Dry Stack Tailings
An Overview and Considerations for Geochemists

2022 ANNUAL BC-MEND ML/ARD WORKSHOP

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Presentation Outline

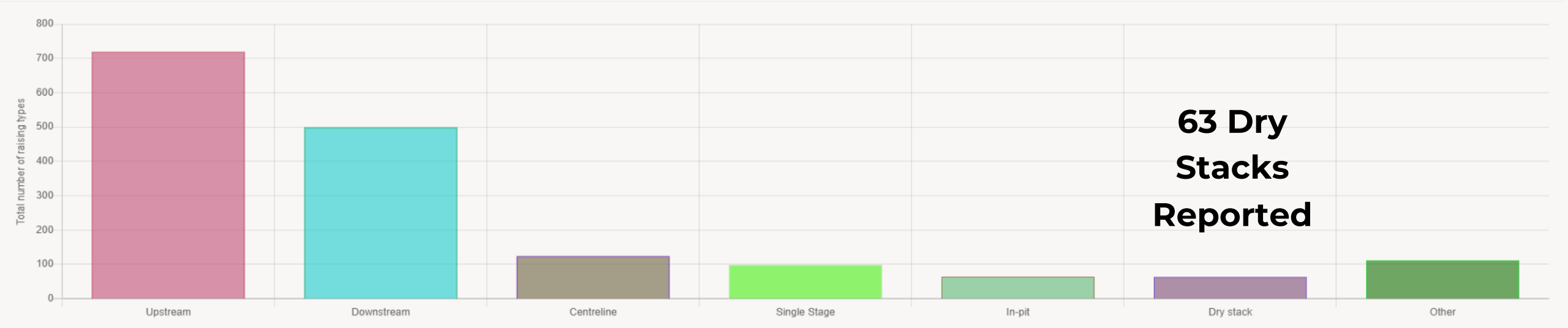
- State of Industry 2022
    - Why Dry Stack
- Design Concepts and Select Case Histories
- Geochemical Considerations

3% of Reported Tailings Facilities are Dry Stacks

Status November 2022

1867 tailings facilities reported

Estimated 3,500 to 33,000 facilities worldwide – (0.03%)



https://tailing.grida.no/map/data/

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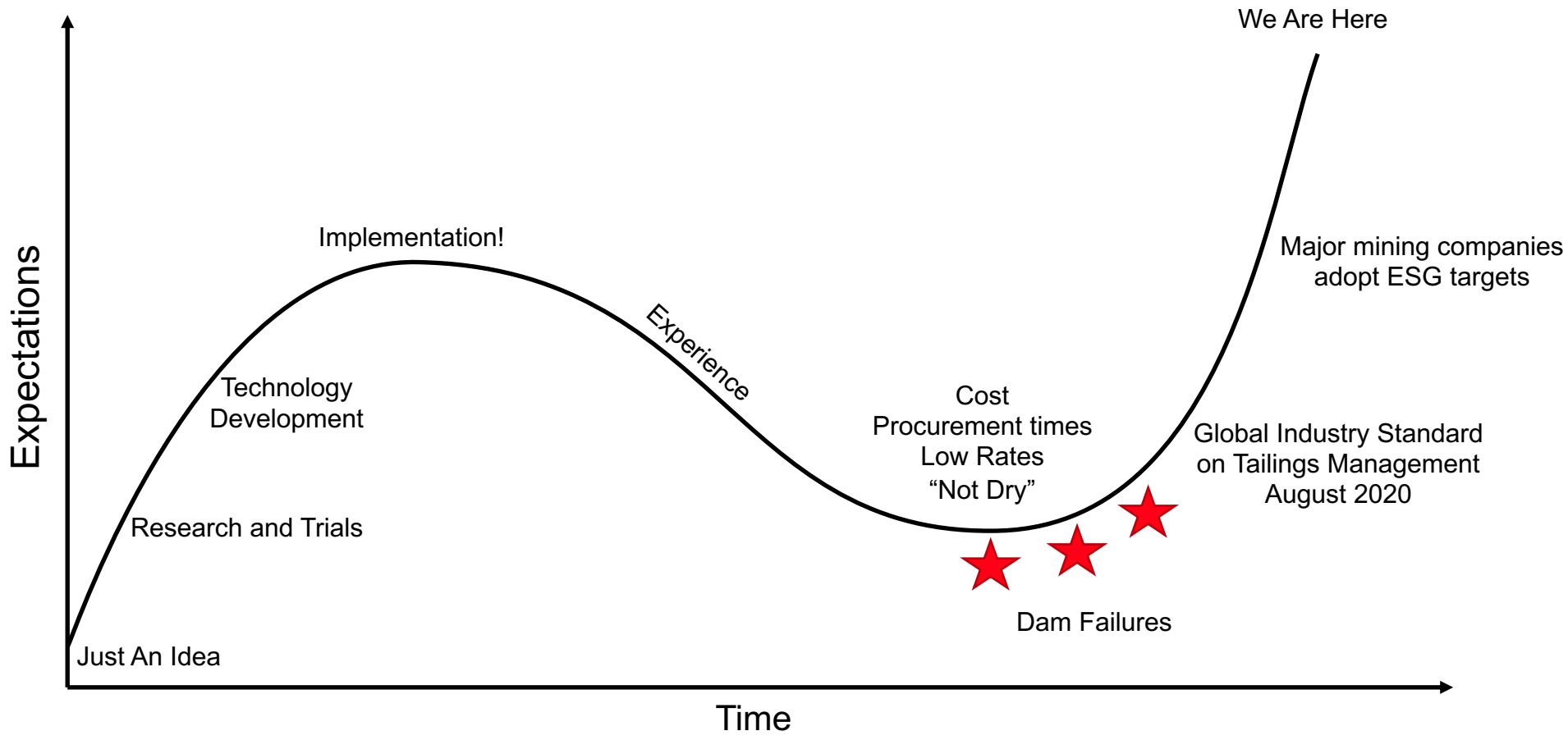
Industry Expectations of Dry Stack Tailings

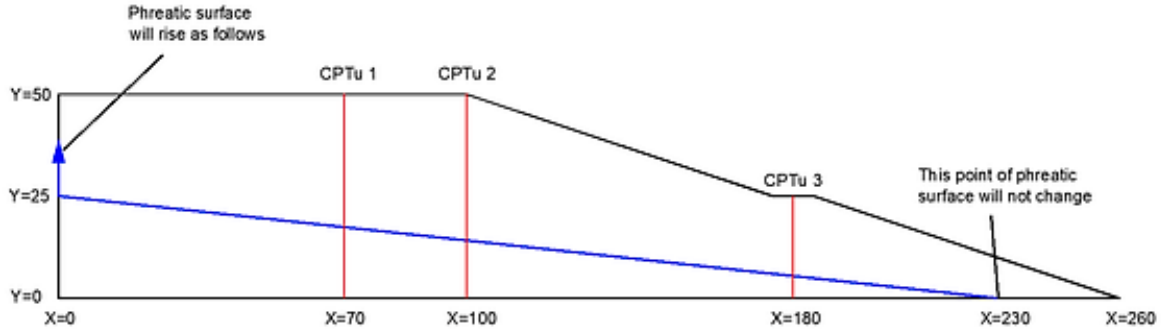


What is New?

- Not many new case histories
- Global Industry Standard on Tailings Management
  - Major miners adopting ESG targets
- Bigger filters
- Soil Mechanics
  - Undrained modes, liquefaction
  - Unsaturated soils are complicated (not new)

Requirement 3.2 For new *tailings facilities*, the *Operator* shall use the *knowledge base* and undertake a multi-criteria *alternatives analysis* of all feasible sites, technologies and strategies for *tailings* management. The goal of this analysis shall be to: (i) select an alternative that minimises risks to people and the environment throughout the *tailings facility lifecycle*; and (ii) minimise the volume of *tailings* and water placed in external *tailings facilities*. This analysis shall be reviewed by the *Independent Tailings Review Board (ITRB)* or a *senior independent technical reviewer*.

GTR 2020. Global Industry Standard on Tailings Management.



https://www.tailliq.com/single-post/2019/10/15/slope-stability-round-robin

Definition of a Dry Stack

'Something you build without a pipeline.'

Ward Wilson

Dry Stack Design

Drivers / Basis

- Production rate
- Tailings water content
- Filter efficiency, frequency of upset
- Climate – wet / dry / hot / cold
- Topography
- Seismicity
- Foundation Conditions

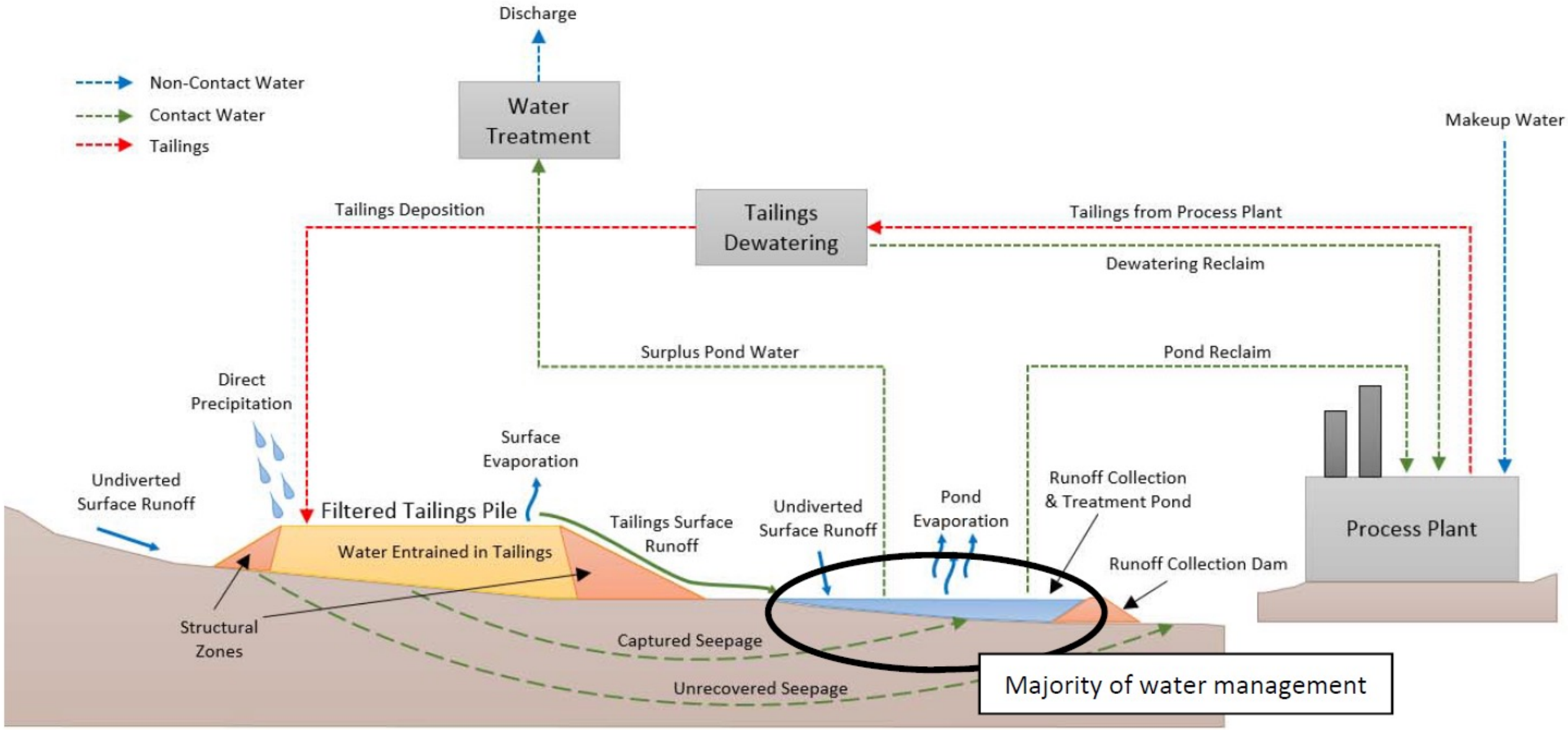
Design elements

- Zoning / dams
- Geometry and stacking plan
- Lift height
- Compaction
- Drying
- Liner and drains
- Progressive closure / covers
- Management of filter upset

Design Concepts and Select Case Histories

Dry Stacks

- Dry
  - Karara
  - La Coipa
- Wet
  - Greens Creek
  - Eleonore
  - Case Study 39



MEND (Mend Secretariat). 2017. Study of Tailings Management Technologies. Klohn Crippen Berger

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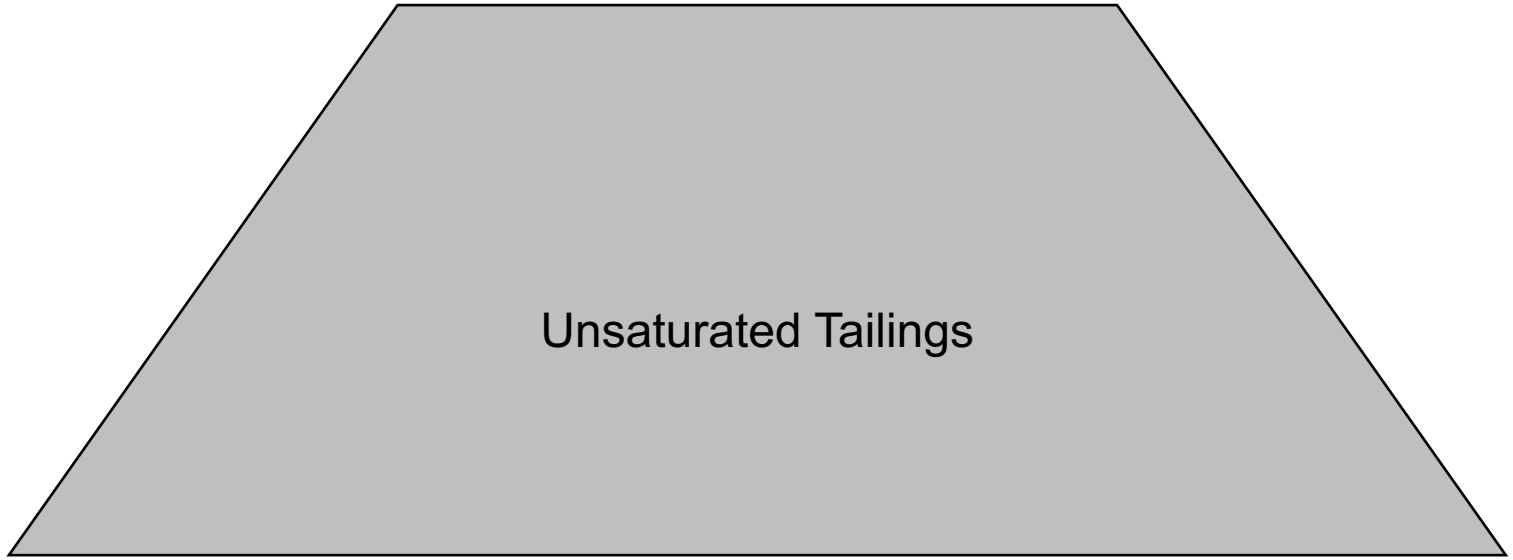
“Dry” Dry Stack

Conceptual Model

- Unsaturated
- No pond
- Oxygen diffusion from edges
- No infiltration?
- No underdrains or liner



Karara

Plant commissioned 2012

- 15% tailings water content
- 400 mm/y precipitation
- 30 m max. lift height
- 22,500 to 35,000 tpd
- Low seismic hazard

- Off spec to wet facility

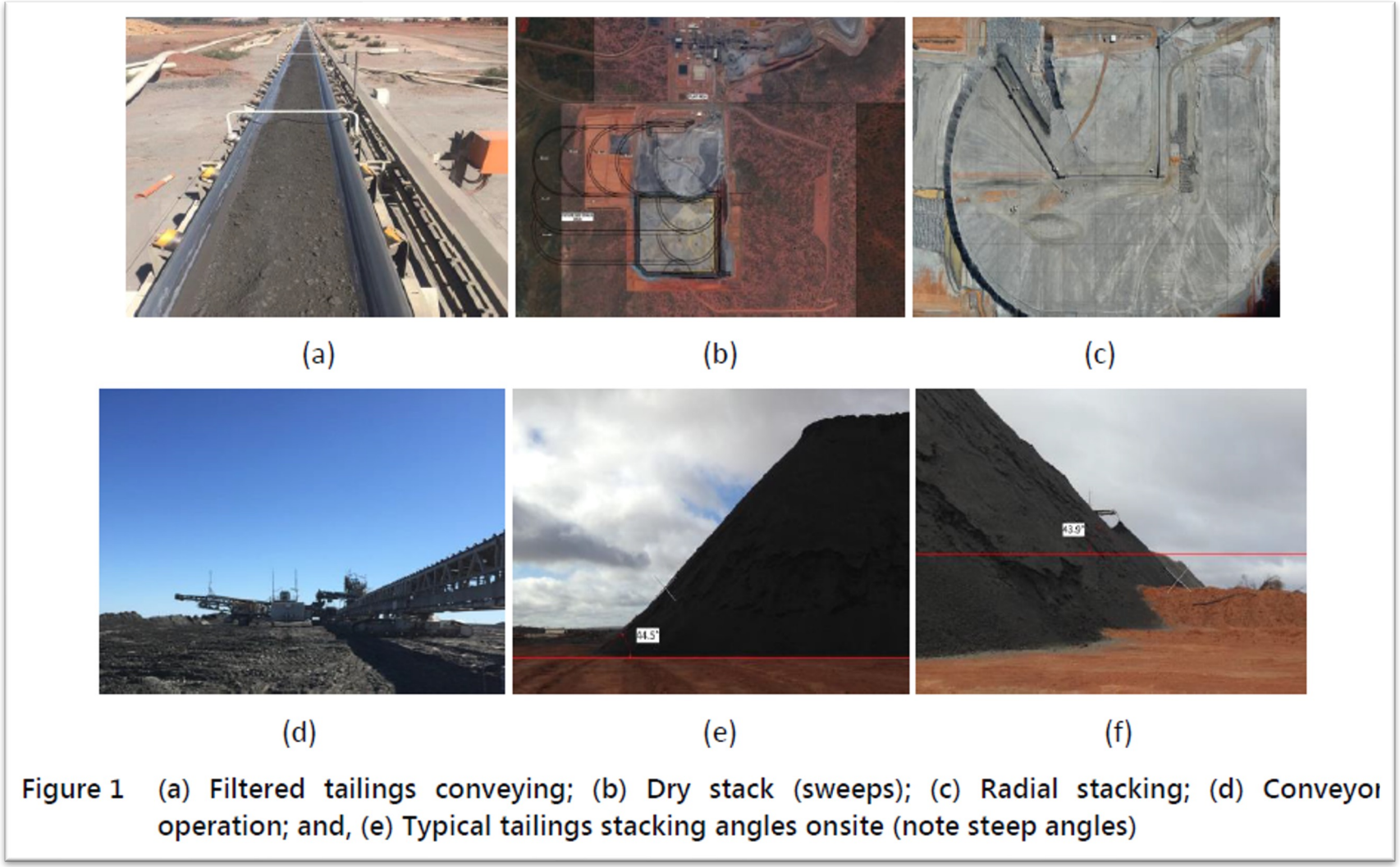
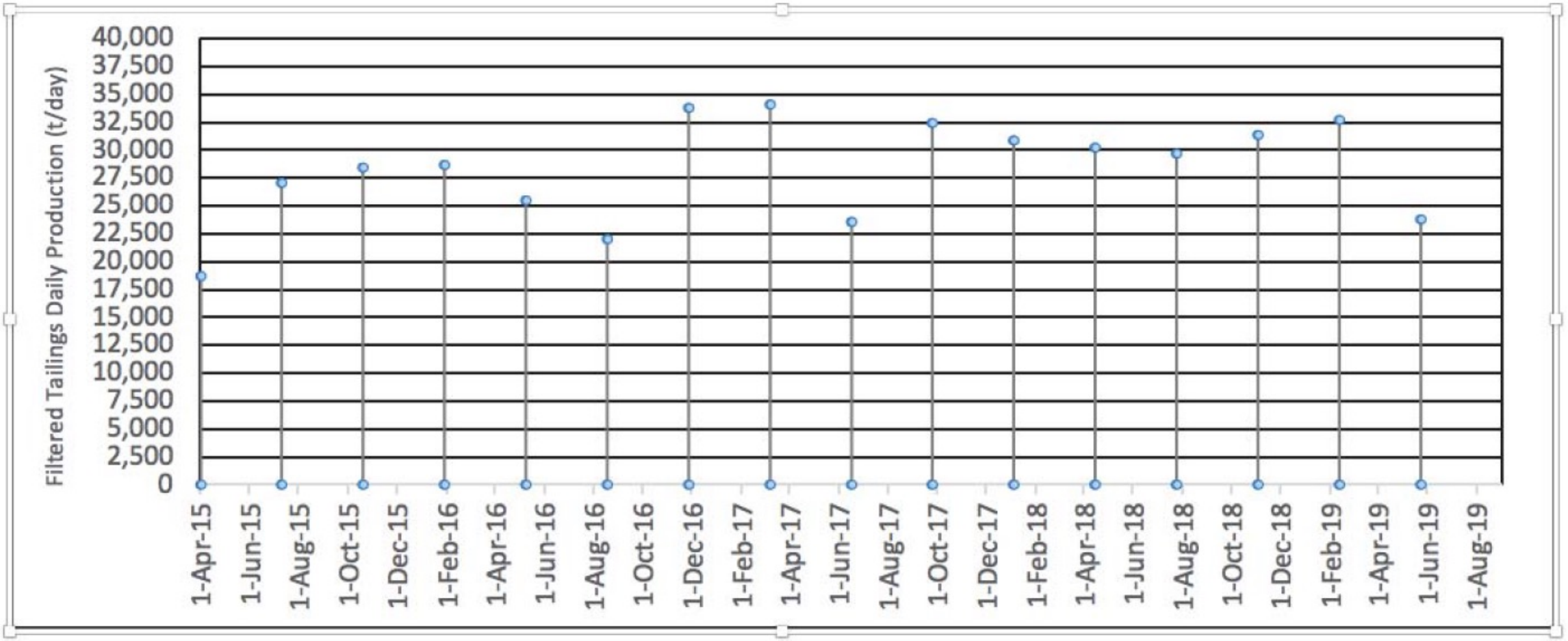


Figure 1 (a) Filtered tailings conveying; (b) Dry stack (sweeps); (c) Radial stacking; (d) Conveyor operation; and, (e) Typical tailings stacking angles onsite (note steep angles)

Amoah N., 2018. Large-Scale Tailings Filtration and Dry Stacking at Karara Magnetite Iron Ore Operation. Tailings and Mine Waste 2019.

Amoah N., W Dressel, AB Fourie 2018. Characterization of unsaturated geotechnical properties of filtered magnetite tailings in a dry stack facility. Paste 2018.

Karara Filter Tailings Production Rate



Amoah N., 2018. Large-Scale Tailings Filtration and Dry Stacking at Karara Magnetite Iron Ore Operation. Tailings and Mine Waste 2019.


Image © 2022 CNES / Airbus
Google Earth

Karara

Dry Stack

- Low initial tailings water content
- Low rainfall
- High lifts
- No compaction
- Unsaturated

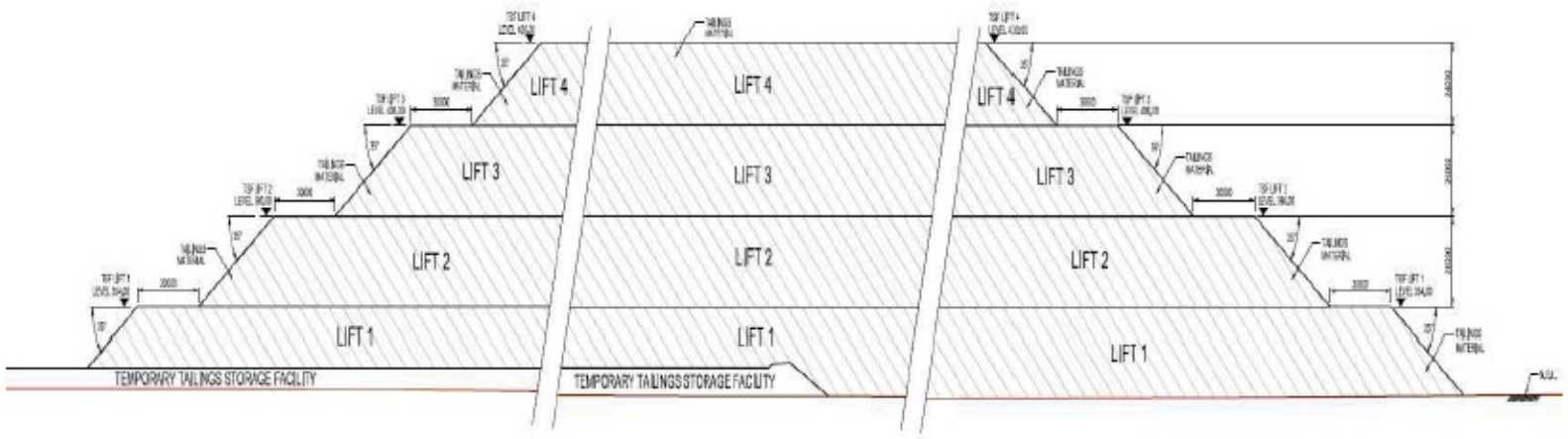


Figure 9: Dry stack concept design for radial stacking — cross section showing different lifts

Amoah N., 2018. Large-Scale Tailings Filtration and Dry Stacking at Karara Magnetite Iron Ore Operation. Tailings and Mine Waste 2019.

Amoah N., W Dressel, AB Fourie 2018. Characterization of unsaturated geotechnical properties of filtered magnetite tailings in a dry stack facility. Paste 2018.

La Coipa

Commissioned 1989, No Longer Operating

- 20-25% tailings water content
- < 50 mm/y precipitation
- 0.2 to 0.3 m lift height
- 20,000 tpd
- 0.54 g high seismic hazard
- Unlined

- Off spec (wet) tailings to separate facility

Photograph: Ward Wilson

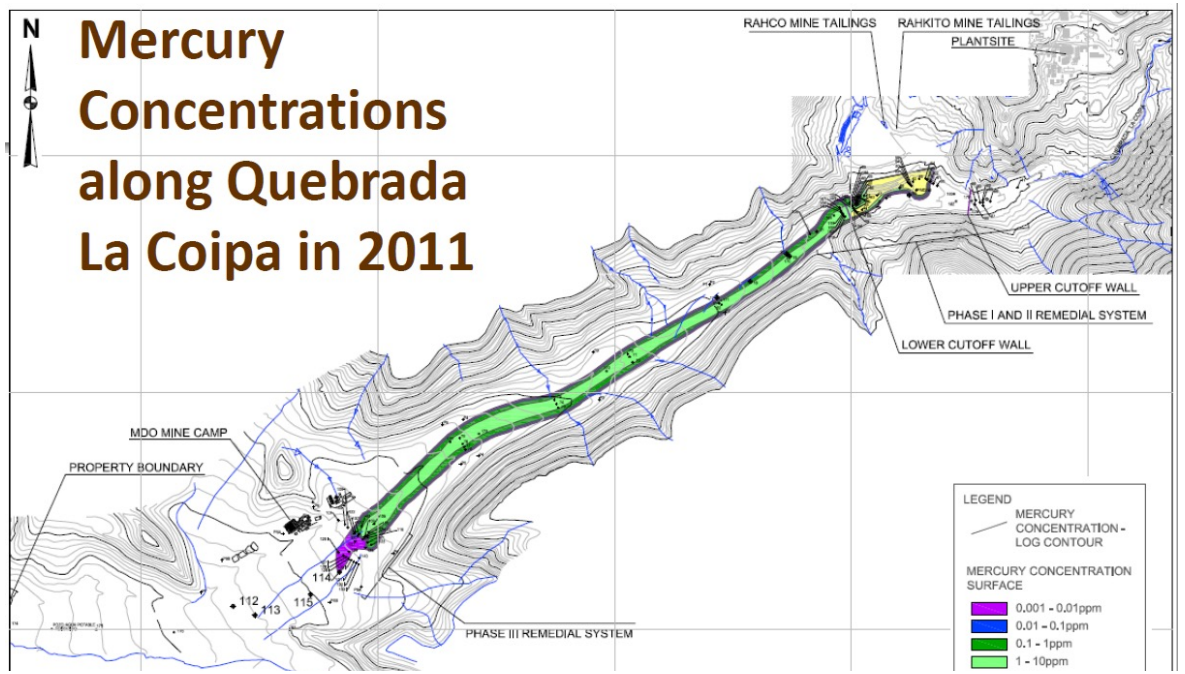
Williams et al. 2012. Dry Stack Tailings and Seepage Management at La Coipa Mine, Chile. BC MEND ARD/ML, Vancouver, BC

La Coipa

2012 ANNUAL BC-MEND ML/ARD WORKSHOP

Dry-stack Tailings and Seepage Management La Coipa Mine, Chile

Dean Williams, Erling Villalobos, Julio Acosta – Kinross
Virginia Cullen and Jim Cassie – BGC
Jack Adams – U. of Utah
Rory Tibbals – Consultant
November 2012



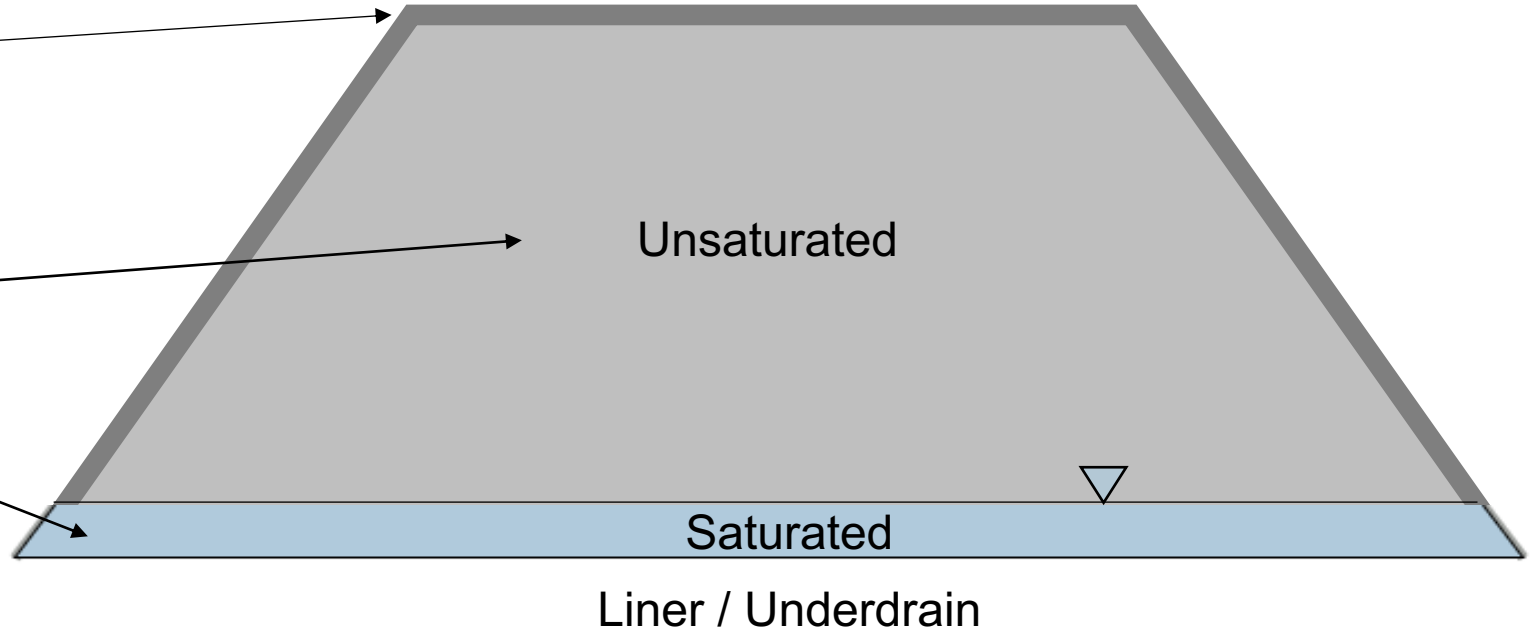
- Dry-stack tailings contain significant quantities of water which will emerge as seepage unless contained or collected

Williams et al. 2012. Dry Stack Tailings and Seepage Management at La Coipa Mine, Chile. BC MEND ARD/ML, Vancouver, BC

“Wet” Dry Stack

Conceptual Model

- Outer zone
  - Oxygen diffusion from edges
  - Infiltration
- Inner zone
- Lower zone
  - saturated



Based on Condon, P. and K. Lear. 2006. Geochemical and Geotechnical Characteristics of Filter-Pressed Tailings at the Greens Creek Mine, Admiralty Island, Alaska. ICARD.

Greens Creek

Operations 1989 - present

- 12 - 16% tailings water content
- 1,450 mm/y precipitation
- 0.3 m lifts, compacted and sloped to shed water
- ~750 to 800 tpd
- 0.3 g - high seismic hazard
- partial liner, under drain system
- PAG rock with the tailings
- water table 4 m above liner (2005)

Condon, P. and K. Lear. 2006. Geochemical and Geotechnical Characteristics of Filter-Pressed Tailings at the Greens Creek Mine, Admiralty Island, Alaska. ICARD.

Eleonore Mine Tailings Storage Facility

2014 – 2026 (planned), studies under way for expansion

- 20% tailings water content
- 742 mm/y precipitation
- 0.5 m lifts
- ~4,100 tpd tailings
- 0.1 g (low seismic hazard)
- liner
- water table 6 to 9 m above liner

Lessard, F., P. Gomez, H. Abdel-Aziz, A.H. Zamani, J.F. Painchaud, and W. Fresser. 2022. Integrated Waste Rock Co-Disposal at the Filtered Tailings Storage Facility. Proceedings of Tailings and Mine Waste 2022. November 6-9, 2022. Denver Colorado. Paper 94

Eleonore

Cross Section

water table 6 to 9 m above liner

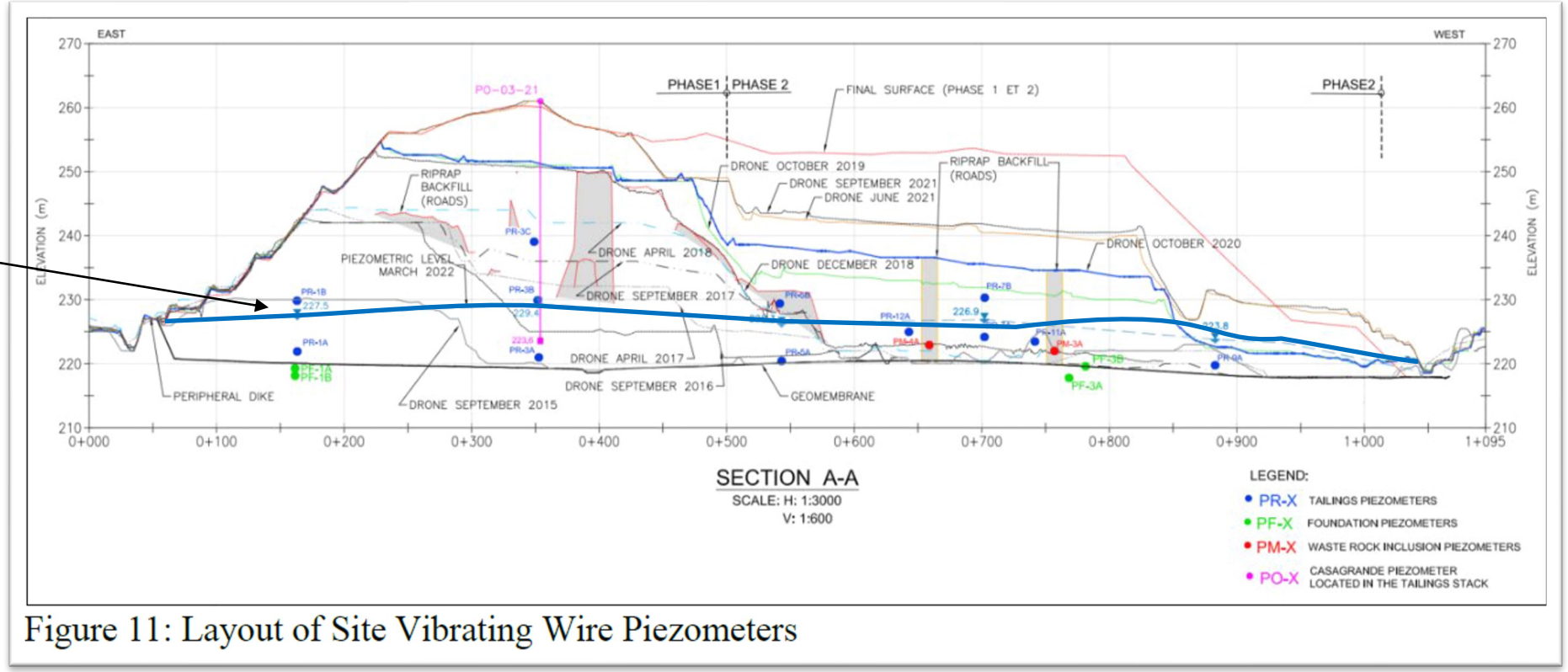


Figure 11: Layout of Site Vibrating Wire Piezometers

Lessard, F., P. Gomez, H. Abdel-Aziz, A.H. Zamani, J.F. Painchaud, and W. Fresser. 2022. Integrated Waste Rock Co-Disposal at the Filtered Tailings Storage Facility. Proceedings of Tailings and Mine Waste 2022. November 6-9, 2022. Denver Colorado. Paper 94

Dry Stacks with Dams or Compacted Zones

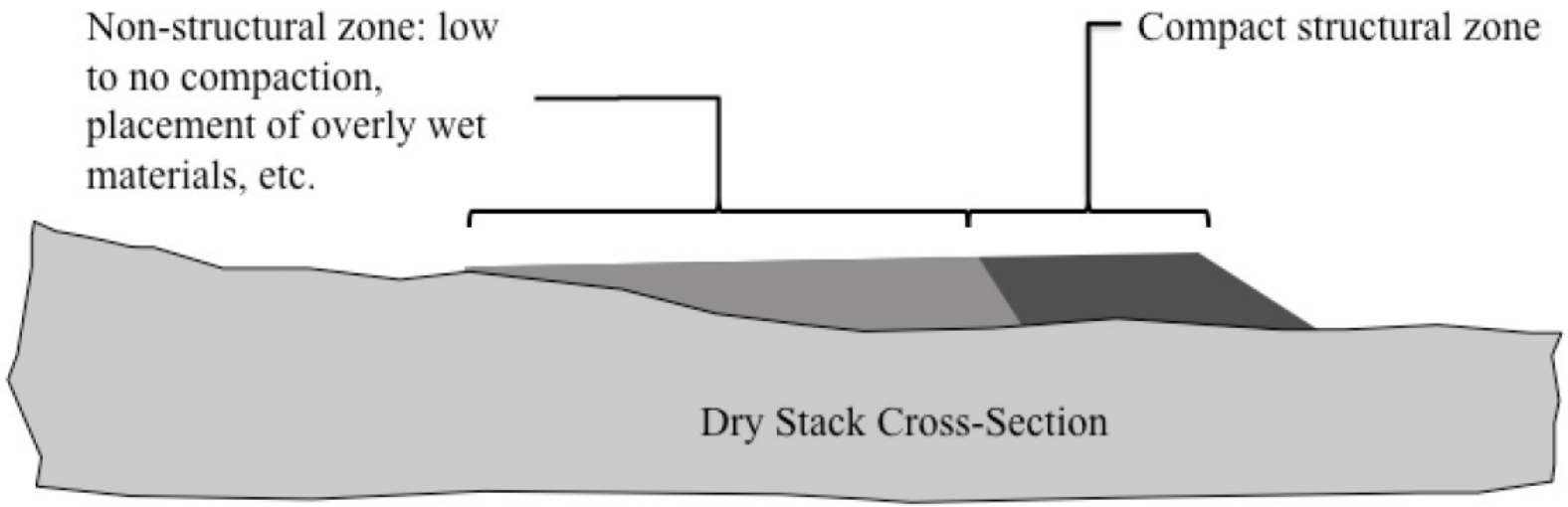


Figure 6. Generalized dry stack cross-section.

Lupo, J. and J. Hall. 2010. Dry Stack Tailings – Design Considerations. Proceedings 14th International Conference on Tailings and Mine Waste, Vail, Colorado.

Case Study 39

Too wet!

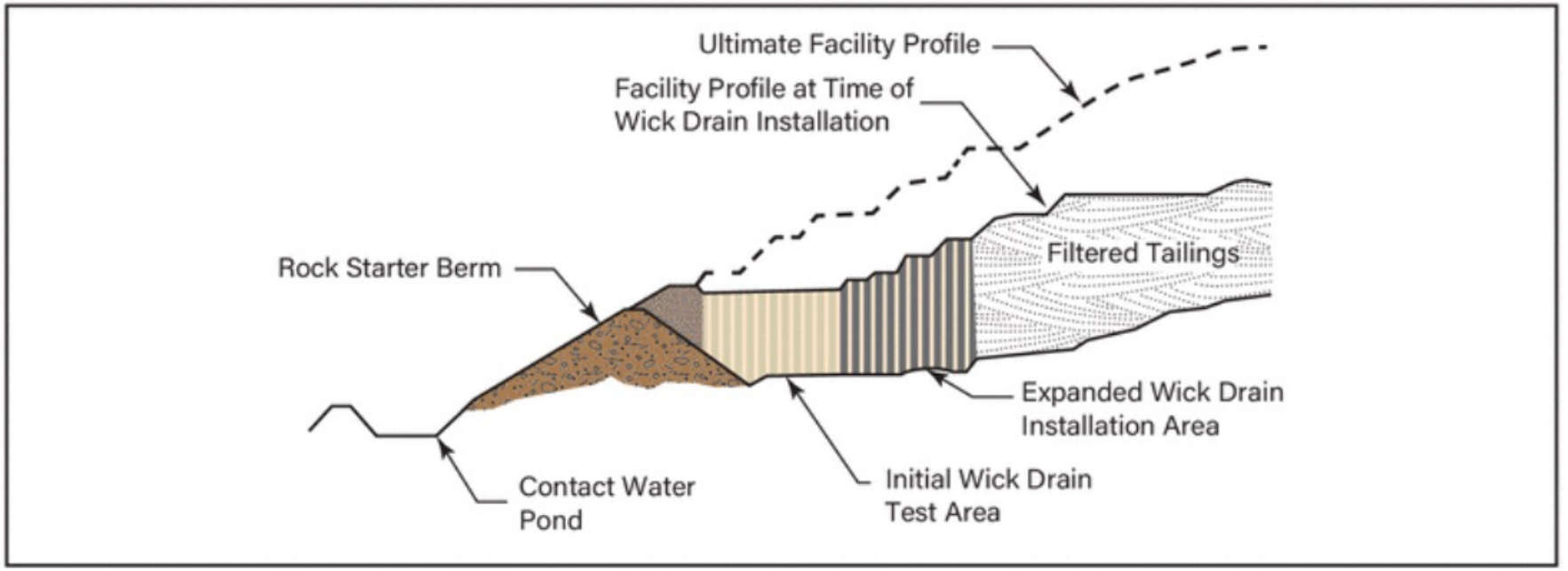


FIGURE 1 Profile through facility showing areas with wick drains installed

Morrison, K.F. (2022). Tailings Management Handbook - A Life-Cycle Approach. Society for Mining, Metallurgy, and Exploration (SME).
Case Study 39 by Bryan Ulrich

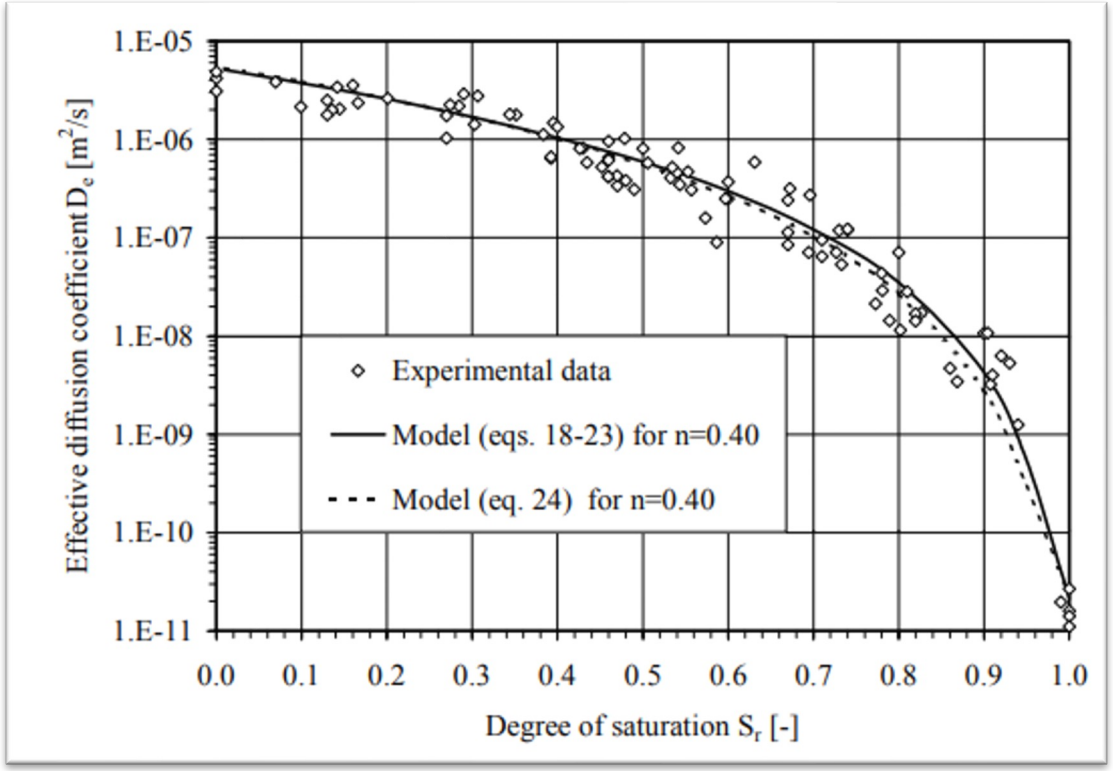
Dry Stacks are Unsaturated

Key Control on Physical and Chemical Stability

Oxygen ingress by diffusion

>85% saturation to limit oxygen

<85% saturation to limit liquefaction



Mbonimpa, M., M. Aubertin, B. Brussiere, M. Aachib. 2002. Oxygen diffusion and consumption in unsaturated cover materials. (Rapport technique no. EPM-RT-2002-04. https://publications.polymtl.ca/2597/

Drainage and Seepage Chemistry

Geochemical Consideration #1

Oxidation and dissolution of sulphides – (ARD/ML)

- Release of acid, metals and metalloids and trace elements

- Limit infiltration - grading, compaction, water diversion, progressive closure and covers
- Limit oxygen - lag time informs the stacking plan
- Control seepage - liner, underdrains, collection systems, and/or treatment

Durocher, J., D. Sprague, B. Usher. 2022. Geochemical Interactions and Long-term TSF Stability: An Update. Proceedings of Tailings and Mine Waste 2022. November 6-9, 2022. Denver Colorado.

Chemical Alteration

Geochemical Consideration #2

Primary mineral alteration - redox processes (sulfides) - precipitation of secondary metal(loid)-oxyhydroxide and –sulfate phases (concentration in pores)

Primary mineral alteration - neutralization (carbonate, oxyhydroxides and silicates) - dissolution and/or formation of secondary clay or simplified oxide phases

- Grain size reduction and mass loss - consolidation and settlement, loss of strength
- Coatings and cementation - introduce brittle failure modes
- Seepage - dissolves karst or alters clays in the foundation
- Precipitates blind the pores
    - Increased degree of saturation - risk to physical stability

Durocher, J., D. Sprague, B. Usher. 2022. Geochemical Interactions and Long-term TSF Stability: An Update. Proceedings of Tailings and Mine Waste 2022. November 6-9, 2022. Denver Colorado.

Summary

Dry Stack Overview and Considerations for Geochemists

- More dry stacks are indicated
  - Best practice is to minimize water on surface for new facilities
  - Physical stability is the driver
- Dry stacks are unsaturated
- **Geochemistry will have to be managed**

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Thank you