tailings cohorts in post graduate programs
Develop Masters-level program focused on training engineers to enter the tailings profession

Develop Tailings Training Portal that reflects available training in the world.
Use the Portal to support developing a coordinated training program.

The Future of Tailings Engineering

1a: Tailings Technology

- Demonstrated defensible decision making (e.g., prevalent use of MAA, ALARP)
- Conventional/slurried tailings:
  - Still the majority with focus on centerline/downstream methods or upstream methods with engineered structural zones (i.e., no new "classical" upstream dams)
  - Improved Perception: high degree of confidence in slurry tailings facilities
- Filtered tailings will play a larger role
  - Embraced as a companion technology to conventional/slurried tailings
    - Needs more technical guidance - SME
- Co-disposal of tailings and waste rock
  - more prevalent
    - Needs more technical guidance

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- MAA that considers the whole mine, not just the tailings. Includes the mining plan, water restrictions, closure, circular economy.
- Work with mining companies and MAC/ICMM to promote this concept.
- Also, develop financial models that can support better closure decisions.
- Recent technical guidance from Rio Tinto and BHP on filtered tailings, SME working group advancing geotechnical aspects

The Future of Tailings Engineering

1b: Closure Strategies

- Consensus on an effective definition of Safe closure/ Responsible closure
- Defined and standardized design criteria for closure, incl. transfer of ownership
- Less water in the tailings and impoundments
- Financial models that benefit good practices and effort from project conceptualization, through operations and into closure
- Long-term monitoring with remote methods and AI
- Establish the role of reclamation designer of record (RDR) working in parallel with EOR

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- SME is tackling a tailings closure handbook

"Begin with the end in mind". Closure should not be an afterthought.
- closure design considerations/ criteria,
- safe closure
- landform design
- governance
- relinquishment
- cost estimating / bonding"

- CDA has a working group on Risk Informed Closure Design
  - Develop guidance on "safe" or "responsible" closure.
- MAC is updating the tailings guide and has a subgroup on closure
- Some jurisdictions are developing guidance for relinquishment of assets
- Need to make more informed decisions from the beginning that are not based on NPV. Don't be naive, need to develop the business case. Engineers don't think like this. Recent discussions suggest Also do all in total cost without discounting.

The Future of Tailings Engineering

1c: Site Characterization

- "tools are already available today, but the toolbox could be better organized, and the tools sharpened"
- Focus on unsaturated soil mechanics and critical state characterization
  - Wider use of innovative technologies for in-situ water content estimation (e.g., nuclear magnetic resonance)
  - New technologies for estimating in-situ void ratio
  - Improved characterization of liquefaction potential and post liquefaction strength
- Initiatives underway by academia, industry, and suppliers

The Future of Tailings Engineering

1d: Design

- "Further recognition of the value of Performance Based Design and significantly greater prominence in its use"
  - Integration of complementary roles of PBD and classical approaches (e.g., LEM)
  - Fully coupled deformation and seepage models
- Regulatory capacity will still be a limitation to implementation
  - Requires educating industry
- Dam breach analysis that reflect the reality of tailings dams vs water dams
  - Informed ERPs

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- PBD: integrating advanced computer modelling with actual performance to reduce uncertainty and conservatisms in design
- It need much more significant characterization to support.
- Need to just do the advanced work as base scopes.
- CSL for every project.
- Treat an extreme consequence facility with the respect that it deserves.
- Reduced uncertainty for dam breach analyses
  - Research to improve models and characterization and enhance guidance
  - CANBREACH – research
  - CDA – guidance
- No water covers required for geochemistry reasons
  - Desulphurization of tailings in the mill.
  - Enhanced financial models.
  - MAA for the mine, not just tailings.

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1e: Surveillance

- Increased use of “area” measurements (e.g., InSAR, fibre optics, “Smart” geofabrics, ERT cables, drones, etc.)
- Surveillance programs/systems developed based on risk assessment and failure modes
- Widespread automation with improved user interfaces with integration of collected data directly into engineering models
- Data scientists employed to manage the reams of data with increased use of AI for data review/screening
- Being implemented by owners and providers

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Tailings Facility Engineering: Current and Future Practice

Summary

- Tailings facilities are getting larger, to meet the challenge, we need:
  - Sophisticated site characterization techniques
  - Robust, inclusive, and defensible decision making
  - Risk-informed performance-based safe design calibrated to site conditions and integrated with surveillance systems

Yesterday

Today

Tomorrow?

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- The future is bright. General sense of optimism.
- Impressed by the overall developments & achievements in recent years
- More impressed by the anticipated & possible developments to 2030
- Aim to keep the momentum of improving tailings facility engineering supported by ICOLD TC L jointly with other organizations
- A comprehensive summary report of this work to be published at the end of 2024

Questions

Audience Input QR Code

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