What Could Tailings Facility Engineering Look Like in 2030?
Version 2.0

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For Presentation to Edmonton Geotechnical Society – May 16, 2024

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Tailings Facility Engineering

- 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

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

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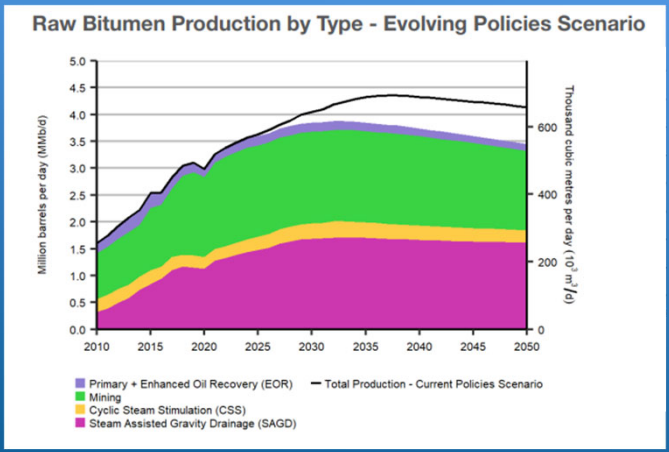
Future Mining (cont'd)

- Mining is expected to grow by about 3% per year
- Oil Sands Mining (from "Canada's Energy Future" in 2021)



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Future Tailings Production and Storage

- Grades of ore bodies are reducing
- To extract a unit of metal, there will need to be more ore processed than previously
- Leads to more tailings
- Repurposing old facilities
- More filtered tailings
- Lots of slurried facilities

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Organizations Supporting T.F.E.

Universities, technical associations, etc.

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Why 2030?

- Why not 2040 or 2050?
- "Next 6 years will go by in the blink of an eye"
- Reflect on some of what has happened in the past 6 years
- Start with guidance documents

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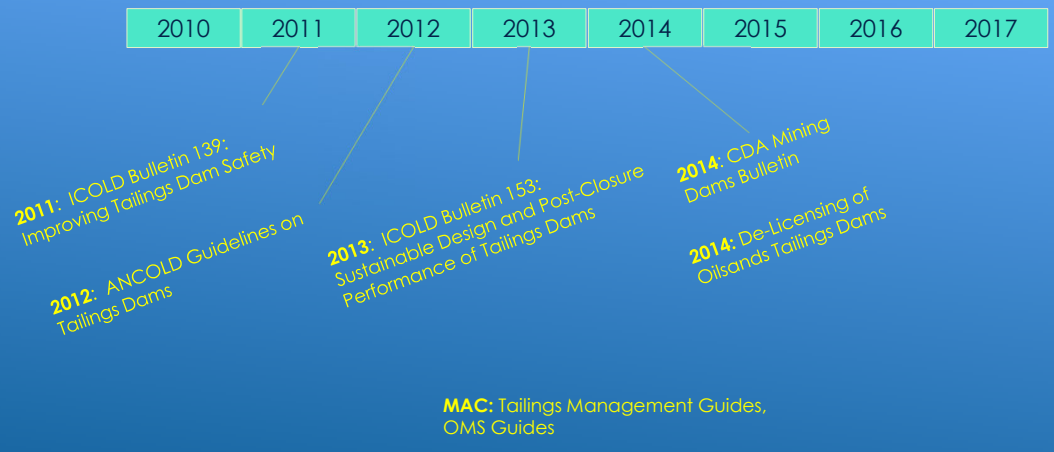
Guides Supporting Tailings Facility Engineering



MAC: Tailings Management Guides, OMS Guides

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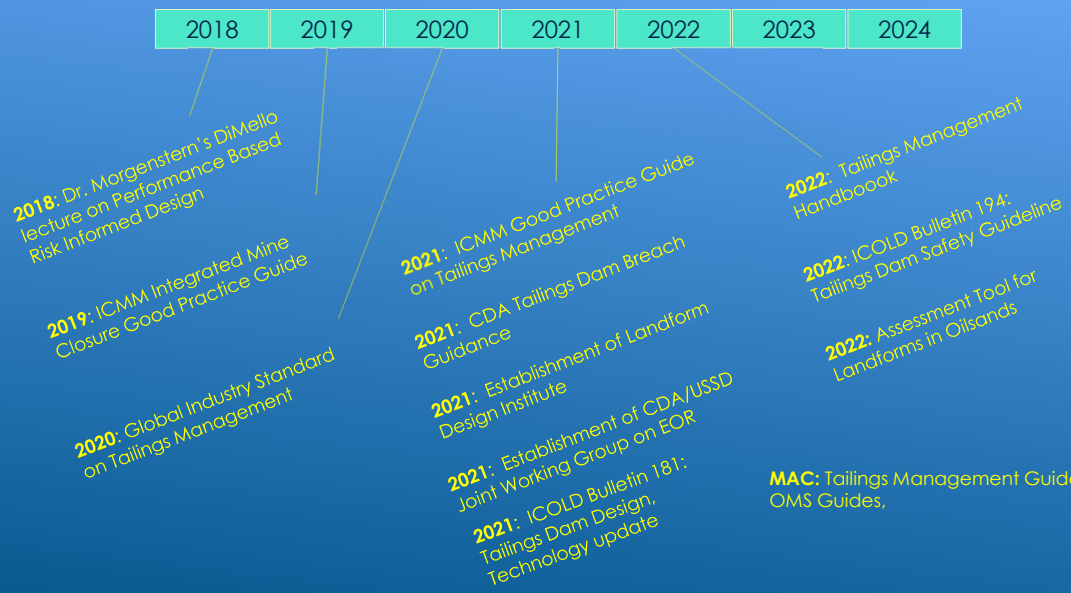
Guides (cont'd)



MAC: Tailings Management Guides, OMS Guides,

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Why 2030?

- Reflect on some of what has happened in the past 6 years:

Topic	2018	2024
Engineer of Record	Significant trepidation	Young engineers are viewing this as a viable career path
Surveillance	Some automation	Extensive automation and innovative technologies
Artificial Intelligence	Not prevalent	Playing a bigger role

- Opportunity to maintain the momentum that has been built
- Opportunity for more than "continuous improvement"
- We believe the next 6 years could see continued significant advancements

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Context

- Positive:
  - Many risk reduction initiatives underway
  - Moving in a good direction
  - Reducing likelihood of catastrophic failures
  - Owners and Consultants have created safe environments for young engineers
  - Training programs
  - Gain in computing power
  - Artificial Intelligence
  - TSF Registry (>21,000 TSFs catalogued)
- Challenges:
  - Water scarcity
  - Investors and insurance companies are paying a great deal of attention
  - Significant demand for EORs, RTFEs, ITRBs
  - Lack of engineers
  - Loss of senior engineers
  - Need to attract and retain talent
  - Dealing with classic upstream facilities

How do we get ahead of some of these challenges?

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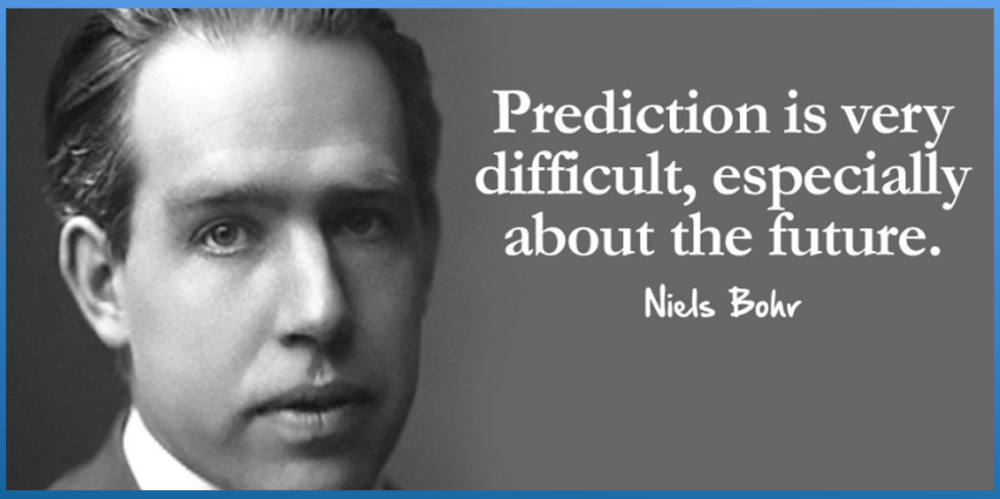
Visioning to 2030



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What Could Tailings Facility Engineering Look Like in 2030?

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

Governance is a key item that is also evolving, but beyond our scope

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Intended Audience

- Owners and Operators
- Consultants
- Academia
- Suppliers
- Regulators

- Geotechnical, geological, hydrotechnical, and civil engineers

- Young engineers who are interested in tailings facility engineering, but would like to know where we are headed

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Papers and Presentations

Version	Forum	Location	Deliverable	Date (2024)	Presenter
1.0	Calgary Geotechnical Society	Calgary	Presentation	May 14	Andy
2.0	Edmonton Geotechnical Society	Edmonton	Presentation	May 16	Andy
3.0	Nova Scotia Mining	Nova Scotia	Presentation	July	Andy
4.0	ICOLD	India	Presentation and paper	September	Annika
5.0	Tailings and Mine Waste	Denver	Presentation and paper	November	Andrew
6.0	International Society of Soil Mechanics and Geotechnical Engineering	Chile	Presentation and paper	November	Andy

- Build the presentations and papers with feedback from each session
- Make presentations and papers available on One Drive that will be available through ICOLD - after September

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Questionnaire to Colleagues/Leaders

- To support development of the presentations and papers
- Six categories:
  - Tailings technology and deposition
  - Closure strategies
  - Characterization of tailings and foundation soils
  - Surveillance of tailings facility performance
  - Design approaches for slope stability assessment
  - Guidance documents for tailings facility safety design
  - Building competency and capacity
- Issued to over 240 colleagues around the world
- Over 50 responses
- Lots is happening, this presentation provides some of the highlights

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Questionnaire Participation

- Alberta Contributors:
  - Nicolas Beier, U of A
  - Norm Eenkooren, Suncor
  - Derek Etherington, CNRL
  - Dr. Renato Macciotta, U of A
  - Chad LePoudre, BHP
  - Scott Martens, Teck
  - Gord McKenna, Landform Design Institute
  - Dr. Norbert Morgenstern, U of A
  - Gord Pollock, WSP
  - Joe Quinn, KCB
  - Marty Sangster, O'Kane Consultants
- Complete list of contributors on last slide
- Results of questionnaire to be posted on OneDrive after September

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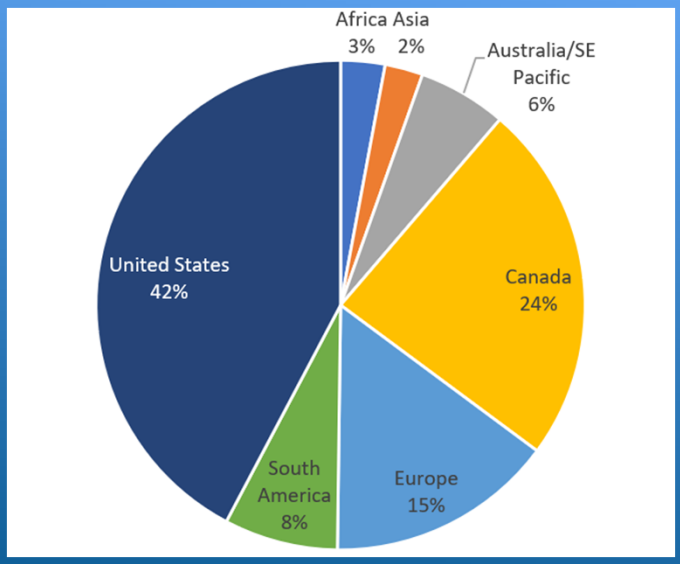
240 Colleagues/Leaders Invited



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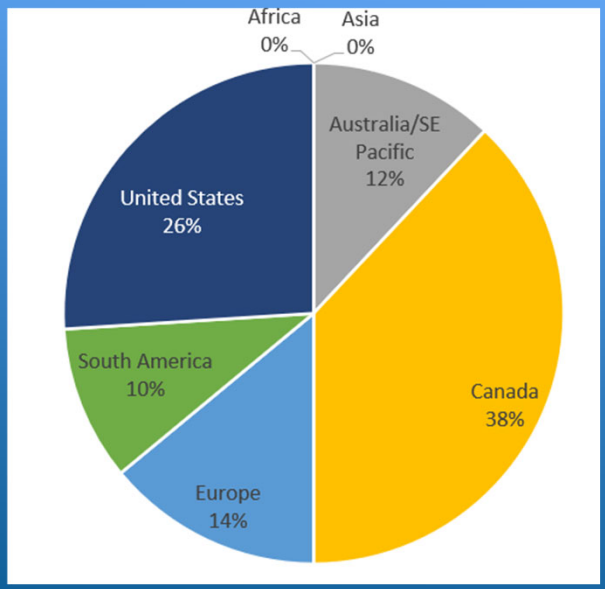
50 Responded



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   c) Regulatory competency and capacity

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Part 2b – Training and Development

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2b – Training and Development – Current Situation

- Positive items:
  - Field of tailings engineering is challenging, highly complex, and interesting
  - Not commodity-based engineering - valued engineering
  - Tailings Conferences (record attendance)
  - Training: UBC, UofA, TailENG, Tailings Center of Excellence, AusIMM, TailLiq, ICOLD, CDA, USSD, USACE, FERC, ANCOLD, SME, WIM, CIM etc.
  - Consulting company training
  - Owners developing in-house capacity
- Challenges:
  - Complexity will increase with future facilities
  - Lack of skilled talent
  - Impending retirements
  - Limited training at undergraduate and masters levels

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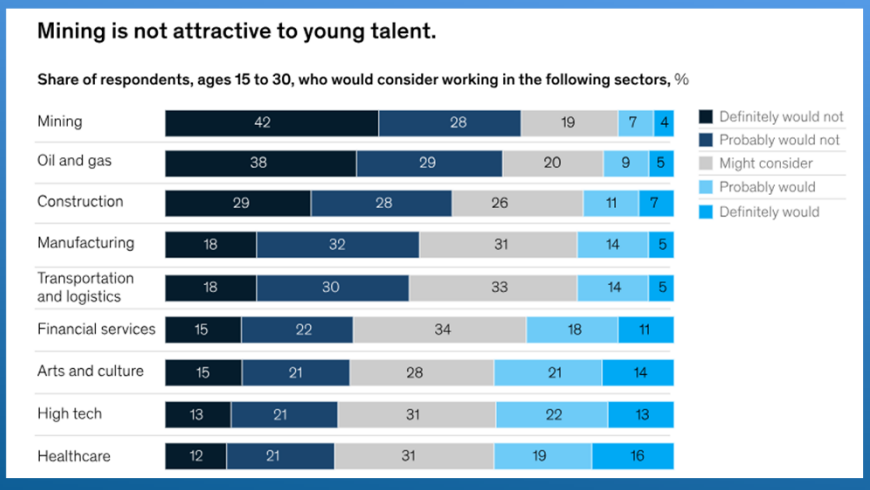
2b – Training and Development – Current Situation

- Challenges:
  - Mining is not attractive to young people



Mining industry employment and talent challenges | McKinsey

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2b – Tailings Management Professional

- Establish the discipline of Tailings Management Professional
- Alternative terms:
  - Mineral Residue Management Professional?
  - Mine Waste Management Professional?
- Tailings management includes the design, construction, operation, and closure of systems that are used to produce tailings and the facilities that are constructed to store tailings.
- Tailings structures include:
  - Conventional slurry, thickened, paste, filtered tailings stacks (wet / dry deposition), residue;
  - Co-disposed, co-deposited, and co-placed mineral residue (e.g. tailings and waste rock, fines and coarse discards, etc.);
  - Sludge and sediment containment facilities from process, water treatment plants, or runoff.

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2b – Tailings Management Professional (cont'd)

- 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

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2b – Training and Development – 2030?

- Recognized discipline of Tailings Management Professional
- An attractive option for young people, rather than "just falling into it"
- Supporting gap assessment to develop training programs
- Tailings Training Portal (SME)
- Coordinated training to fill the gaps
- Decision made as to whether there should be a certification program for a Tailings Management Professional.
- Improved diversity and equity
- Limited liability exposure to Tailings Management Professionals

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2b – Training and Development – 2030?

- Additional post graduate programs for Tailings Management Professional.
- From Chris Bareither, Colorado State: "*Establish a post graduate tailings cohort in a university program that is focused on developing tailings engineers, less research focused.*"
- More engagement between industry and academia

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What Could Tailings Facility Engineering Look Like in 2030?

1. Technical Items:
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   d) Design
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2. Competency and Capacity:
   a) Guidance documents
   b) Training and development
   c) Regulatory competency and capacity
3. Path forward

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Part 1 - Technical Topics

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1a - Tailings Technology – Current Situation

- >99% are slurried facilities
- Filtered/dewatered tailings project <1% worldwide and technologies are constrained (throughput, dust, acid generation, water management)
- Co-mingling/disposal with waste rock gaining traction

- Use of decision analysis (e.g., Multiple Accounts Analysis, MAA) for selecting tailings technology in North America
- Limited application of MAA outside of North America

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1a - Tailings Technology – 2030?

- Conventional/slurried tailings:
  - Still will be the majority of tailings systems with focus on centerline and downstream dams
  - No more classical upstream dams being constructed in the world
  - Modified upstream dams not "black-listed" (e.g., large compacted sand beaches are accepted)
  - From Joe Quinn, KCB: "*Safety of conventional/slurried tailings systems have been achieved to instill a high degree confidence in stakeholders*"

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1a - Tailings Technology – 2030 (cont'd)?

- Filtered tailings:
  - The technology exists and is proven
  - From Norm Eenkooren, Suncor: "*Hopefully, there will be publications which show the benefits of filtered tailings stacking both from a risk perspective and a cost perspective.*"
  - Publicly available, comprehensive guidance on filtered tailings stacks
    - Addresses geotechnical aspects in detail
    - Provides operational approaches to limit dust and water infilitration
  - Hybrid solutions with filtered and slurried systems
  - The term "dry stack" is no longer used

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1a - Tailings Technology – 2030?

- Widespread use of decision analysis:
  - Consider the whole mine
  - Separate costs from other variables in MAA
  - Develop financial models that embrace full life-cycle costing without discounting closure costs to low values
  - Support selection of appropriate tailings technology
  - Place high priority on water conservation

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1a - Tailings Technology – 2030?

- From Derek Etherington, CNRL: "*I think water management will become the governing factor of oilsands mining by 2030. If Alberta goes into a period of drought, river water intake by operators may be limited or cut-off completely*."
- Geochemical segregation more intentional (e.g., management of sulphide concentrates in isolated areas)
- Co-mingling of tailings and wasterock more viable

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1b – Closure Strategies – Current Situation

- Landforming and geomorphology are gaining prominence
- Oilsands delicensing continuing to advance
- "Designing for closure from the start" is an old saying, but not enough is being done
- Many regulations require a closure plan for permitting, but it is not always clear how to get there
- Costs for closure and post closure measures are seldom accurate and costs discounted with NPV

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1b – Closure Strategies – 2030?

- Consensus between all parties of 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
- Long-term monitoring with remote methods and AI
- Marty Sangster, O'Kane: "*With AI, we would have the ability to assess and design closure structures for possible changed conditions in the future*."
- Gord McKenna, LDI: "*Establish the role of reclamation designer of record (RDR) working in parallel with EOR*".
- Ecosystem Specialists part of independent review boards

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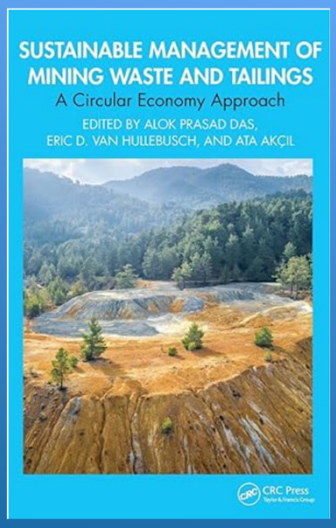
1b – Closure Strategies – 2030?

- More focus on circular economy approach - value-added products and recovery of strategically important critical minerals



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1c – Char. of Tailings and Foundation Soils - Current

- Budgets for site characterization used to be limited, but have been by evolving Owner's commitments and regulatory requirements
- Most of the tools are there (CPT, sampling, lab testing, CSSM etc.), but could be organized, refined, and the tools sharpened.
- From Gord Pollock, WSP: "*CPT is the obvious tool but it is not the silver bullet. The scatter in the case histories shows we do not have a handle on this issue*."
- From Scott Martens, Teck: "*Methods for characterizing and understanding the behaviour of unsaturated tailings are severely limited, and understanding unsaturated behaviour (for both strength and seepage) will be essential for assessing safe closure of tailings facilities*."

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1c – Char. of Tailings and Foundation Soils – 2030?

- Improved characterization of liquefaction potential and post liquefaction strength
- Improved understanding of the impact of tailings fabric/layering
- Use of nuclear magnetic resonance well logging and other in-situ technologies on CPTs for water content estimation
- Ability to estimate in-situ void ratio
- Methods for recovering "undisturbed" samples of fine and coarse tailings

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1c – Char. of Tailings and Foundation Soils – 2030?

- New geophysics and non-destructive/non-invasive technologies
- Include pore pressure measurement on electric vane shear tests (eVSTu)
- Integrated and updated site characterization models
- Widespread sharing of common data (e.g., adjacent mines in districts sharing data, consortiums like in the Oil Sands)
- Machine learning techniques for core logging and interpretation
- Comprehensive 3-dimensional models

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1d – Design – Current Situation

- Limit equilibrium used for most stability assessments
- Conservative approaches for stability assessment of classical upstream dams
- Performance based design for slope stability assessment is evolving with increased computing power and surveillance methods
  - ICMM Training on PBD
  - CDA Training on PBD
- Risk informed design – accounting for consequences to the Owner by enhancing design criteria

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1d – Design – 2030?

- Performance Based Design for Slope Stability Assessment:
  - Wide range of views in the questionnaire
  - From Dr. Morgenstern: "*Further recognition of the value of Performance Based Design and significantly greater prominence in its use*."
  - Integration of complementary roles of PBD and LEM
  - Fully coupled deformation and seepage models
  - Regulatory capacity will still be a limitation to implementation

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1d – Design – 2030?

- From Dr. Macciotta, U of A: "*Full recognition of uncertainty in the design, implementation, operation and closure process. The state of Engineering will be advanced sufficiently to reduce/control these uncertainties such that risks are minimized*."
- Dam breach analysis that can be relied upon.

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1e – Surveillance – Current Situation

- Widespread use of "point" measurements (e.g., vibrating wire piezometers (VWPs), survey prisms, inclinometers, and weirs)
  - Somewhat ad-hoc, historical locations, not always tied to failure modes
- Limited automation
  - Reliance on humans to collect and process data
  - False positives in so called "real-time" data
  - Cumbersome data management interfaces
- Limited application of remote sensing technologies (e.g., InSAR)

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1e – Surveillance – 2030?

- 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
  - Integration of collected data directly into engineering models
  - Data scientists employed to manage the reams of data
  - Increased use of AI for data review/screening

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Part 2 – Competency and Capacity

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2a – Guidance Documents – Current Situation

- Some said: "We have enough guidance documents, use what we have!"
- Guidelines in review/being updated:
  - MAC
  - CDA
  - USSD (FEMA)
  - CDA/USSD EOR
  - ICOLD Bulletin 194
  - Others

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2a – Guidance Documents – Current Situation

- Gaps in the guidelines:
  - Filtered stacks
  - Safe/Responsible Closure
  - Risk informed design practices
  - Methods for characterizing tailings and foundation soils
  - Spillway design
  - Credible Failure Modes

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2a – Guidance Documents – 2030?

- Wide adoption of GISTM, MAC, ICMM, ICOLD, etc.
- Refined guidance with holes plugged
- Detailed closure guidance
- Detailed filtered stack guidance
- Credible Failure Modes Guidance
- Landform design guidance including long term monitoring
- Version X of ICOLD Bulletin 194:
  - More on hydrogeology and hydrology
  - Conducting undrained stability analyses
  - Brittleness and stability
  - Spillways
  - Tailings and Foundation Characterization

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2c – Reg. Competency and Capacity - Current

- From Dr. Morgenstern: "*A major issue is the capacity of the regulatory community*."
- Limited technical capacity among regulators
- Limited ability of external consultants to support regulators with reviews
- CDA providing training to regulators in Canada

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2c – Reg. Competency and Capacity – 2030?

- Role of industry to support regulators?
- To be determined

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Part 3 – Path Forward

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3 – Path Forward – Training and Development

Vision for 2030	Action	Organizations	Role
Tailings Management Professional	Develop scope for this discipline and embrace usage	ICOLD	Lead development, work with ICMM, SME, CDA, ANCOLD, universities, etc.
Decision w.r.t. certification of Tailings Management Professional	Study this issue and land on a decision	ICOLD	Form working group to explore this issue. Work with ICMM, SME, CDA, ANCOLD, universities, etc.
Coordinated training	Develop Tailings Training Portal that reflects available training in the world. Use the Portal to support developing a coordinated training program.	SME	Host for the portal, supported by several organizations
Tailings cohorts in post graduate programs	Develop MS-level program focused on training engineers to enter the tailings profession	Colorado State University	Lead development of this initiative, supported by other universities

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3 – Path Forward – Tailings Technology

Vision for 2030	Action	Organizations	Role
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.	To be determined	To be determined
Co-disposal of tailings and waste rock more prominent	To develop		
"Safety of conventional/slurried tailings systems have been achieved to instill confidence in stakeholders."	Continue training and development	All	Continue solid engineering

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3 – Path Forward – Closure

Vision for 2030	Action	Organizations	Role
Tailings Closure Handbook	"Begin with the end in mind. Closure should not be an afterthought. Elements will include closure design considerations/criteria, safe closure considerations, landform design, closure governance, closure cost estimating / bonding / relinquishment, among other."	SME	SME to lead development of handbook. The book editors are engaging with other organizations (e.g., USSD, CDA).
Risk Informed Closure Design	Develop guidance on "safe" or "responsible" closure.	CDA	CDA to lead with input from ICOLD, USSD, SME, ICMM, etc.

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3 – Path Forward – Char. of Tailings and Foundations

Vision for 2030	Action	Organizations	Role
Ability to measure void ratio in-situ	Continued research with NMR, density, and additional tools	Universities and Investigation companies	Undertake research
Ability to discern brittleness	Continued research in in-situ and laboratory testing approaches	Universities and Investigation companies	Undertake research

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3 – Path Forward – Design

Vision for 2030	Action	Organizations	Role
Greater use of Performance Based Design	Education, case studies	ICMM, CDA, and industry	ICMM and CDA – training Industry – case studies on PB design
Reduced uncertainty for dam breach analyses	Research to improve models and characterization and enhance guidance	CANBREACH CDA	CANBREACH – research CDA - guidance
No water covers required for geochemistry reasons	Improved desulphurization. Enhanced financial models. MAA for the mine, not just tailings.	Mining companies	ICOLD will monitor

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3 – Path Forward – Surveillance

Vision for 2030	Action	Organizations	Role
"Area" measurements	Continued implementation of available tools	Owners and providers	Implement and provide case studies
Widespread automation	Increased use of AI to support automation	Owners and providers	Implement and provide case studies

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3 – Path Forward – Guidance

Vision for 2030		Organizations	Role
Guidance on Filtered Tailings	Comprehensive guidance document that addresses process and geotechnical aspects, but also, possibly enhanced financial models	Filtered tailings industry	To lead the development of the guidance. Supported by ICOLD and other organizations.
Preferred definition of Credible Failure Modes	Objective guidance on thresholds for physical possibility and negligibility	CDA	Lead development of guidance, supported by other organizations

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3 – Path Forward – Guidance (cont'd)

Vision for 2030	Action	Organizations	Role
Landform Design Guidance	Develop comprehensive guidance for landform design	LDI	Lead development of guidance with support from other organizations
ICOLD Bulletin 194 Version X	Additional guidance on hydrogeology and hydrology, undrained stability analyses, brittleness stability, spillways, characterization	ICOLD	Lead preparation of guidance with input from other organizations

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3 – Path Forward

- Fraction of the initiatives that are happening in the world
- Many other good initiatives are underway, pleased to include in our paper
- Let's maintain the momentum and go beyond just "continuous improvement"!

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Being a Tailings Management Professional is and will be very interesting!

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End of Presentation

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