SwedCOLD Workshop 3:
Best Practices for Tailings Dam Breach Analysis

Disclaimer

- This presentation is intended to be shared with the participants of the Workshop 3: ”Best Practices for Tailings Dam Breach Analysis” held on June 14th 2023 at ICOLD’s annual meeting in Gothenburg.
- We kindly ask to not share this document with third parties.
- Some graphical content originally used to illustrate case studies have been removed to avoid misuse of information.

Welcome!

Agenda

- Introduction, presentation of GruvRIDAS and guidance document no 3 (”TV3”) on Tailings Dam Breach Analysis and consequence classification

- Workshop on Tailings Dam Breach Analysis:
  - Part 1 - Case study of different tailings dam breach cases (1A-1B-2A-2B)
  - Part 2 - Group discussions on chosen topics

- Round-up and conclusion
  - Summary of group discussions
  - Conclusion

Who are you?

- Who are you?

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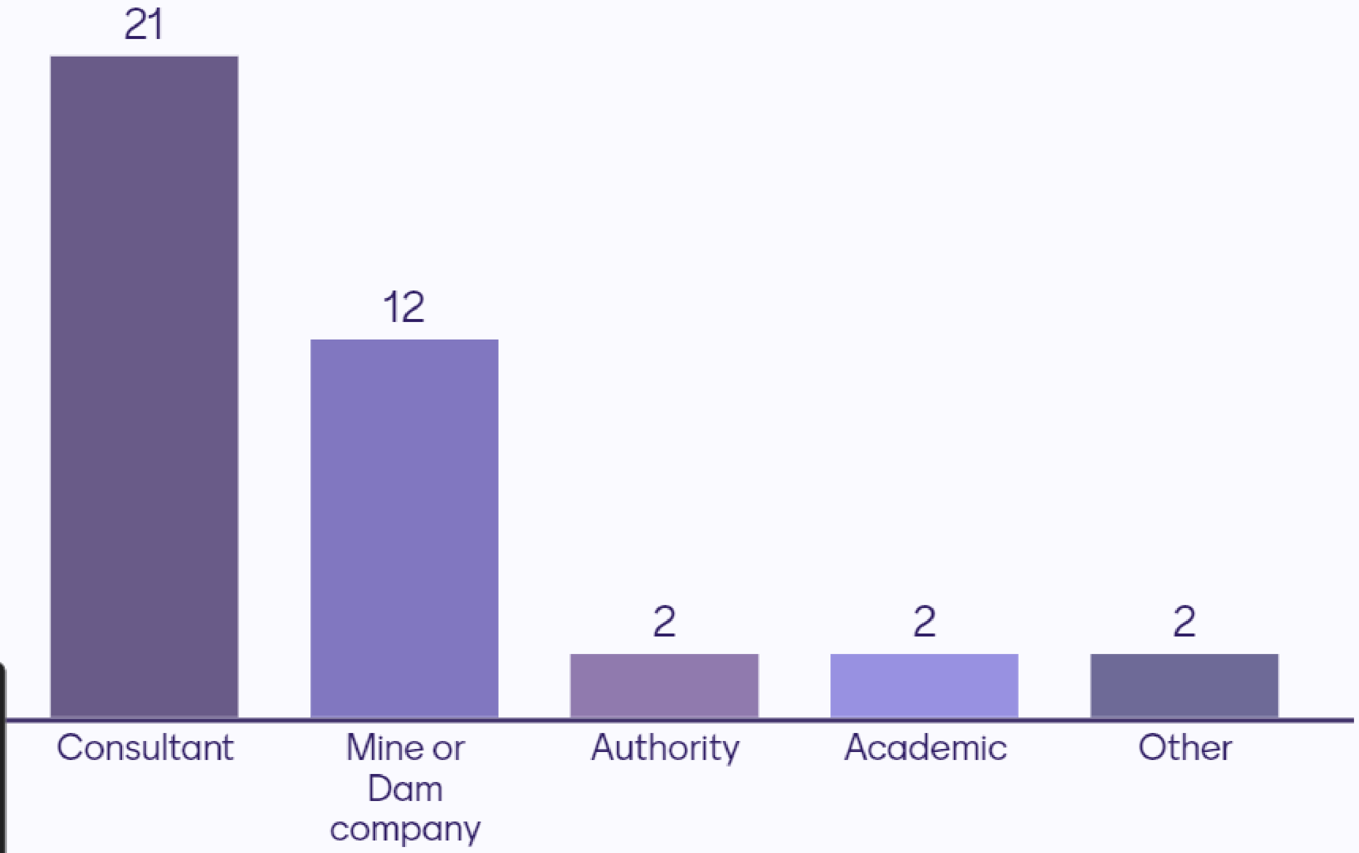
Who are you?



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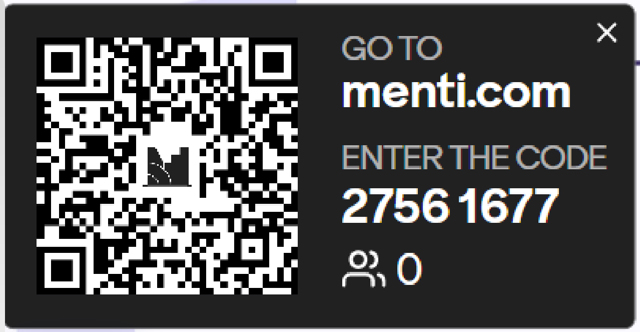

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Presenter

Sara Töyrä
LKAB
sara.toyra@lkab.com

- M.Sc. Mechanical engineering 1999-2004 (Lund, Sweden)
- Team manager Dam safety at LKaB
- Tailings Governance
- 10 years of tailings management at LKAB
- 6 years as consultants in both hydro power sector and mining sector
- Chair of the Swedish dam safety group within (Svemin) the mining sector for 5 years

Presenter

Hans Häggström
Boliden
hans.haggstrom@boliden.com

- M.Sc. Civil Engineering 2005-2010 (Luleå, Sweden)
- Geotechnical engineer
- Dam safety and tailings management
- Dam safety controller / RIDAS-ansvarig
- Dam safety review, geotechnical investigation and stability calculations (2011-2017, Ramböll)

Presenter

Pierre-Louis Ligier
Sweco
pierre-louis.ligier@sweco.se

SWECO

- M.Sc. Hydraulic and Geotechnical engineering 2002-2006 (Grenoble, France)
- Specialist Hydraulic engineering
- Numerical modelling
- Dam & Tailings Dam Breach Assessments
- Dam safety
- Hydrological design

Presenter

Anna Risberg
Sweco
anna.risberg@sweco.se

- M.Sc. Aquatic and Environmental engineering 2000-2006 (Uppsala, Sweden)
- Team manager Hydraulics and dams
- Dam safety, hydraulics and consequence classification
- Dam safety supervision at County Administrative Board 2019-2022

Presenter

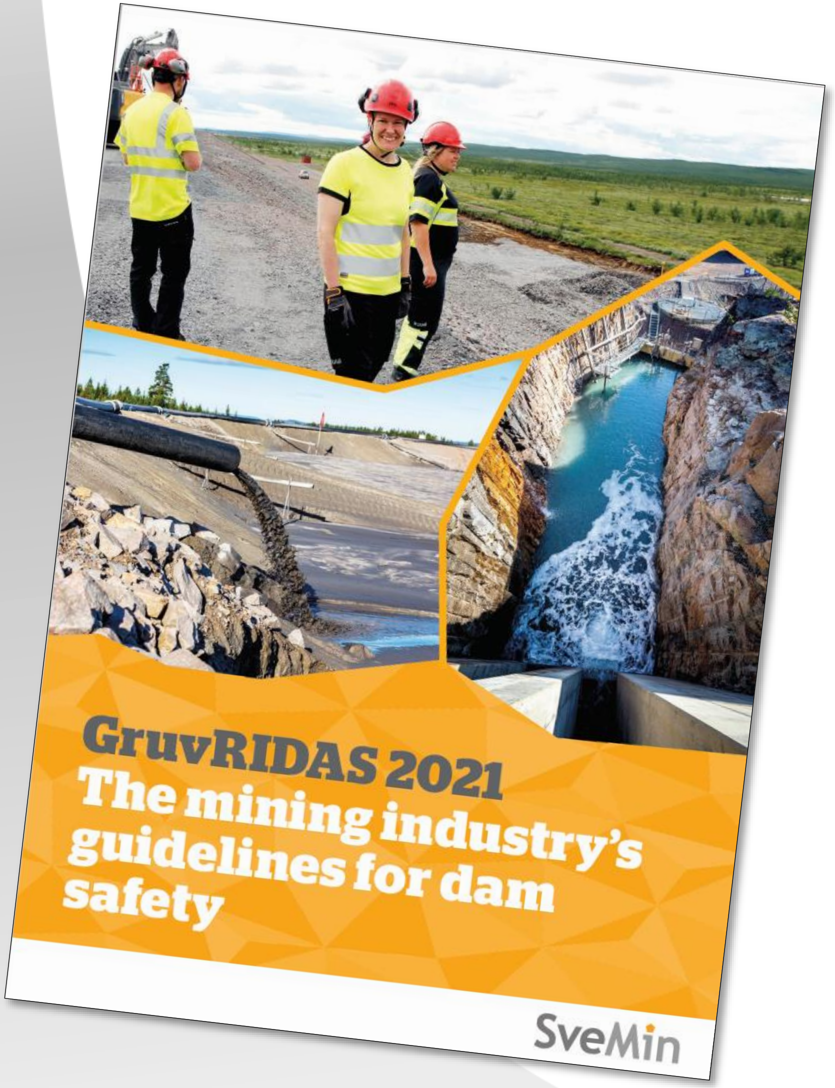
Mohammad (Mamun) Al-Mamun
Tetra Tech
Mamun.almamun@tetratech.com

TETRA TECH

- M. Sc. Eng. Geotechnical Engineering, 2001-2003 (Univeristy of Calgary, Canada)
- Principal Consultant – Dam Practise
- Design, construction, operation, and rehabilitation of dams (hydro and tailings)
- Mining waste and tailings management; mine closure and reclamation, tailings dam breach analysis (TDBA)
- Dam safety management and risk assessment
- Co-chair, Tailings Dam Breach Working Group, Canadian Dam Association (CDA.ca)
- Member, Technical Committee on Climate Change Adaptation of Dams, Canadian Standard Association (CSAgroup.org)

1 Introduction

National guidelines for dam safety

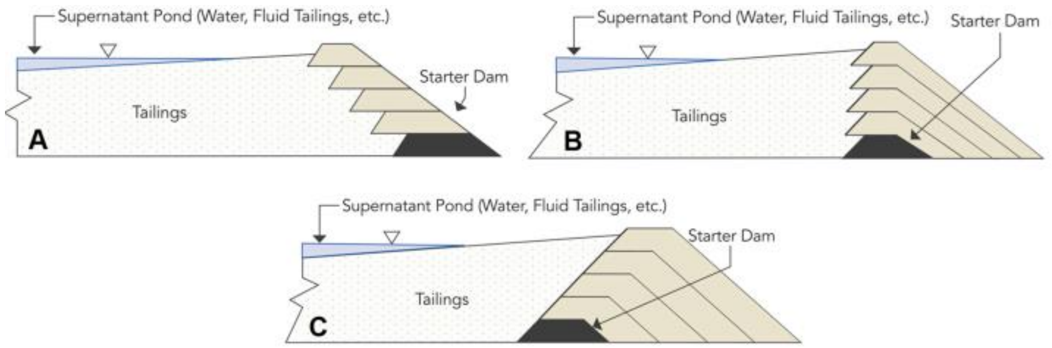


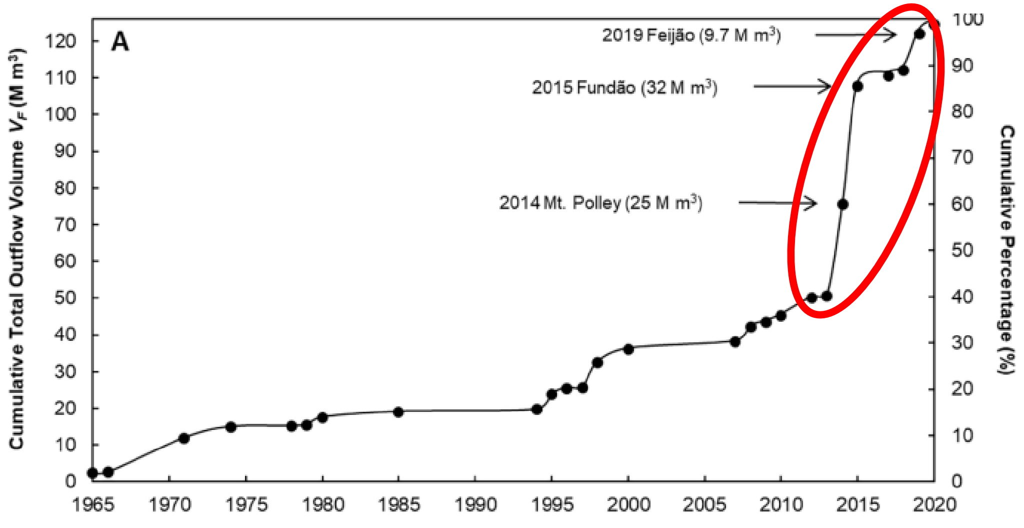
- 2021 third edition of GruvRIDAS.
- Ambition to guide Swedish mining company to compliance according to Swedish legislation.
- 1 main document and approximately 15 guidance document.
- Guidance document for "Dam breach assessment and dam safety classification" will be launched in 2023.
- Ambition to translate all documents to English.

Evolution of methods involved in TDBAs: overview

- Historically: mainly based on classic dam breach methodology for water retention dams
- TSFs are more complex:
  - Different media stored, complex geotechnical conditions
  - Variety of specific dam designs
  - Often, varying operating levels, dam raise operations
  - Tailings dam failures ~1.2% of total number of facilities (Azam & Li, 2010). ~ 100x than for water dams
- Lessons learned from failures:
  - Large variety of failure modes, overtopping / seepage not dominant as for water dams
  - Tailings liquefaction can dramatically influence the outflow volume and runout

From *Technical Bulletin on Tailings Dam Breach Analysis*, CDA (2021)

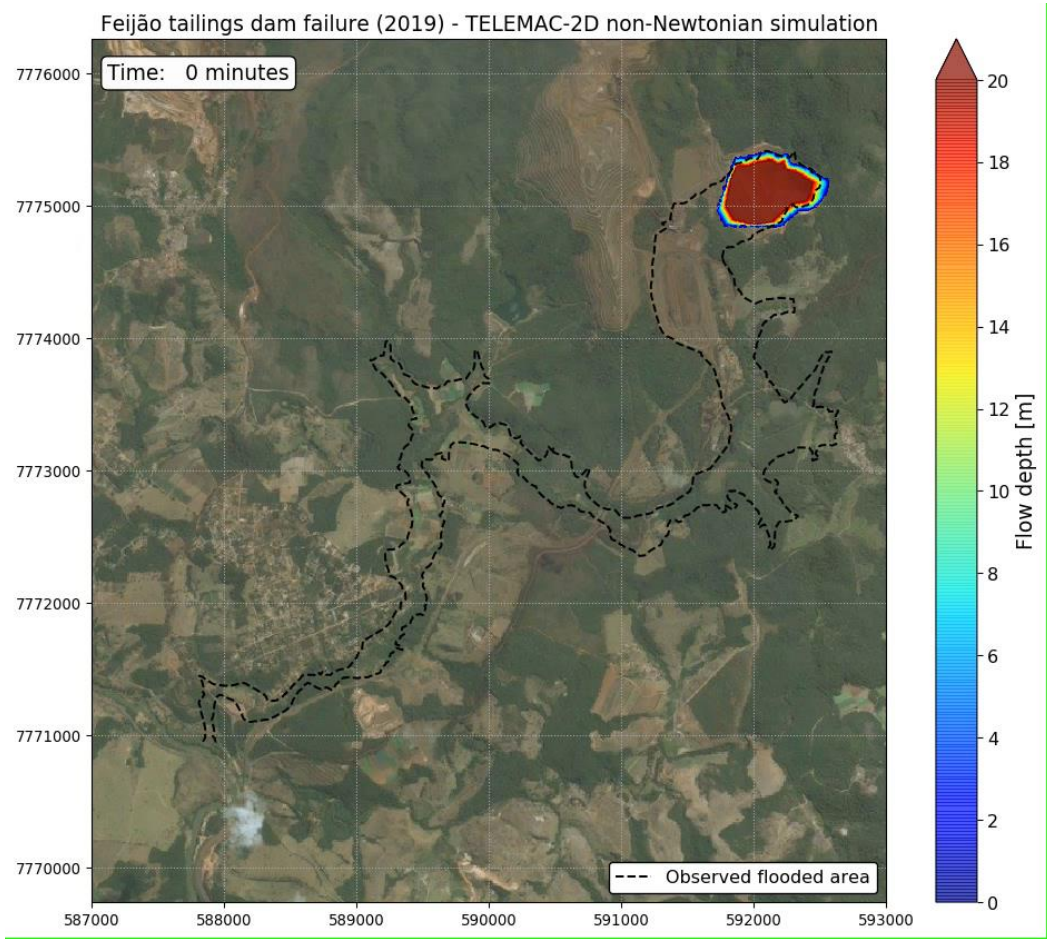




From Rana *et al.* (2021)

Evolution of methods involved in TDBAs: overview

- Recent & ongoing developments:
  - Better understanding of tailings geotechnical properties to inform dam breach assumptions
  - New and dedicated dam breach modelling methods + probabilistic analysis of dam breach parameters
  - Improved runout modelling (1D -> 2D -> 3D/CFD), including non-Newtonian rheological models, geo-mechanical models
  - Widespread use of sensitivity analyses to estimate and communicate about uncertainties
  - Consequences estimation and mitigation (emergency response plans, Loss-of-life and evacuation modelling…)



GruvRIDAS TV3 - The new guidelines for Tailings dam breach analysis and classification

1 INTRODUCTION

2 ASSESSMENT OF CONSEQUENCES

2.1 Introduction

2.2 Prerequisites to analyze and describe the Tailings Storage Facility (TSF)

2.3 Dam breach assumptions and scenarios

2.4 Runout analysis

2.5 Documentation specific to the TDBA

2.6 Identification of objects within inundation area

2.7 Assessment of consequences

3 CLASSIFICATION

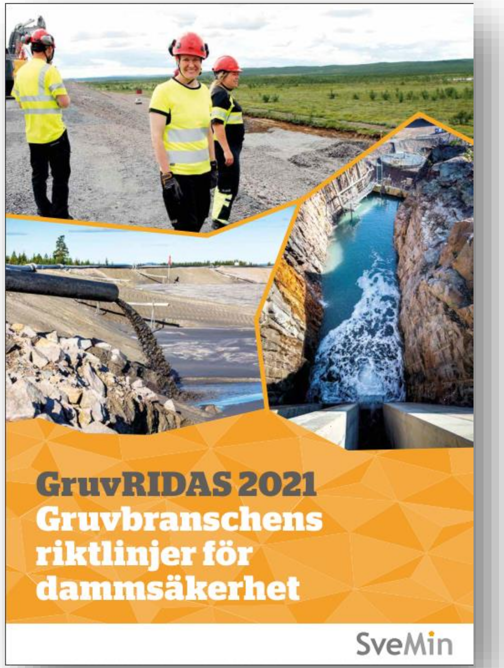
3.1 Dam safety classifcation according to Swedish Environmental Code

3.2 Decision on risk facility according to regulation on extractive waste

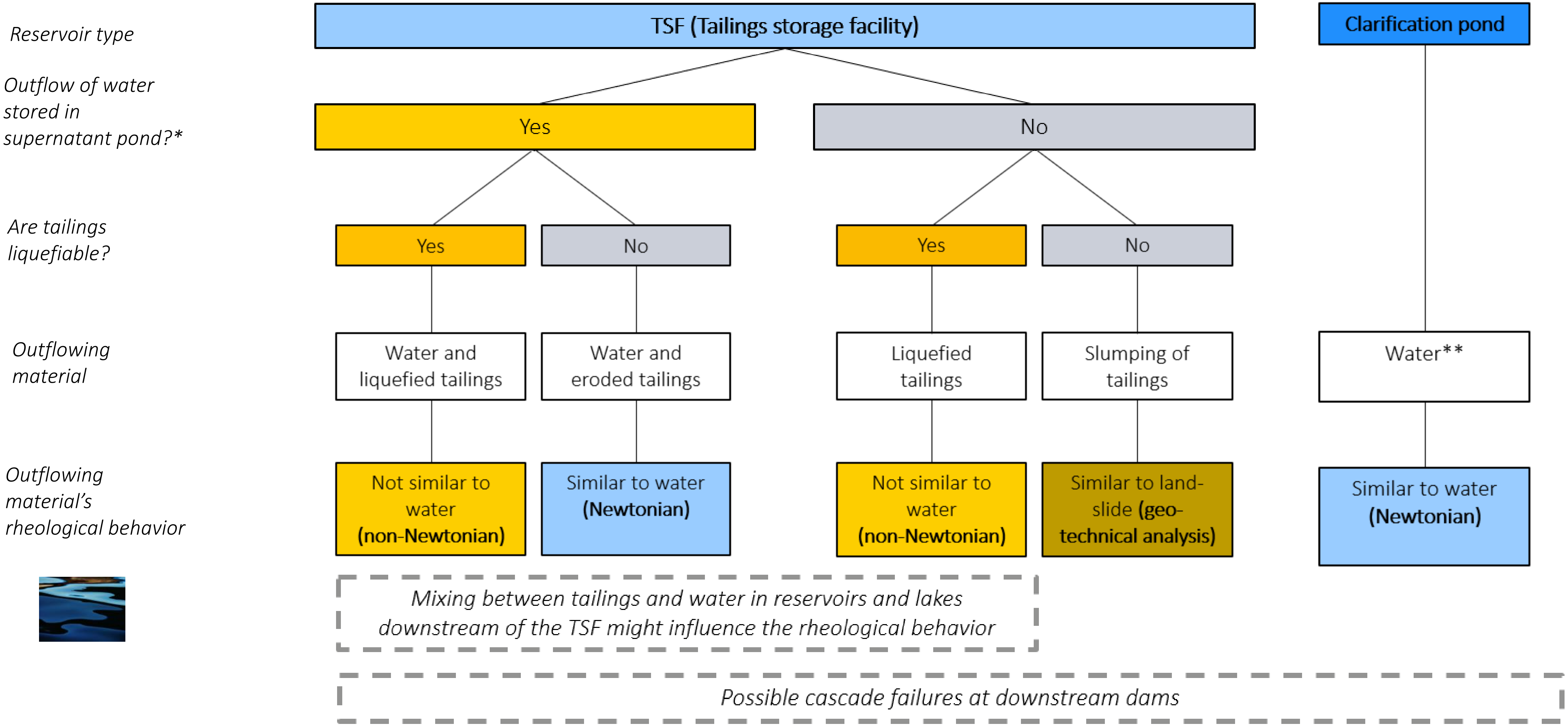
3.3 Classification for specific contingency requirements

3.4 Consequence classification according to Global industry standard on tailings management (GISTM)

3.5 Assessment of severity of consequences for design flood determination



GruvRIDAS TV3 - The new guidelines for Tailings dam breach analysis and classification

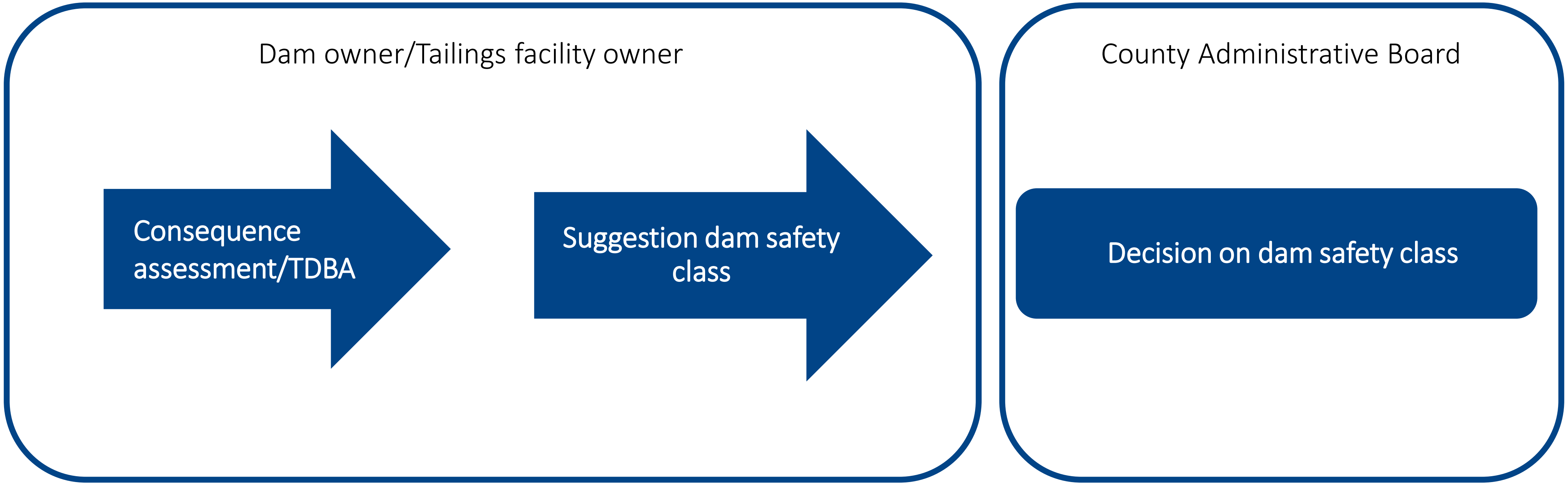


*The potential for outflow of water stored in supernatant pond should be assessed considering the pond's location, the beach width and the reservoir levels.

**The potential for erosion of deposited material and/or natural bottom sediments in the clarification pond should also be estimated.

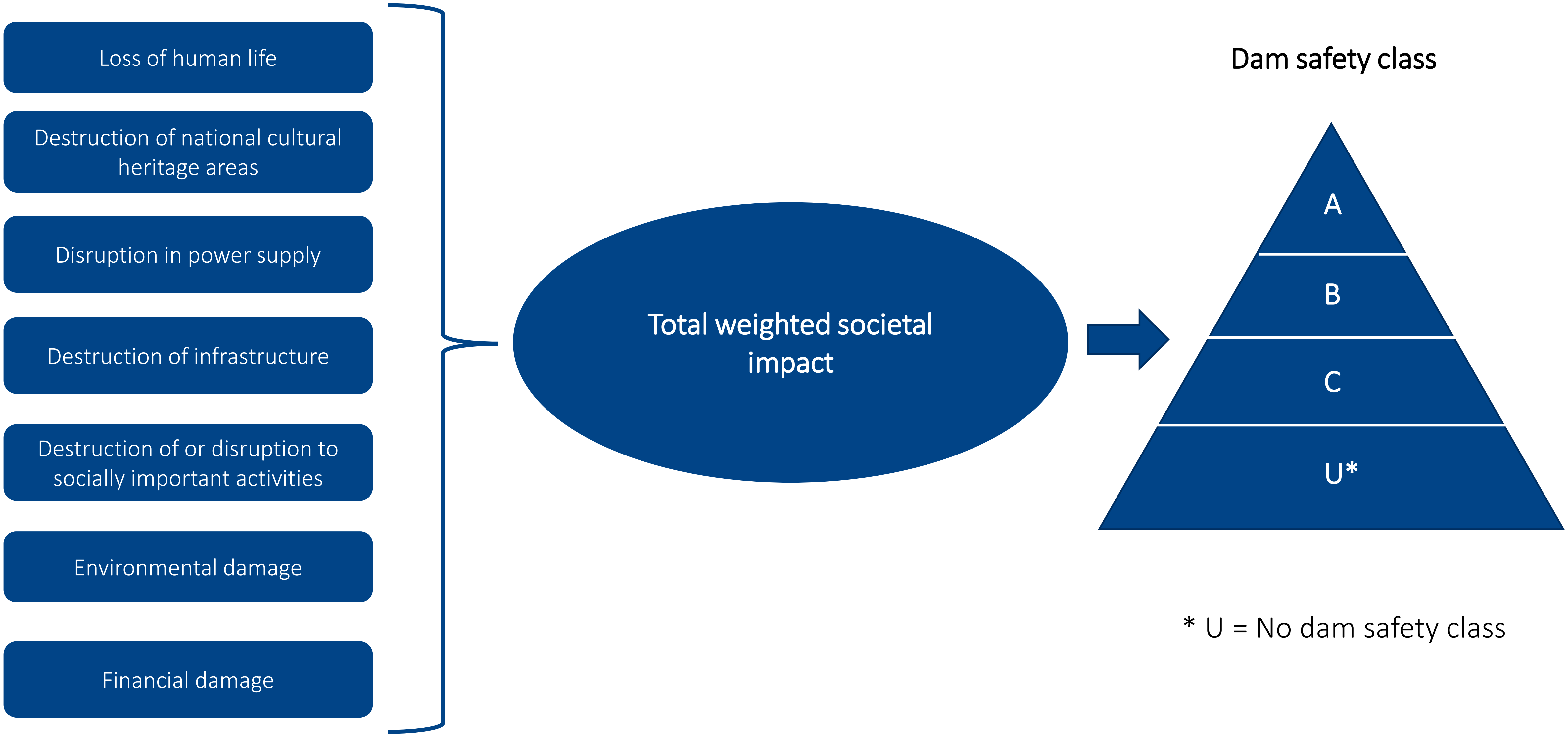
Dam safety classification in Sweden - process

- According to Swedish Environmental Code, 11 chapt. 24-26§§



Dam safety classification in Sweden

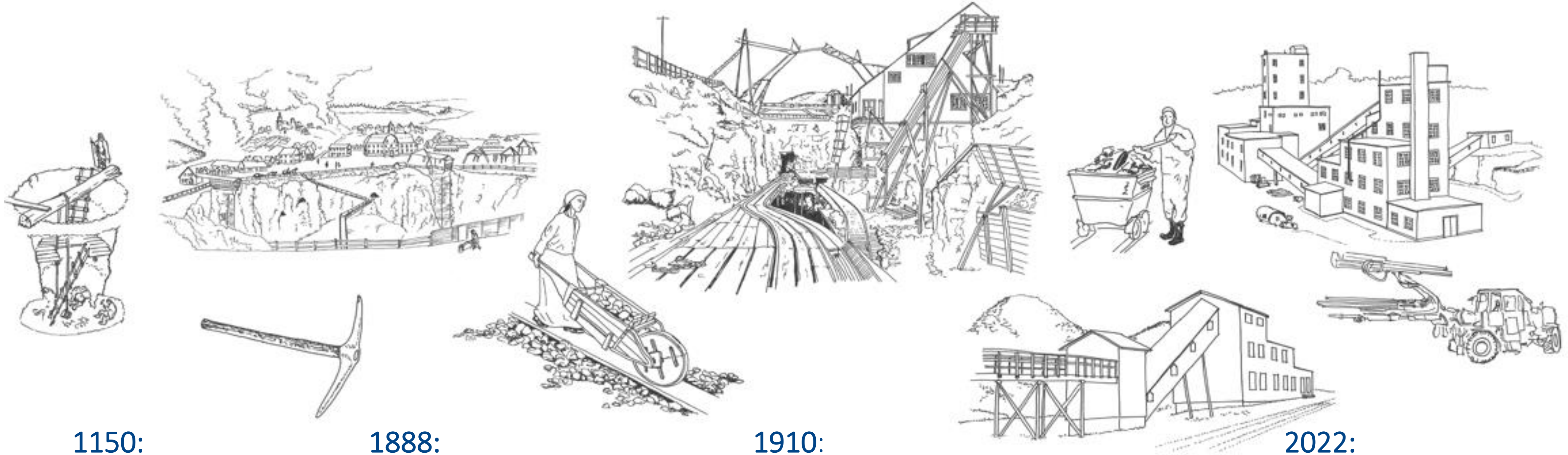
Incremental consequences



Dam safety classification in Sweden

Dam safety class	Severness/impact to society	Potential causes
A	Very serious	• A national crisis affecting large numbers of people and large parts of civil society and threatening fundamental values and functions. • Non-negligible risk of loss of human life.
B	Serious	• Major regional and local consequences or disruption. • Non-negligible risk of loss of human life.
C	Moderate	• Significant local consequences and disruption, injuries on local infrastructure, damage to property or environmental damage, or temporary disruptions. • Negligible risk of loss of human life.
U (No dam safety class)	**Small/Low**	• No significant consequences or disruptions. • Minor and local damage that can be restored without excessive costs.

Swedish mining history



1150:
First iron mine

16th century:
Largest copper mine in Europe

1888:
The Iron Ore Line

1890:
LKAB was founded

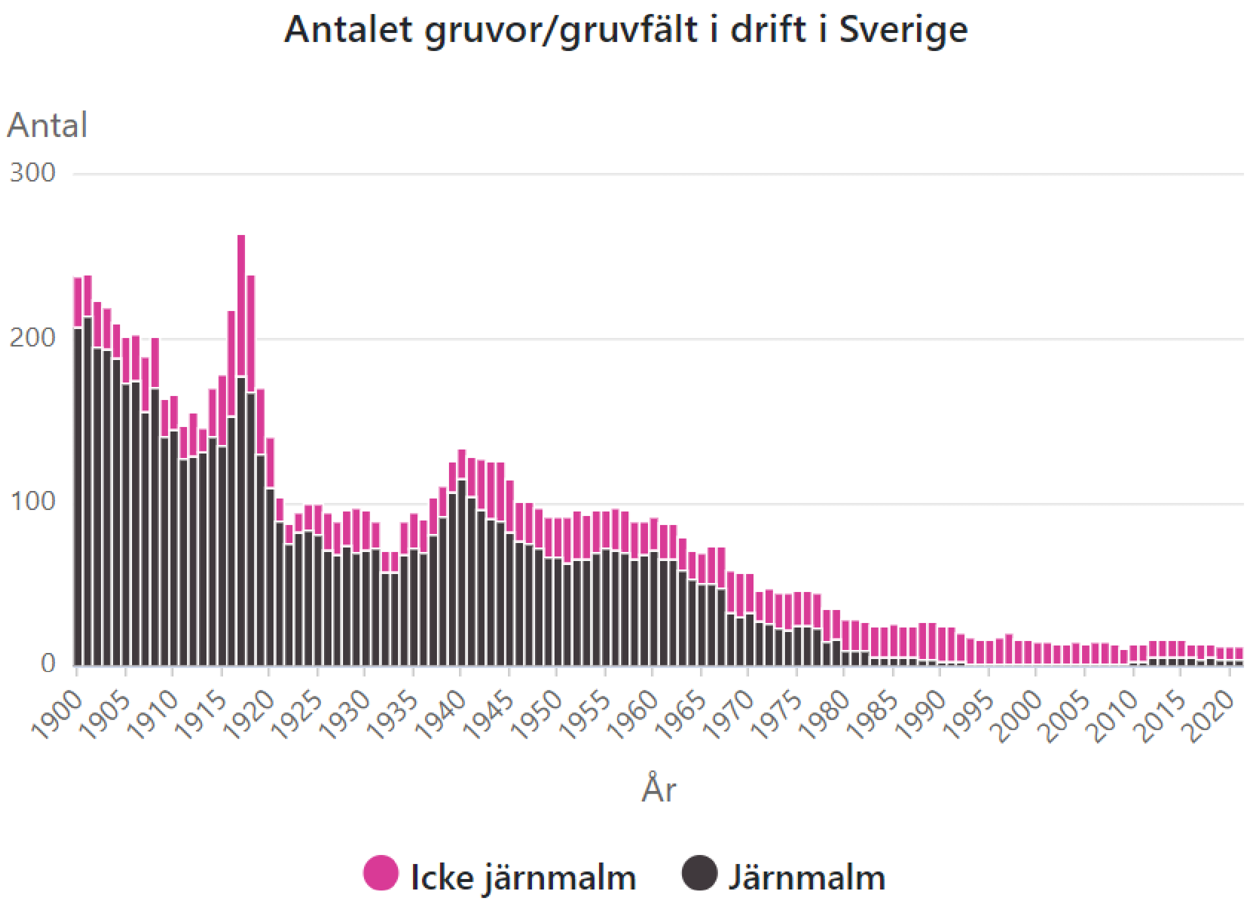
1910:
5 million tons,
240 mines

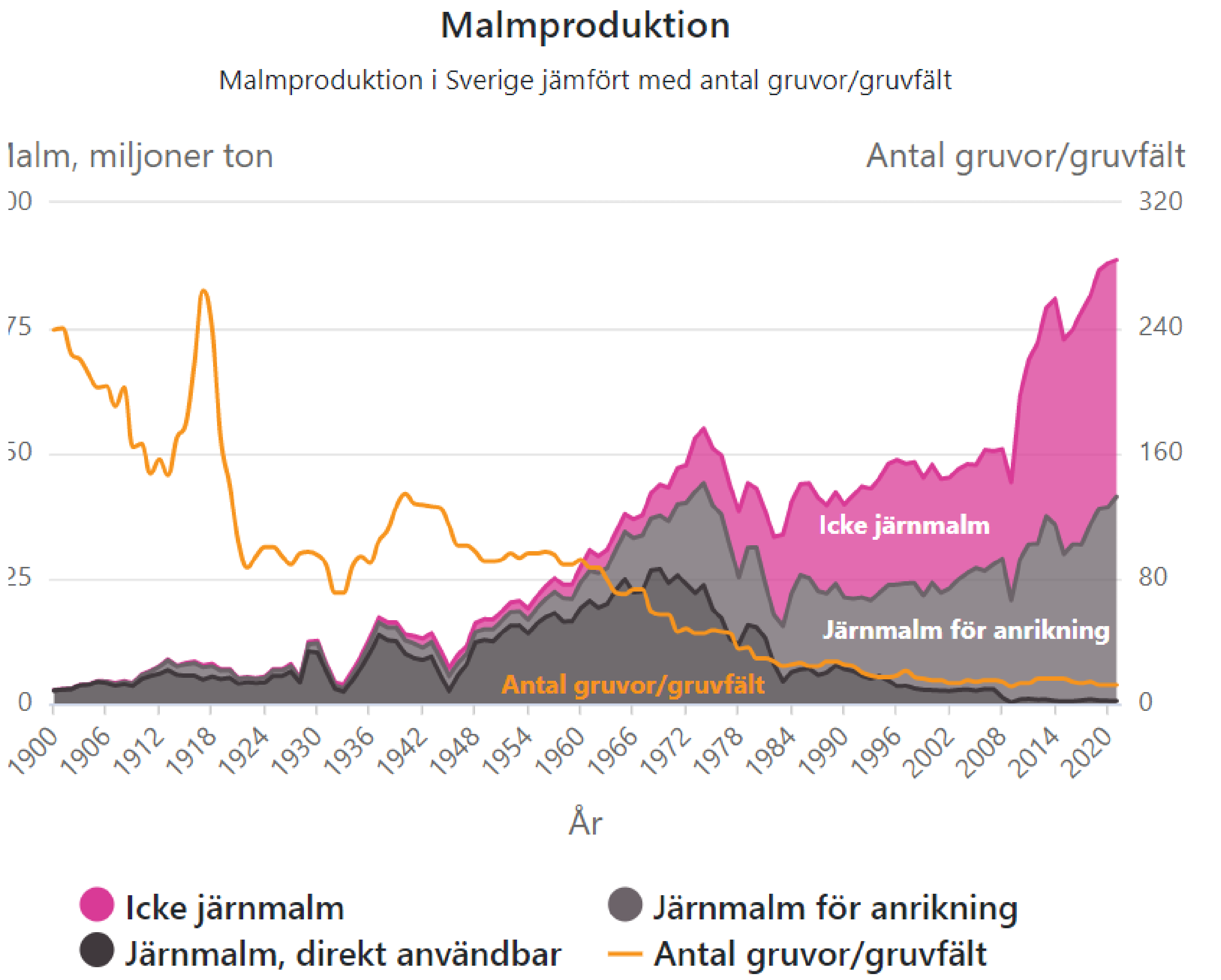
1924:
Boliden was founded

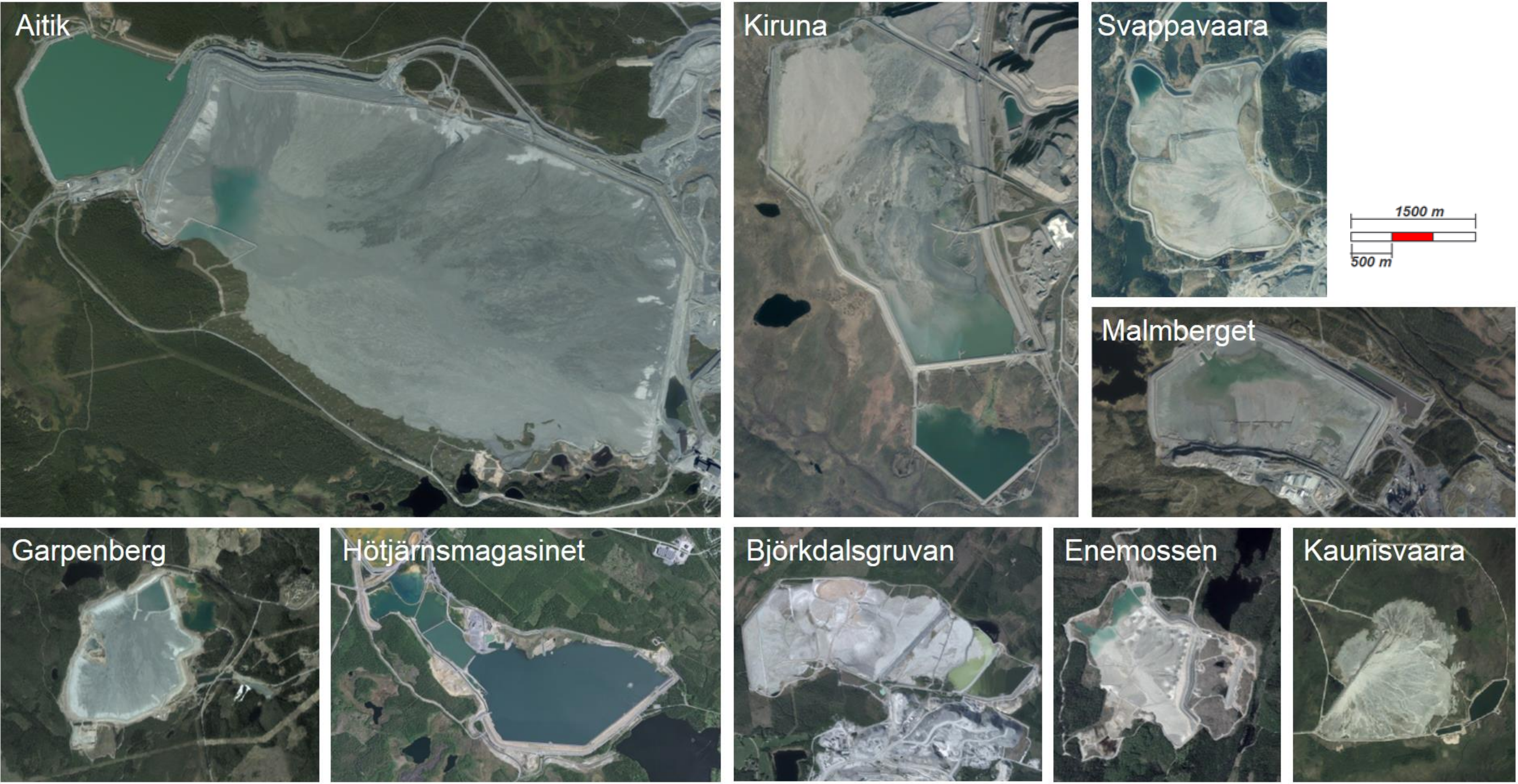
1960:
25 million tons,
100 mines

2022:
87 million tons,
12 mines

Swedish mining statistics






Aitik
Kiruna
Svappavaara
1500 m
500 m
Malmberget
Garpenberg
Hötjärnsmagasinet
Björkdalsgruvan
Enemossen
Kaunisvaara

Development of Management Practice in Sweden

1960-1970

Peak of hydropower

Several tailings dams

1995

11 Tailings facilities in operation.
single/end pipe discharge point from natural ground

2000

Shift to upstream construction

2022

9 TF in operation.
Shift to construction with low tailings dependency.

TDBA: Current State of Practice and Global Perspective

Current State of Practise

Pre-2010s’	2015-2020	2020- Present
• Not often done • When done, tailings is considered as water • No concerted effort to progress TDBA	• Growing awareness and interests • Workshops, technical papers, forum style discussions • Early initiatives to develop guidelines by CDA	• English version issued Sep. 2021 by CDA • Numerous research program by universities • Efforts by other groups to develop process, guidelines, etc.

- Limitations of water-based models are generally accepted by the industry
- More awareness to accurately analyze downstream impacts due to tailings dam breach

GISTM, August, 2020

- Requirements 2.3: Develop and document a *breach analysis* for the *tailings facility* using a methodology that considers *credible failure modes*, site conditions, and the properties of the slurry. The results of the analysis shall estimate the physical area impacted by a potential failure. When flowable materials (water and liquefiable solids) are present at *tailings facilities* with Consequence Classification of 'High', 'Very High' or 'Extreme', the results should include estimates of the physical area impacted by a potential failure, flow arrival times, depth and velocities, and depth of material deposition.

- Requirements 2.4: In order to identify the groups most at risk, refer to the updated *tailings facility breach analysis* to assess and document potential human exposure and vulnerability to *tailings facility credible failure scenarios*.

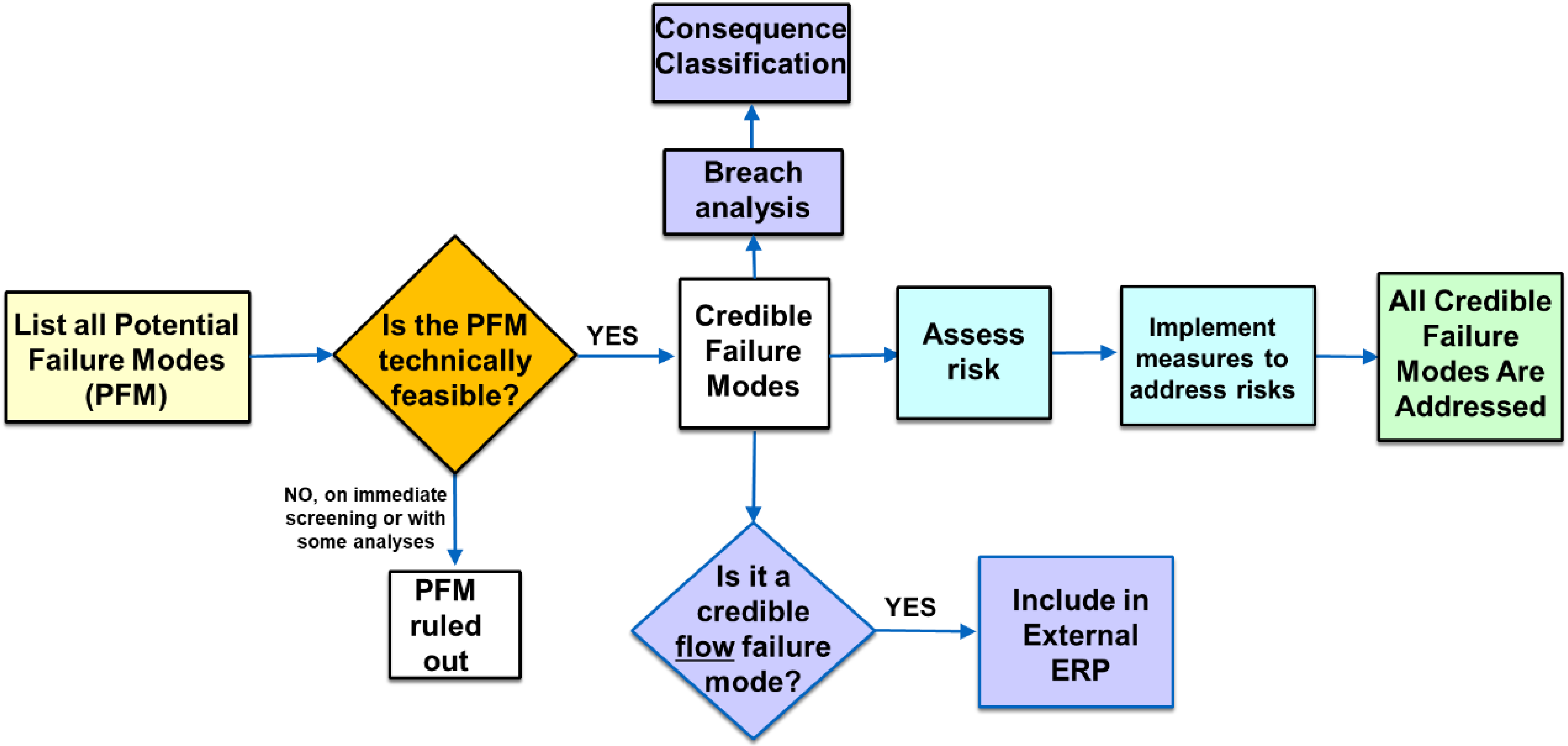
Credible Failure Mode

- Global Industry Standard on Tailings Management (GISTM, 2020) defines credible failure modes as follows:

Credible: *Refers to* ***technically feasible failure mechanisms*** *given the materials present in the structure and its foundation, the properties of these materials, the configuration of the structure, drainage conditions and surface water control at the facility, throughout its lifecycle.*

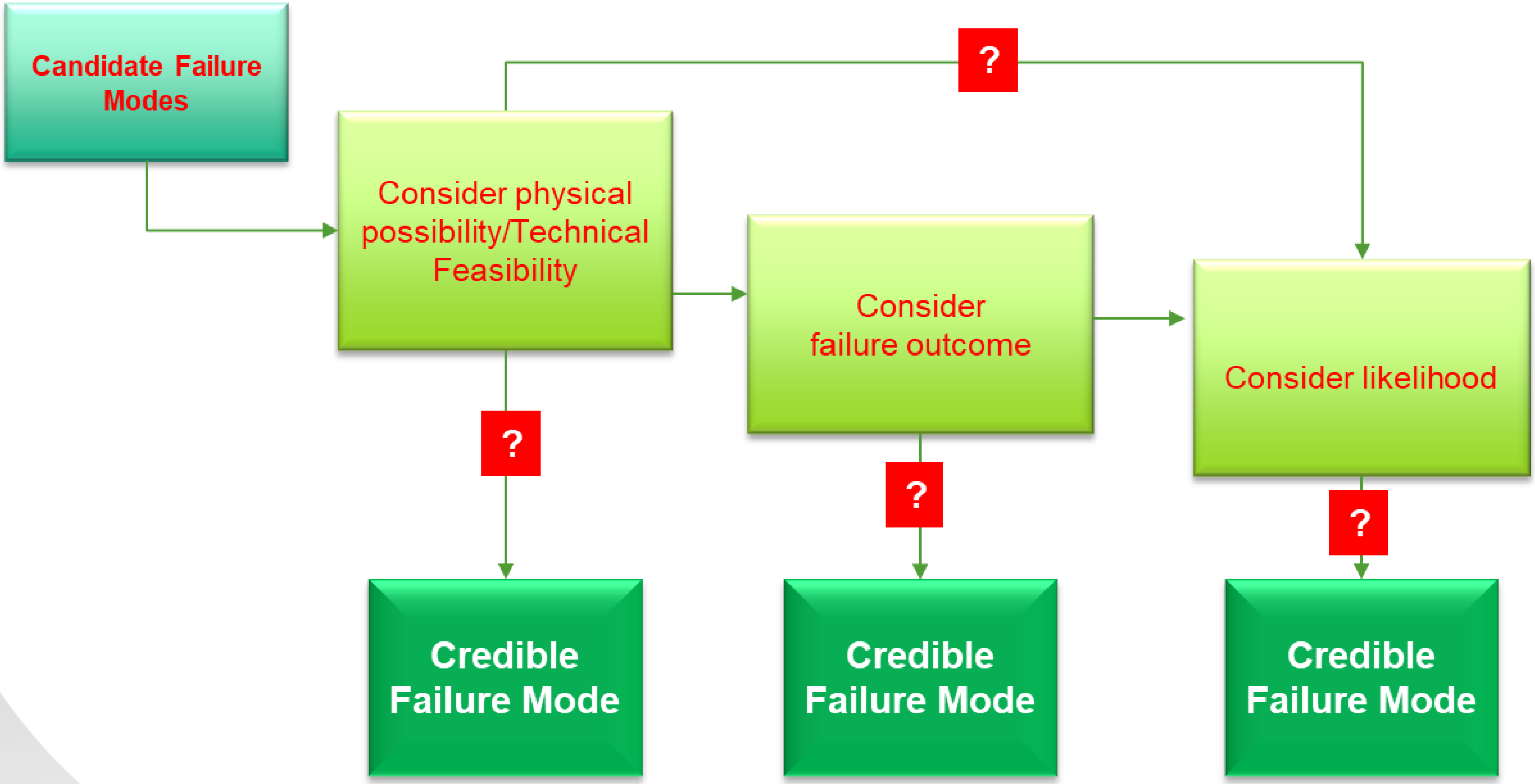
- GISTM also noted:
  - *Credible failure modes can and do typically vary during the lifecycle of the facility as the conditions vary.*
  - *Credible catastrophic failure modes do not exist for all tailings facilities.*
  - *The term 'credible failure mode' is* ***NOT*** *associated with a* ***probability of this event*** *occurring and having credible failure modes is not a reflection of facility safety.*

Credible Failure Mode – GISTM Flowchart



Prepared by: Angela Kupper for CFM workshop, Tailings and Mine Waste, 2021, Banff, Canada.

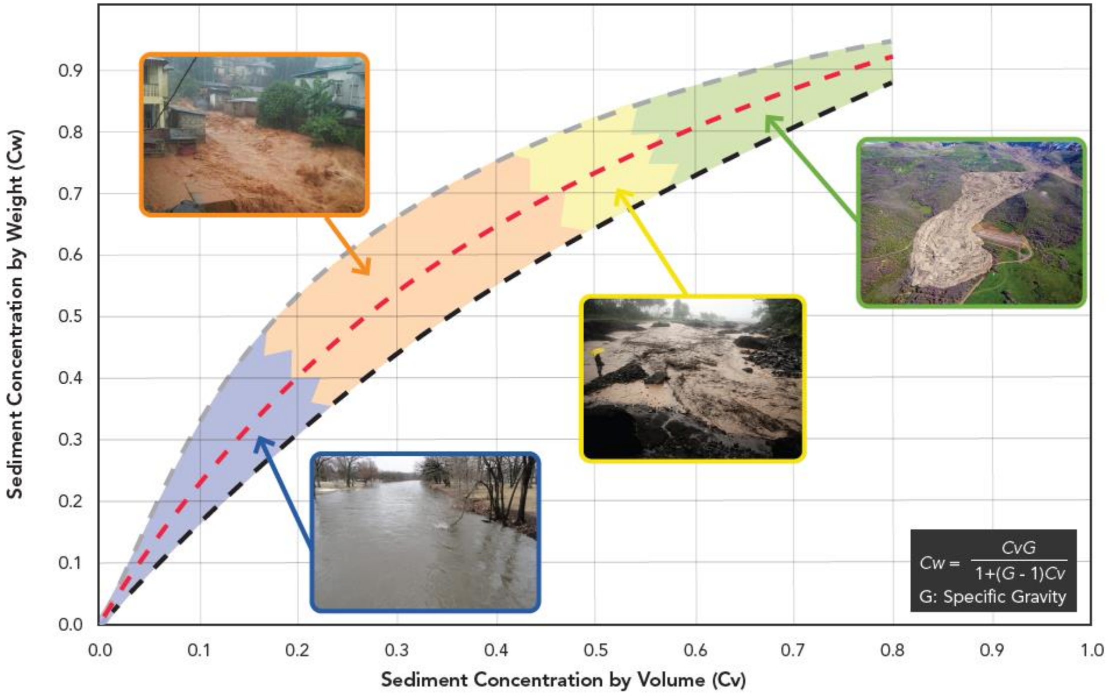
Credible Failure Mode – other thoughts



Credible Failure Modes Workshop, 2021 Tailings and Mine Waste Conference, Vancouver, Canada

Properties of Tailings

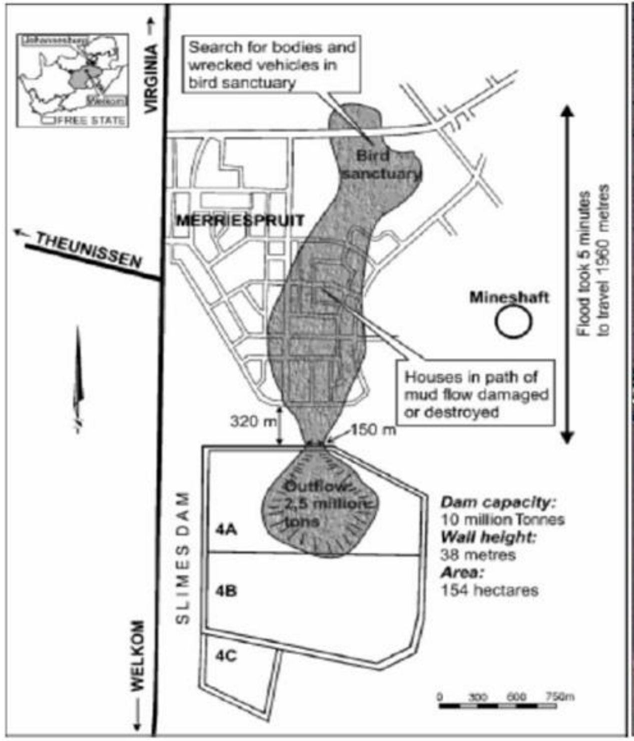
- Vast difference between different mineral tailings.
- In-situ rheology of tailings is relevant for tailings mobilization process.
- Rheology parameters tested for pipeline design or design of thickeners may not be suitable for TDBA.
- Information on tailings composition and characteristics are sourced from literature review due to the limitations testing data.

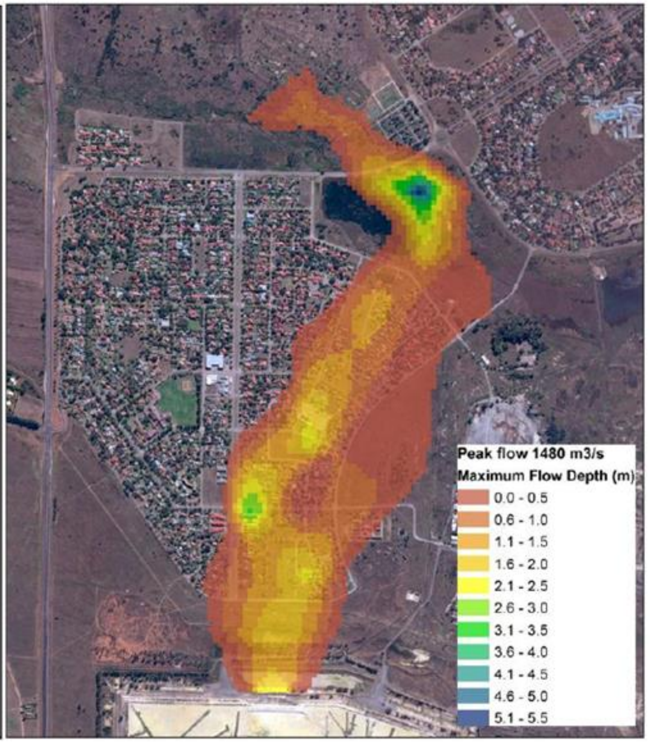


Technical Bulletin: Tailings Dam Breach Analysis, Canadian Dam Association, 2021.

Application of TDBA – Consequence and emergency planning

- For ‘extreme’ or ‘very high’ consequence TFS TDBA may not be required to establish design criteria
- But, for all TSF, TDBA is required to delineate inundation zones for emergency planning
- TDBA and inundations maps are useful tool for stakeholder engagement and risk communication



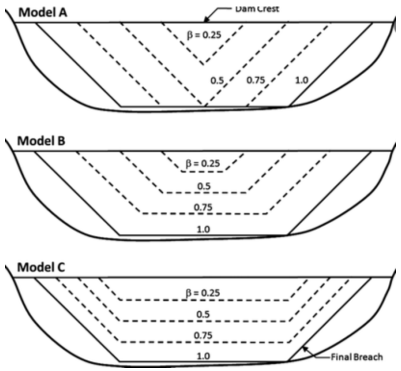


Tailings Dam Breach Workshop 2015, Canadian Dam Association

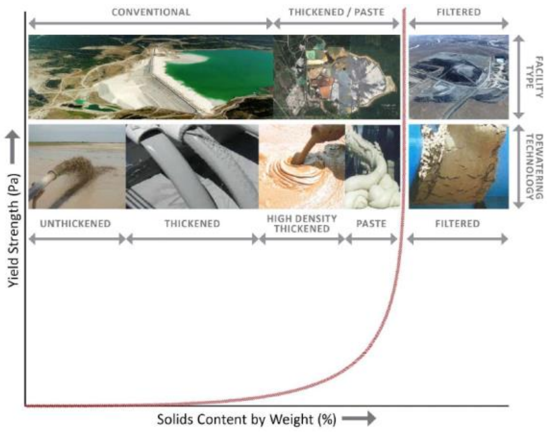
Challenges remain!

ICOLD•CIGB 2023 GOTHENBURG

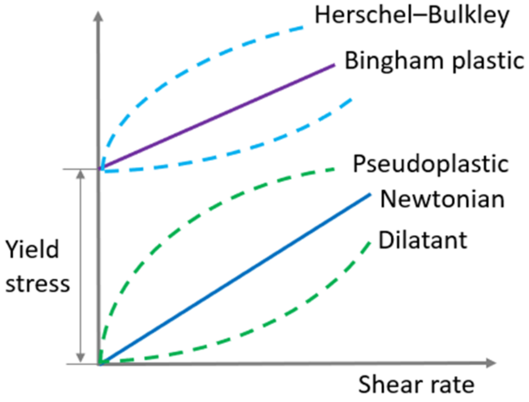
Breach modelling for upstream dams, zoned dams, etc.



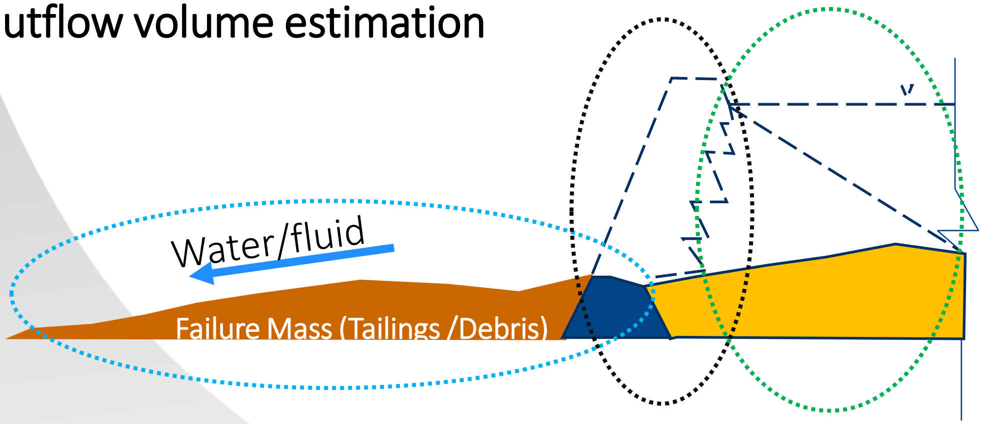
Tailings characterization



Outflow rheology



Outflow volume estimation



Runout assessment, Flood routing

- Hydrodynamic models – commercial packages available can do 2D Newtonian and Non-Newtonian flow model;
- Geomechnical models – limited models available primarily from geohazards study;

2 Workshop Part 1

Part 1: Case study of different tailings dam breach cases

- Examples of cases involving each of the 4 tailings dam breach cases
  - 1A-2A: Example from Swedish mine (Garpenberg TSF, Boliden)
  - 1B-2B: Examples from historical & hypothetical cases

- Runout analysis:
  - Basic requirements
  - Challenges and limitations

- Consequences – Example estimating potential loss of life

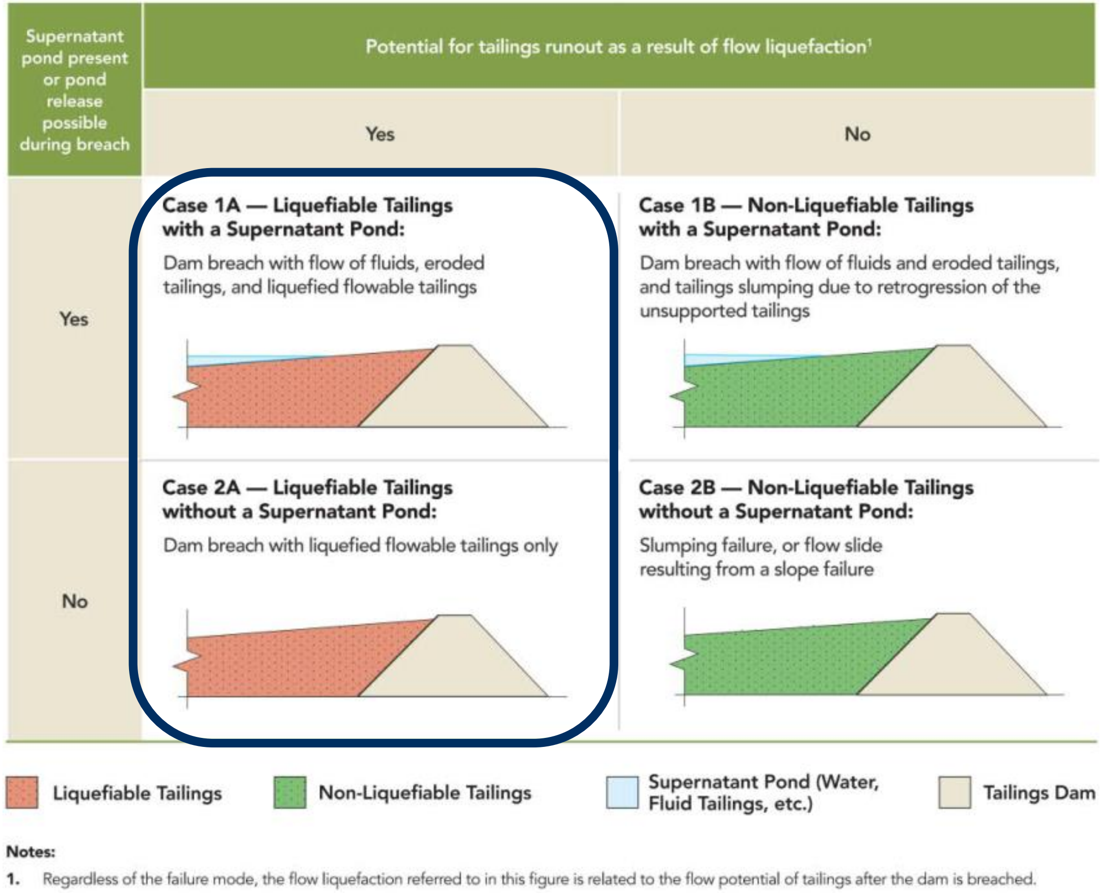
- Questions

Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Cases 1A & 2A: **liquefiable tailings** with/without a pond

- TDBA study case: Garpenberg TSF
  - Permit application
  - Consequence classification according to Swedish Environmental Law and GISTM
  - Disclaimer: no generalization from this specific example

From *Technical Bulletin on Tailings Dam Breach Analysis*, CDA (2021)



Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Garpenberg TSF (Boliden)
- First mining operations started in 1200-1300
- Mine/TSF recent history:
  - Acquired by Boliden in 1957
  - First, deposition in lake
  - Deposition above water (spigotting) since 2007-2008
  - Dam construction methods:
    - 1960-2008: centerline
    - 2008-2022: upstream raised
    - 2023-2025: centerline with d/s rockfill embankment

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Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Geotechnical conditions:
  - Tailings characterization study (2021)
  - CPT, shear vanes, triaxial (critical state tests), in-situ void ratio
  - **Risk for liquefaction can't be excluded** (loose deposits of contractive and strain softening silt tailings at depth)
  - Geotechnical properties highly dependant on deposition methods/levels:

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Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Hydrological conditions:
  - Design flood: ”Klass I” (AEP < 1:10,000)
  - Supernatant pond:
    - 0,2 Mm^3 for normal operation
    - 0,5 Mm^3 for design flood (spillway’s passive design allows to account for flood evacuation) – very small additional volume w.r.t. tailings outflow
  - Hydrographic network:
    - Lakes and rivers located d/s all the considered breach locations

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Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Critical failure mode:
  - **Foundation failure involving low-levels tailings**
  - Static liquefaction: not credible (dam design can withstand it)
  - Internal erosion: can be considered as credible, but less critical than stability / foundation failure
  - Overtopping: not credible (freeboard + spillway's passive operating, risk for debris blockage minimal)

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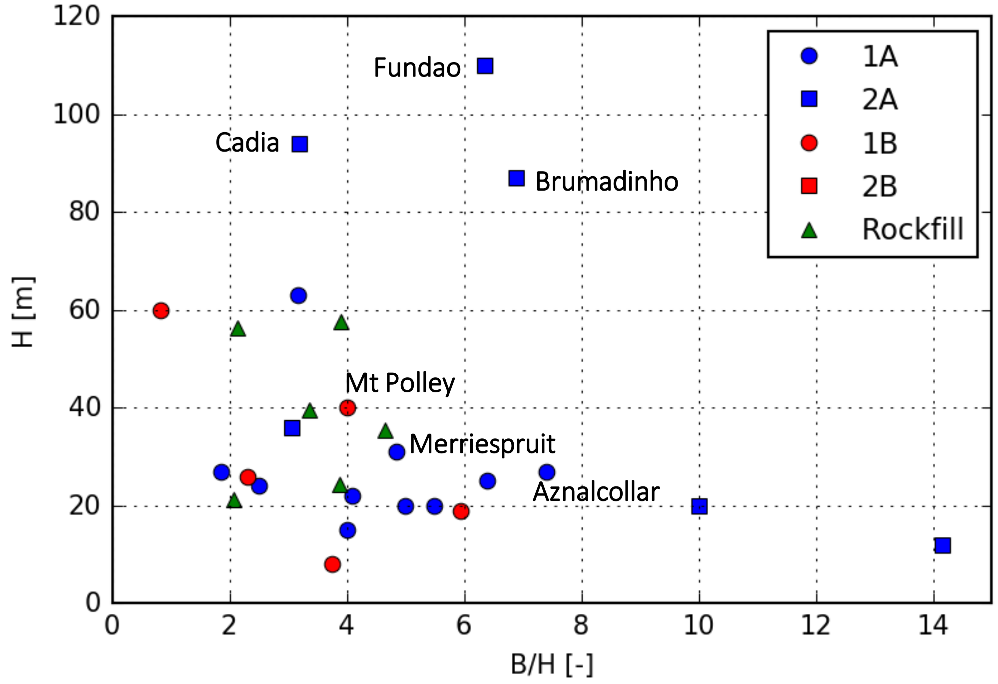
Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Breach dimensions:
  - Analysis of historical events and existing guidelines
  - Data from rockfill dam failures included
  - Considered breach ratio B/H: 3 to 5
  - Advanced numerical models can also potentially be used

Source of data: Rana et al. (2021), Wahl (1998)



Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Outflow volumes:
  - Water (supernatant pond, if relevant)
  - Liquefied tailings
- Case 1A or 2A depending on breach location w.r.t. supernatant pond
- Different outflow processes depending on breach location w.r.t. supernatant pond:
  - 1st Tailings 2nd Water
  - 1st Water 2nd Tailings

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Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Outflow volumes, tailings:
  - Several methods investigated
  - Determined by geometry of depression cone, most suitable (see previous slide)
  - Cone slope defined following hypothesis:
    - Tailings liquefy during outflow
    - Tailings can be considered saturated
    - Cone's slope can be estimated using Infinite slope theory from residual shear stresses (Seddon, 2007)
  - Slopes between 3 and 5 degrees were considered
  - Advanced numerical models can also potentially be used

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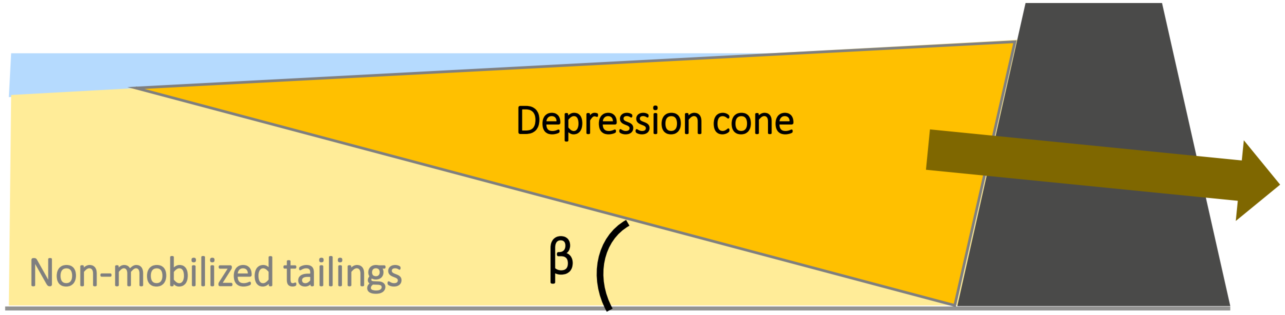
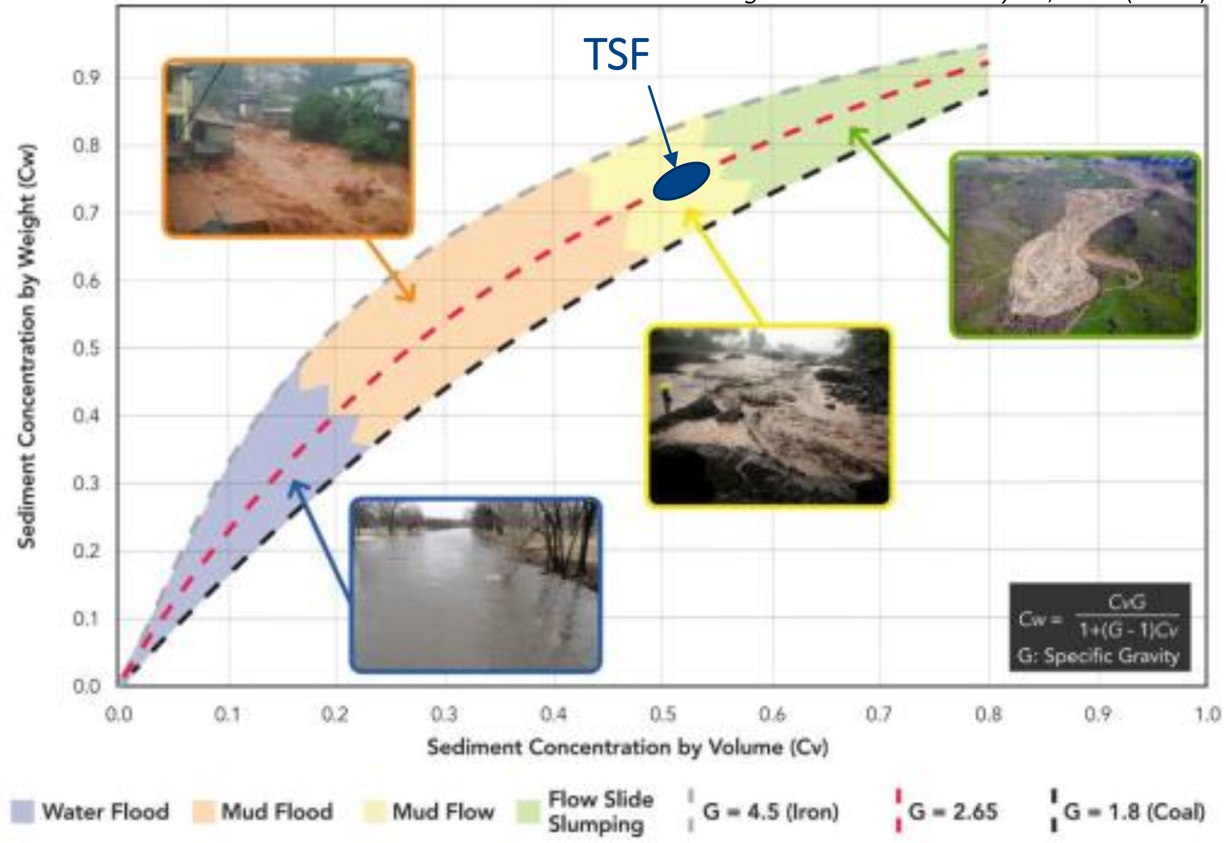


Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Tailings rheology:
  - Outflow behaviour highly dependant on material concentration & degree of saturation
  - Tailings' volumetric concentration in TSF estimated in range **Cv = 50-54%**
  - Rheological model used (runout):
    - Bingham
    - Bulk density, viscosity, yield stress
  - Uncertaintes in rheological properties: two scenarios (span)
  - Mixing with d/s water bodies affects the rheological behaviour

From *Technical Bulletin on Tailings Dam Breach Analysis*, CDA (2021)



Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Runout analysis:
  - 2D hydrodynamic models
  - Non-Newtonian (Bingham) & Newtonian rheology with mixing effects accounted for
  - Outflow processes:
    - 1st Tailings 2nd Water
    - 1st Water 2nd Tailings
    - Handling of both Non-Newtonian (Bingham) and Newtonian behaviour based on local Cv
  - Casacade failure in d/s dams or infrastructure

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Part 1: Examples of TDBA for Tailings dam breach cases 1A & 2A

- Sensitivity analysis:

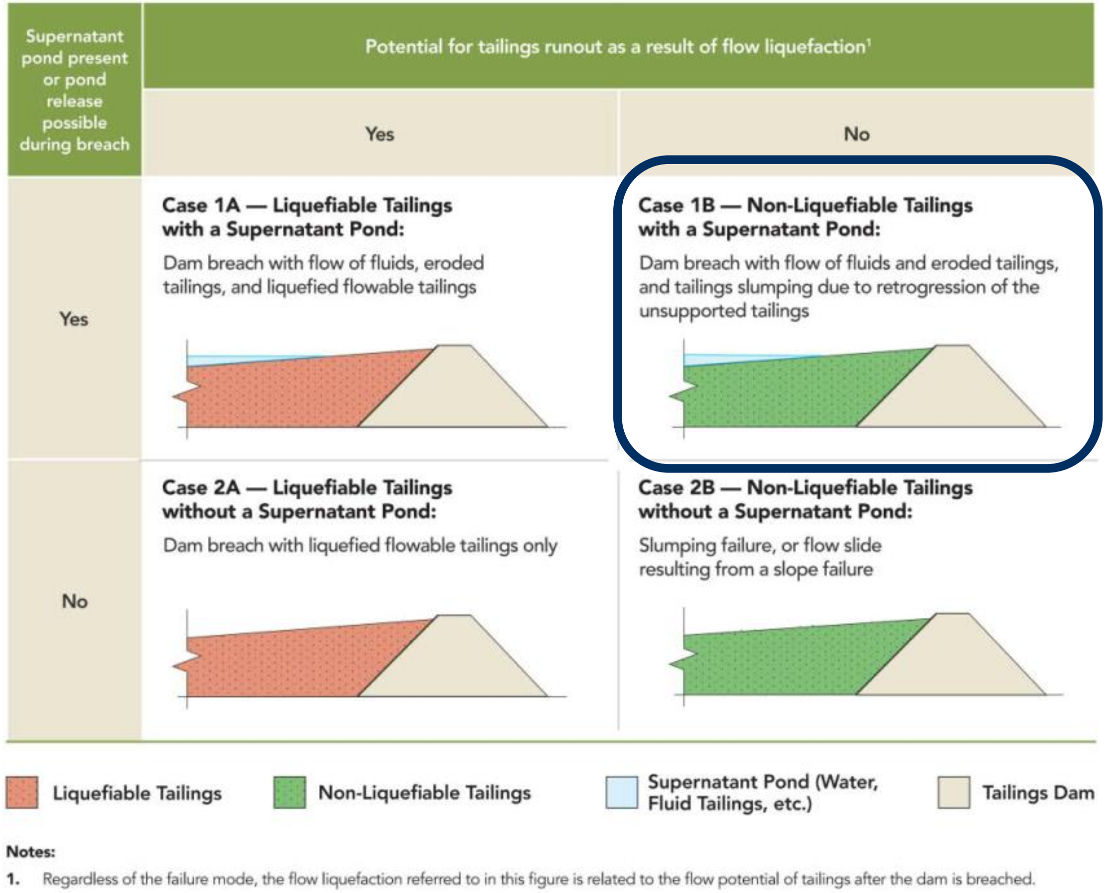
Scenario	Outflow volume (i.e. slope of erosion cone)		Rheological parameters		Breach development time	
	3 degrees	5 degrees	Low	High	Short	Long
1	O		O		O	
2	O			O		O
3		O	O		O	
4		O		O		O

Part 1: Examples of TDBA for Tailings dam breach cases 1B

- Mount Polley TSF (open pit copper and gold mine)
- Located British Columbia, Canada

https://www.cbc.ca/news/canada/british-columbia/mount-polley-spill-blamed-on-design-of-embankment-1.2937387

From *Technical Bulletin on Tailings Dam Breach Analysis*, CDA (2021)



Part 1: Examples of TDBA for Tailings dam breach cases 1B

- Operation since 1995
- Dam Height: ~40 m
- Surface Area : ~2.2 km^2
- Storage:
  - Pond Water ~ 10.6 Mm^3
  - Copper, Gold, Silver Tailings ~63.3 Mm^3
- Failed on August 4, 2014

✓Pond presence

? Liquefiable tailings

Independent Expert Engineering Investigation and Review Panel. 2015. Report on Mount Polley Tailings Storage Facility Breach, January 30, 2015 (https://www.mountpolleyreviewpanel.ca/sites/default/files/report/AppendixC_SurfaceInvestigation.pdf)

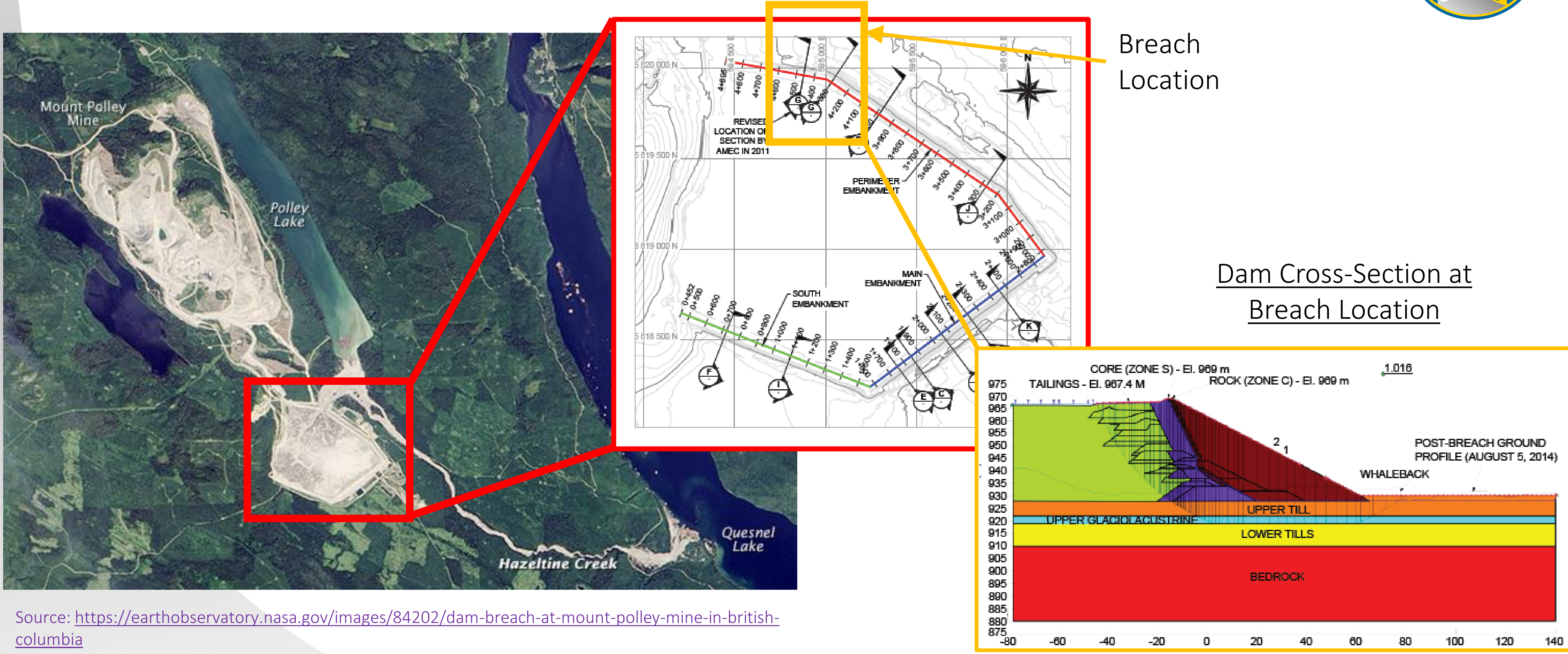
https://en.wikipedia.org/wiki/Mount_Polley_mine#/media/File:Mount_Polley_Mine_site.jpg

Part 1: Examples of TDBA for Tailings dam breach cases 1B

- Failure Mode:
  - Climate condition: Fair Weather
  - Triggers of the failure:
    - Weak foundation layer
    - Overly steep dam slope
    - Excavation near the dam toe
    - Mismanagement (pond close to the crest, insufficient freeboard)
  - Failure sequence
    - Phase 1 – Dam crest deformation
    - Phase 2 – Overtopping failure

Geotechnical Investigation of the Mount Polley Dam - KCB (klohn.com)

Part 1: Examples of TDBA for Tailings dam breach cases 1B



Source: https://earthobservatory.nasa.gov/images/84202/dam-breach-at-mount-polley-mine-in-british-columbia

Source: Report on Mount Polley Tailings Storage Facility Breach, 2015

Part 1: Examples of TDBA for Tailings dam breach cases 1B

- Release Volume estimate:
  - Pond water:
    - ~10.6 Mm^3
  - Mobilized Tailings:
    - ~13.8 Mm^3
  - No noticeable flow liquefaction

TABLE C4.5.2: BULK TAILINGS AND WATER VOLUMES

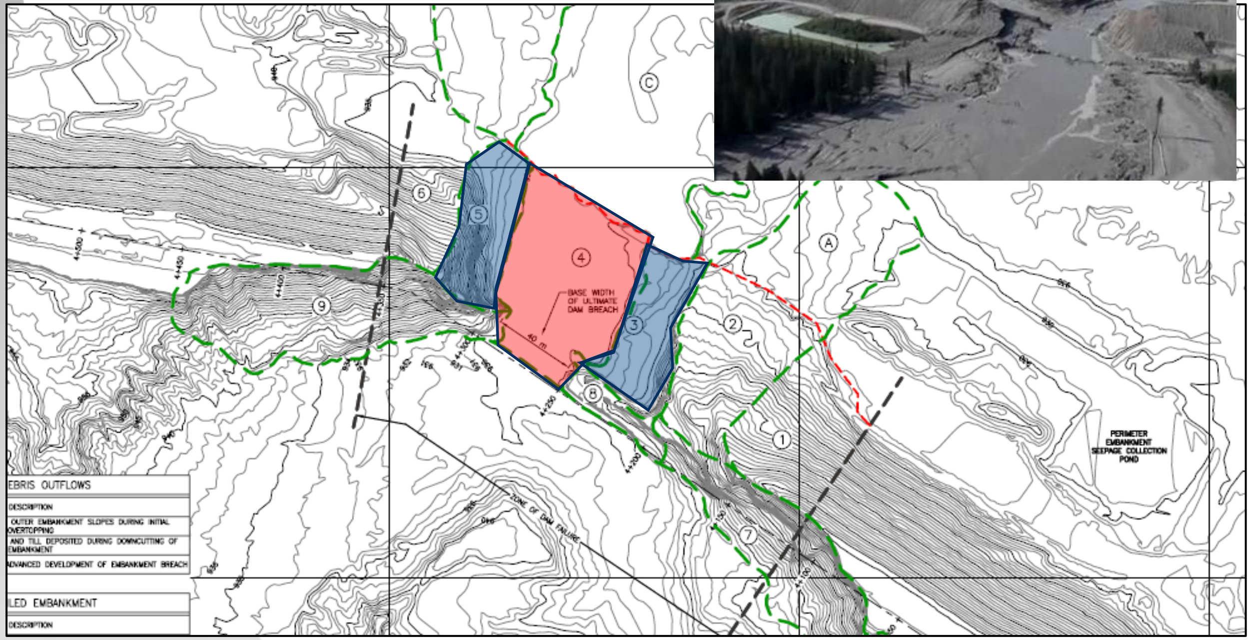
MATERIAL/PROPERTY	PRE-BREACH CONTENTS (million cubic meters)	CONTENTS RELEASED (million cubic meters)
FREE WATER	10.6[a]	10.6
BULK TAILINGS	63.3	13.8
TOTAL	**73.9**	**24.4**

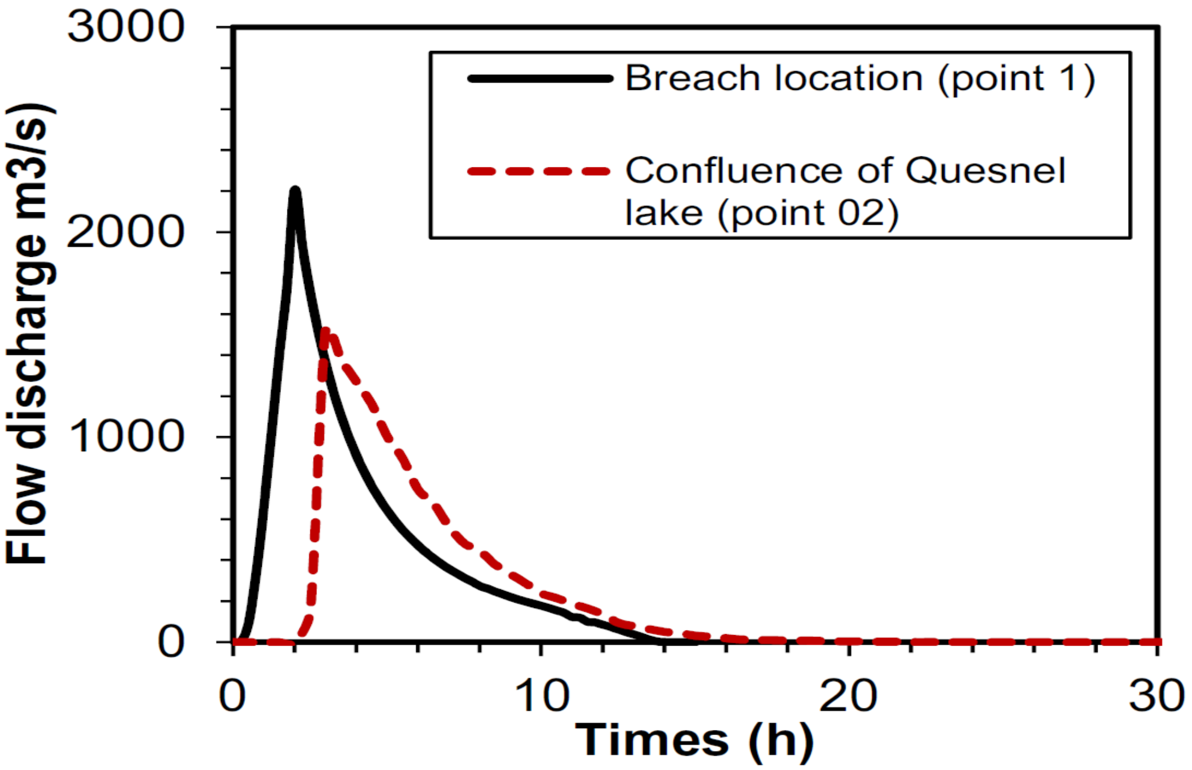
https://www.mountpolleyreviewpanel.ca/sites/default/files/report/AppendixC_SurfaceInvestigation.pdf

Klohn Crippen Berger. 2015. Mount Polley tailings dam failure – Assessment of failure mechanism. Report No. M09954A01.730. BC Ministry of Energy and Mines, May 2015.

Part 1: Examples of TDBA for Tailings dam breach cases 1B

- Breach height: ~40m
- Breach bottom width: ~ 40m
- Breach side slope (H:V): ~1:1
- Breach runout duration time: ~12 hours





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Part 1: Examples of TDBA for Tailings dam breach cases 1B

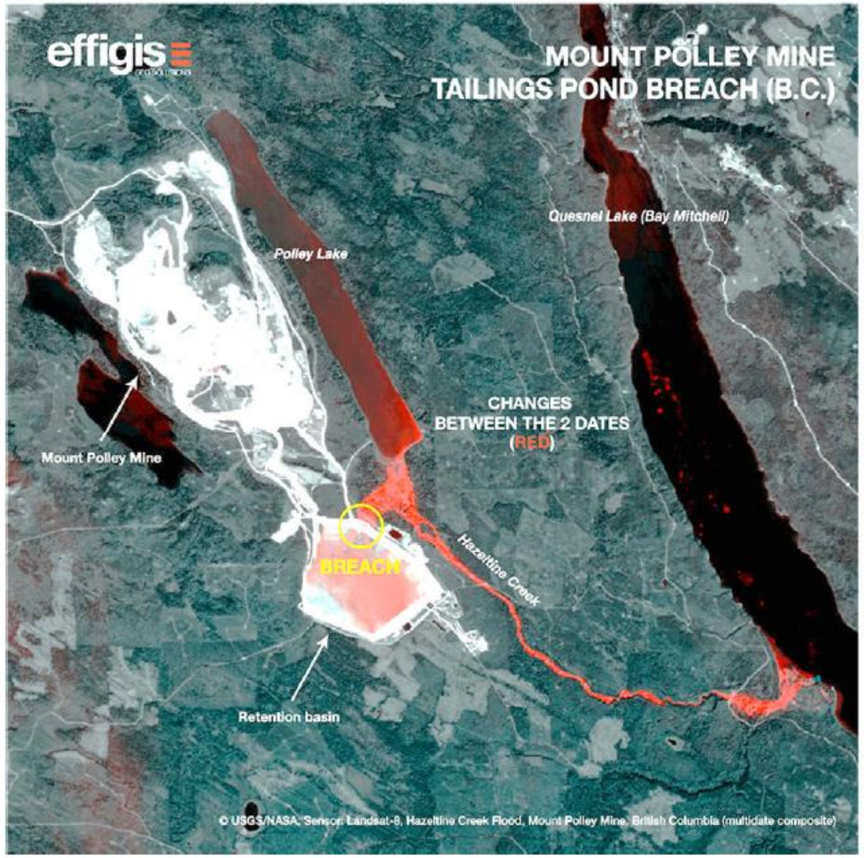
Runout Model:

- Total volume of outflow was used assuming non-Newtonian flow
- Measured water level data from the lake at the downstream was used to calibrate rheology parameters
- Commercially available software Flo-2D was used (Mahdi and Dibike, 2020*)

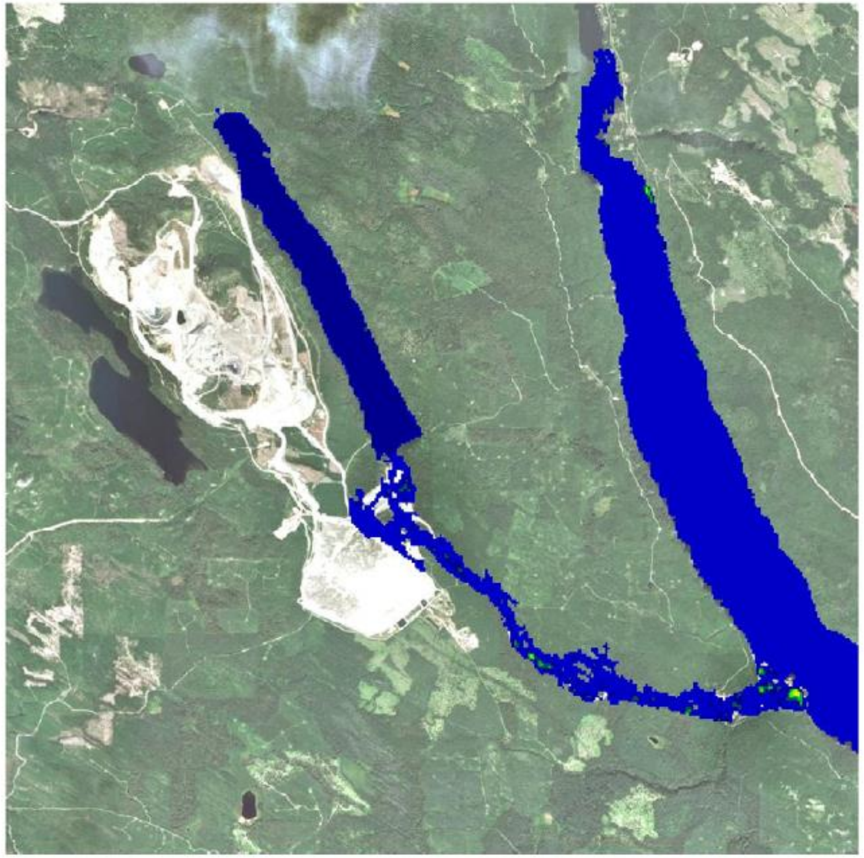
*Mahdi, A., Shakibaeinia, A., Dibike, Y.B., 2020. Numerical modelling of oil-sands tailings dam breach runout and overland flow. Sci. Total Environ. 703, 134568. https://doi.org/10.1016/J.SCITOTENV.2019.134568.

Part 1: Examples of TDBA for Tailings dam breach cases 1B

(a) Satellite Imagery



(b) Modelling result - inundation extent

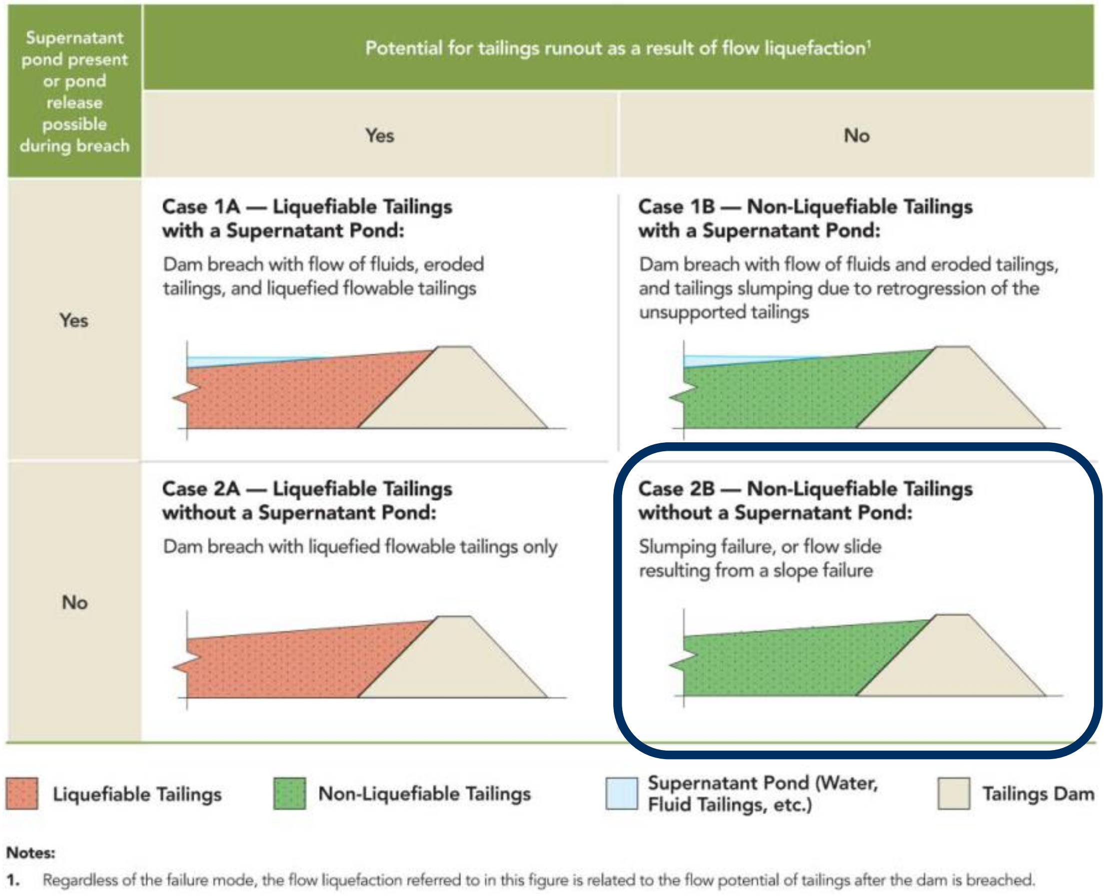


Mahdi, A., Shakibaeinia, A., Dibike, Y.B., 2020. Numerical modelling of oil-sands tailings dam breach runout and overland flow. Sci. Total Environ. 703, 134568. https://doi.org/10.1016/J.SCITOTENV.2019.134568.

Part 1: Examples of TDBA for Tailings dam breach cases 2B

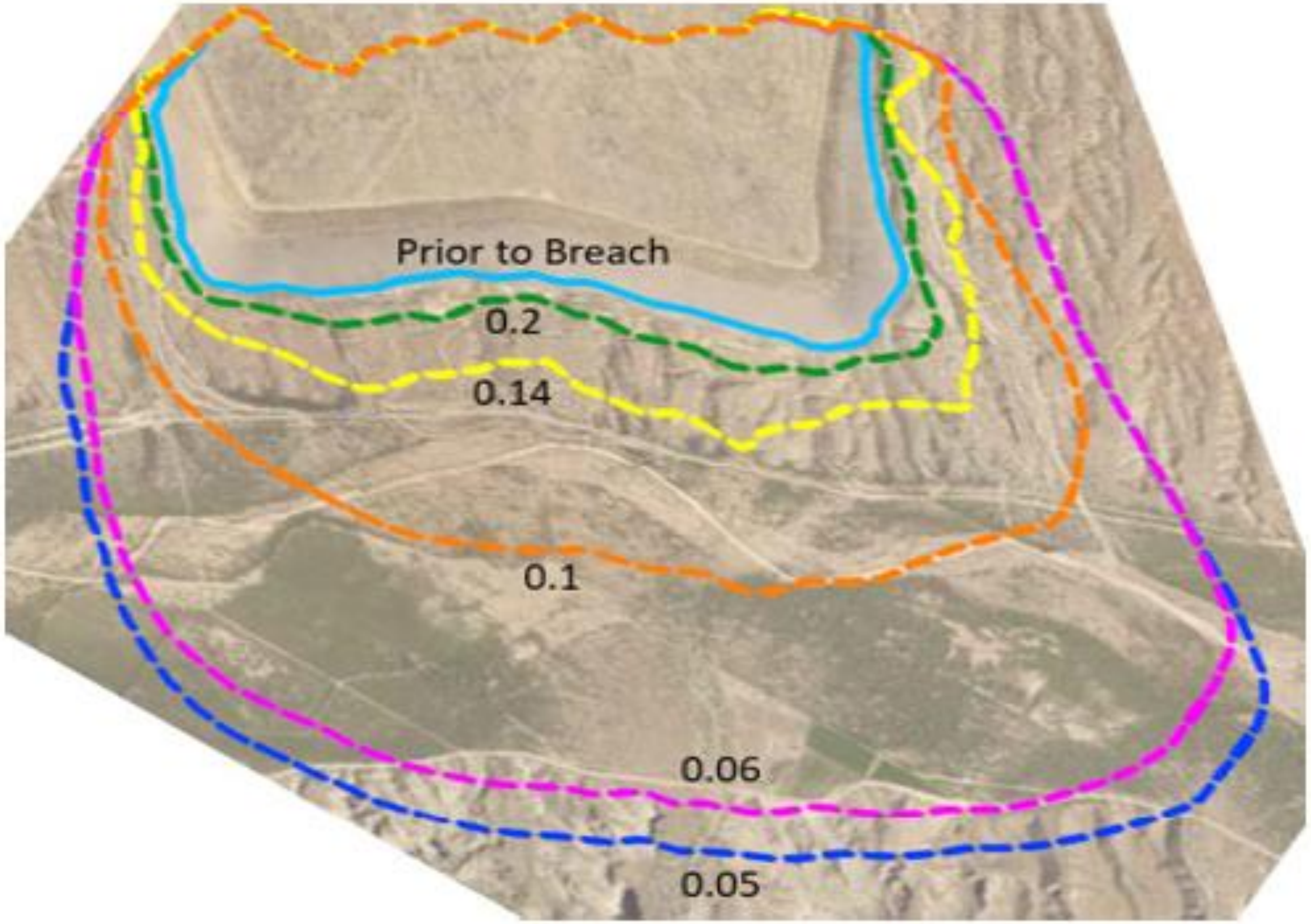
From *Technical Bulletin on Tailings Dam Breach Analysis*, CDA (2021)

- Two hypothetical cases presented
- Both are closed sites
  - One site assumed post-earthquake failure condtion
  - Other site assumed foundation shearing at normal conditon



Part 1: Examples of TDBA for Tailings dam breach cases 2B

- Closed TSF with no liquefiable tailings stored
- It assumed entire dam can be breached
- Post-earthquake factor of safety was assumed less than 1.0 to initiate a hypothetical failure.
- Sensitivity analysis conducted on runout extent using a range of residual undrained shear strength ratios.



CDA 2021 Annual Conference (Chen et al. 2021)

Part 1: Examples of TDBA for Tailings dam breach cases 2B

- TSF with no liquefiable tailings stored
- Two breach locations assumed
- For normal condition – there is no water on the TSF
- Can only fail due to foundation shearing or shearing through the dam

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Part 1: Examples of TDBA for Tailings dam breach cases 2B

- Assumption for runout assessment
  - Rheology: frictional material
  - Erosion: no
  - Unit Weight: 20 kN/m3
  - Internal friction angle of tailings: 35 degree
  - Friction angle of the sliding surface: 5.7 degree (equivalent to su/sigv = 0.1)

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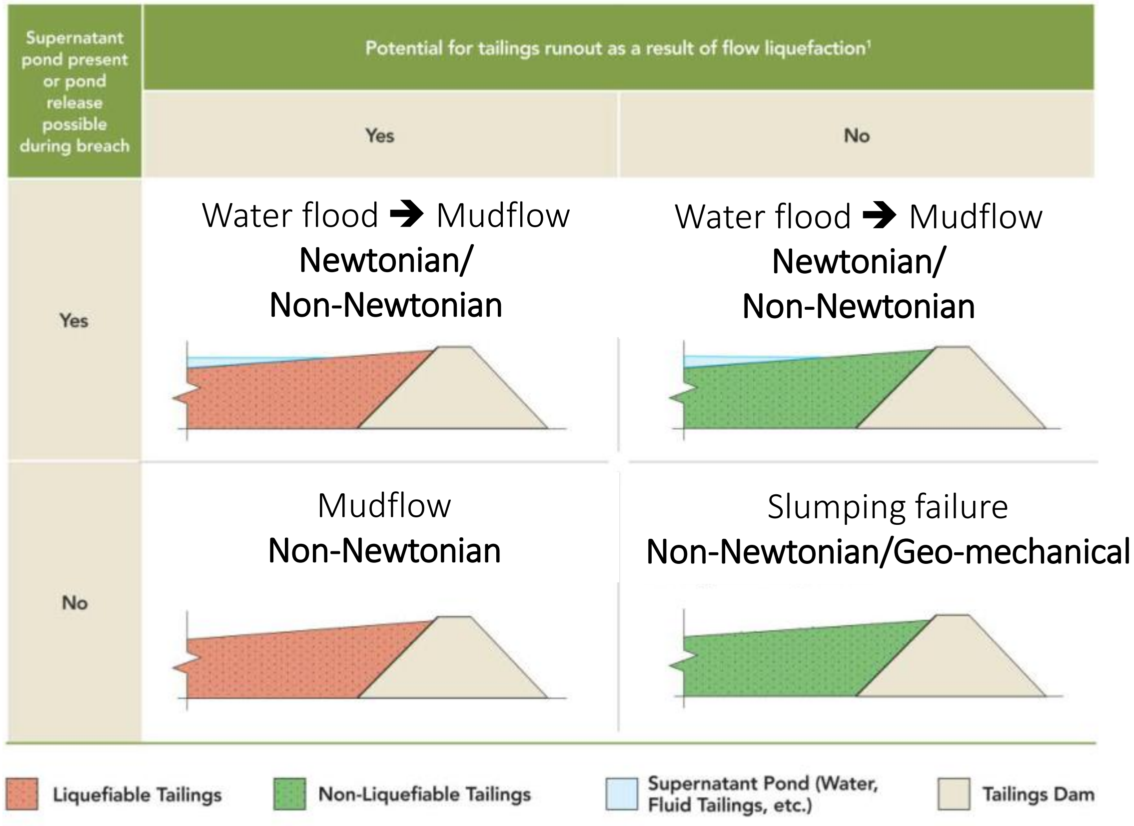
Part 1: Runout analysis, basic requirements

- Type of analysis based on expected rheological behaviour (liquefaction potential, value of Cv)
- Importance of outflow processes and their order (water pond, tailings)
- For outflow of types water flood ➔ mudflow, 2D hydrodyamic models with Newtonian & non-Newtonian rheological models are adapted
- Use of geomechanical models required for slumping failures

From *Technical Bulletin on Tailings Dam Breach Analysis*, CDA (2021)



Notes:

1. Regardless of the failure mode, the flow liquefaction referred to in this figure is related to the flow potential of tailings after the dam is breached.

Part 1: Runout analysis, challenges & limitations

- Representative tailings rheology for dam breach runout is difficult to estimate, large uncertainties
- Actual flow characteristics & processes are very complex VS relatively simple rheological models used (e.g. Bingham)
- Mixing with d/s water bodies can dramatically influence rheology, runout distance & deposition (e.g. Fundão, 2015, > 600 km)
- Importance of appropriate model type and of sensitivity analysis to assess range of consequences


Lab test

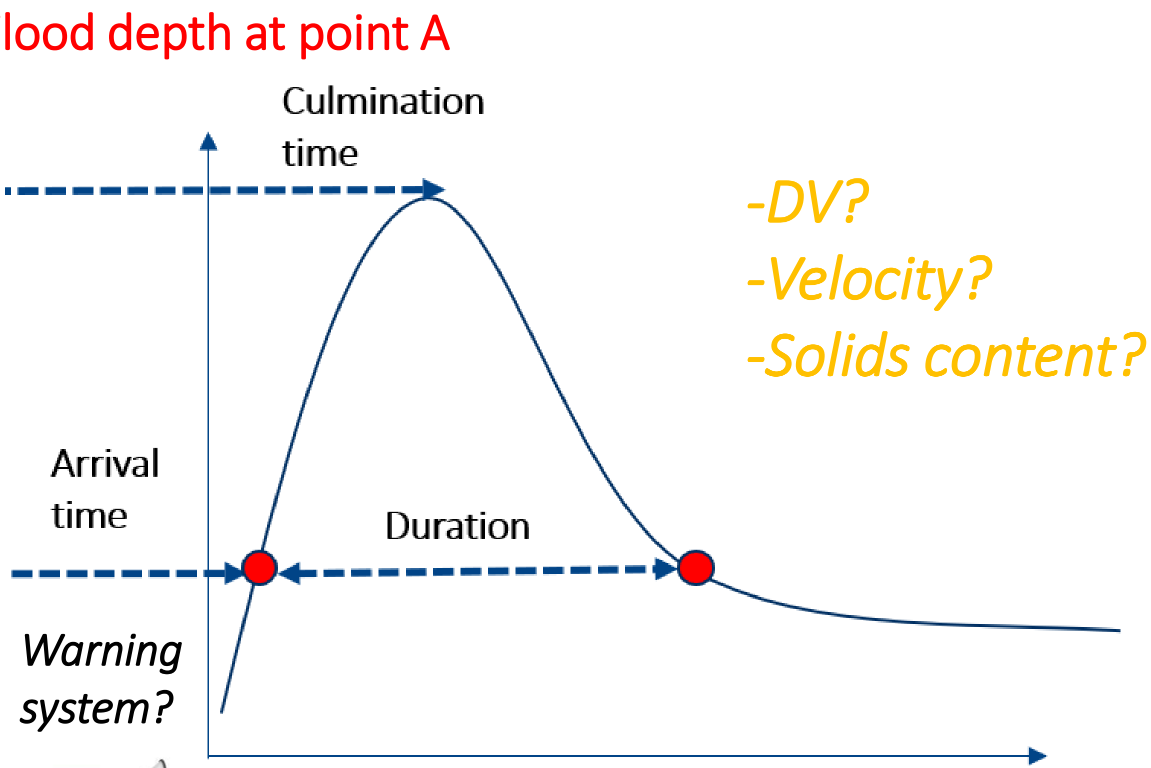
VS


Feijão tailings runout (2019)


Fundão tailings plume outflow into the Atlantic ocean (IUCN, 2018)

Part 1 – Consequences - Estimating potential loss of life

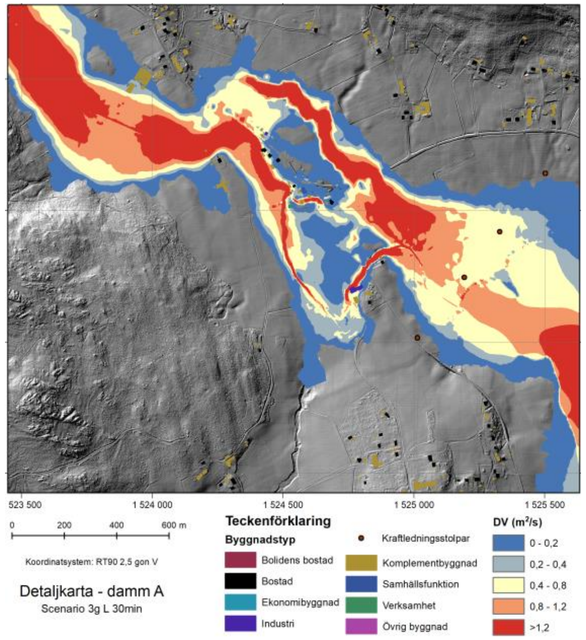
Breach



-DV?

-Velocity?

-Solids content?



Part 1 – Consequences - Estimating potential loss of life

- RCEM Methodology (USBR, 2014)
  - Database with world-wide case histories of fatalities caused by floods/breaches in water dams
  - Two charts:
    - "Little or no warning"
    - Warning is considered to be "adequate".
  - Observed fatality rates are specific to the warning scenario, time of day and year, etc of the incident
  - Uncertainty range is increasing for the lowest flood severity values (DV values < approx. 5 m2/s)

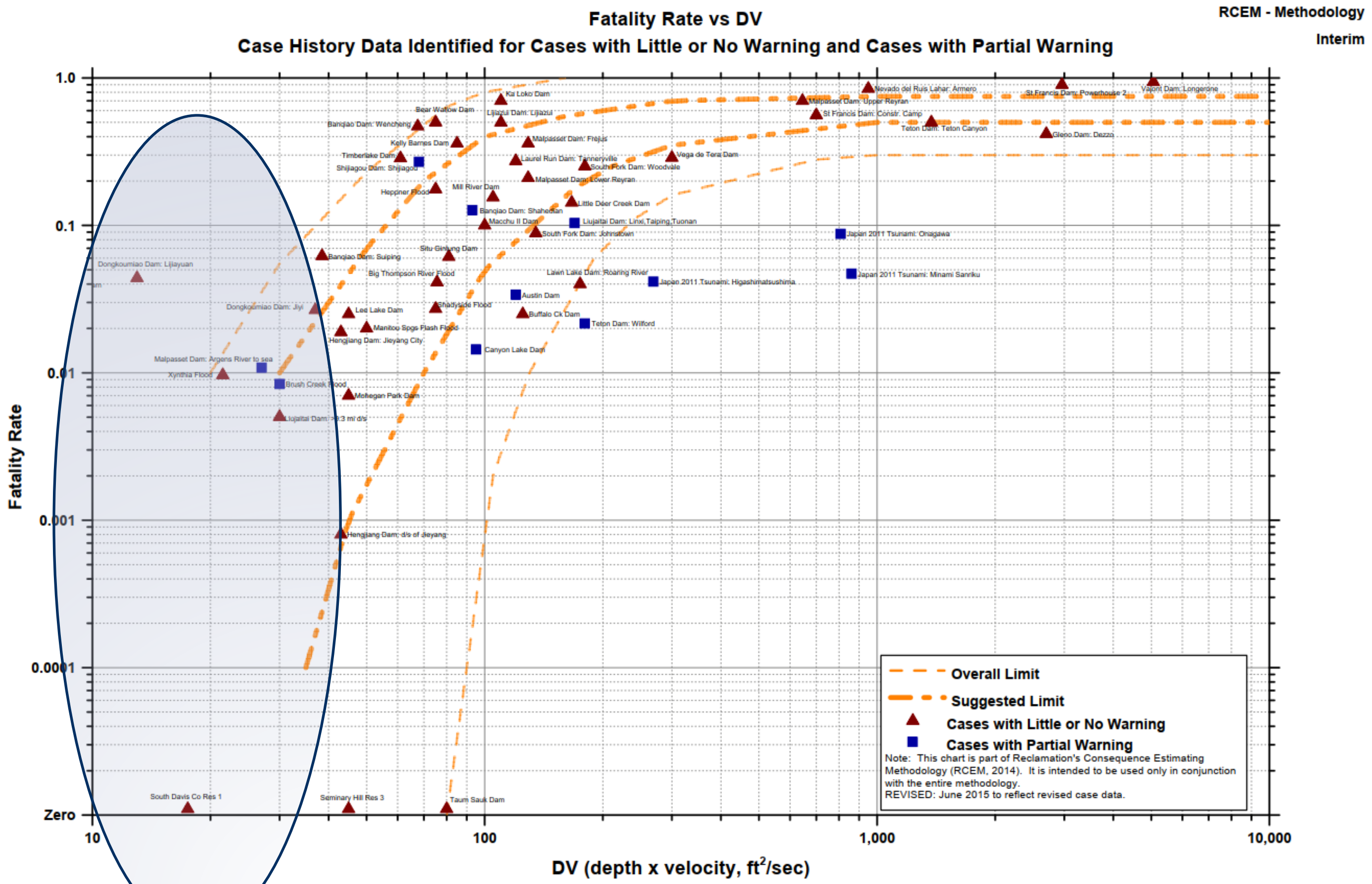


Figure 1 - Fatality Rate vs. DV - Case History Data Identified for Cases with Little or No Warning and Cases with Partial Warning

Part 1 – Consequences - Estimating potential loss of life

- Flood hazard assessment method (ARR, 2010)
- Limiting values for unsafe conditions (ARR, 2019):
  - depth of 1,2 m (children and elderly) or 2 m (adults)
  - velocities of 2 m/s (adults, children and elderly)

Table 6. Interval of DV values and the corresponding hazard for different age groups (ARR, 2010). "H.M" corresponds to the product of Height (m) by Mass (kg).

<table>
<tr><th>DV (m^2s^{-1})</th><th>Infants, small children (H.M ≤ 25) and frail/older persons</th><th>Children (H.M = 25 to 50)</th><th>Adults (H.M > 50)</th></tr>
<tr><td>0</td><td>Safe</td><td>Safe</td><td>Safe</td></tr>
<tr><td>0 – 0.4</td><td rowspan="5">Extreme Hazard; Dangerous to all</td><td>Low Hazard[1]</td><td rowspan="2">Low Hazard[1]</td></tr>
<tr><td>0.4 – 0.6</td><td>Significant Hazard; Dangerous to most</td></tr>
<tr><td>0.6 – 0.8</td><td rowspan="3">Extreme Hazard; Dangerous to all</td><td>Moderate Hazard; Dangerous to some[2]</td></tr>
<tr><td>0.8 – 1.2</td><td>Significant Hazard; Dangerous to most[3]</td></tr>
<tr><td>> 1.2</td><td>Extreme Hazard; Dangerous to all</td></tr>
</table>

Part 1 – Consequences - Estimating potential loss of life

- Ex debris flows and fluidized landslides, Pollock and Wartman, 2020

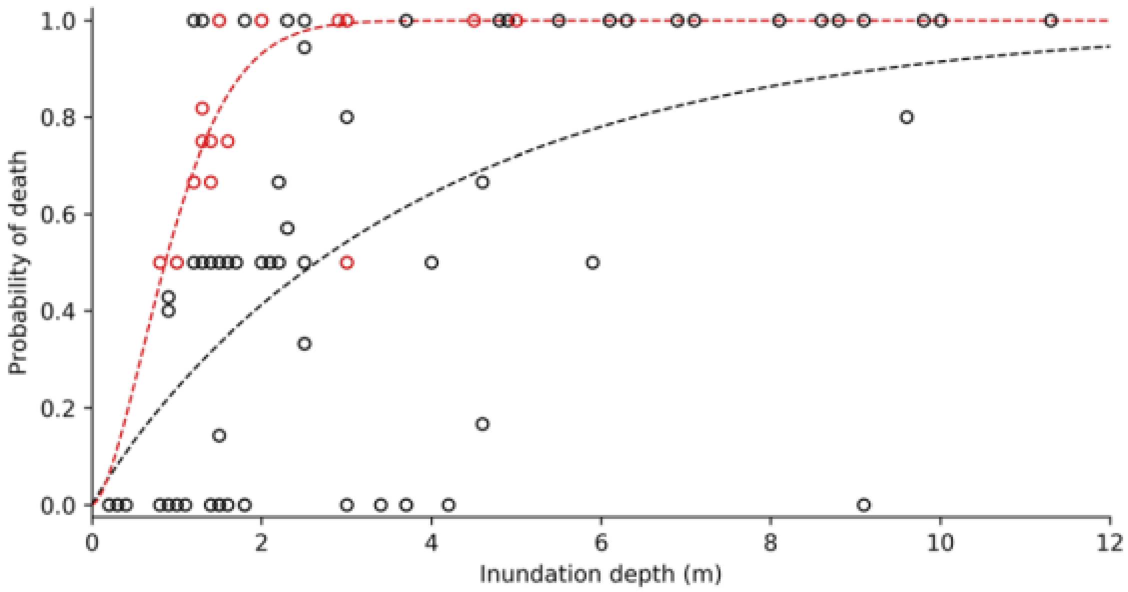


Figure 11. Fatality rate depending on flow depth for debris flows and fluidized landslides in economically developing (red curve) and developed (black curve) countries (Pollock and Wartman, 2020).

3 Workshop Part 2

Part 2: Group discussions

1. Appointed group leaders

Prepare:

1. Summary for big group
2. Summary of discussions at Microsoft Forms

SwedCOLD Workshop 3: Best Practices for Tailings Dam Breach Analysis

Part 2: Group discussions

1. Dealing with uncertainties and simplifications

Dealing with uncertanties/simplifications	• Which uncertanties are the most important to analyse in a sensitivity analysis? • How can simplifications be made without increasing uncertanties in results too much?
A) Methodolgy and geotechnics	• Tailings characteristics, foundation • Runout volume • Impact from hydrology: reservoir volume, lakes downstream, flow scenarios
B) Dam breach modelling	• Definition of tailings rheological properties • Breach parameters and development • Model tools, domain etc.

Part 2: Group discussions

1. Dealing with uncertainties and simplifications

A) Methodolgy and geotechnics

- Tailings characteristics, foundation
- Runout volume
- Impact from hydrology: reservoir volume, lakes downstream, flow scenarios

- How to define geotechnical parameters in case of scarce data?
- What can influence the degree of saturation within the TSF?
- Which kind of assumptions can be overly conservative?
- What are the limitations of the different methods available to estimate runout volume?
- What should be taken into account to define relevant hydrological scenarios?

Part 2: Group discussions

1. Dealing with uncertainties and simplifications

B) Dam breach modelling

- Definition of tailings rheological properties
- Breach parameters and development
- Model tools, domain etc

- How to define tailings rheological properties to be used in TDBAs?
- What are the advantages and drawbacks of parametric breach parameters estimation methods vs. advanced numerical breach modelling?
- What are the advantages and drawbacks of 2D vs. 3D/CFD models for runout analysis?
- How to handle complex hydrological conditions downstream of the TSF (mixing, temporary blockages…)?
- What are the main uncertainties involved for geo-mechanical modelling of slump failures for identifying runout extents?

Part 2: Group discussions

2. Credible failure mode

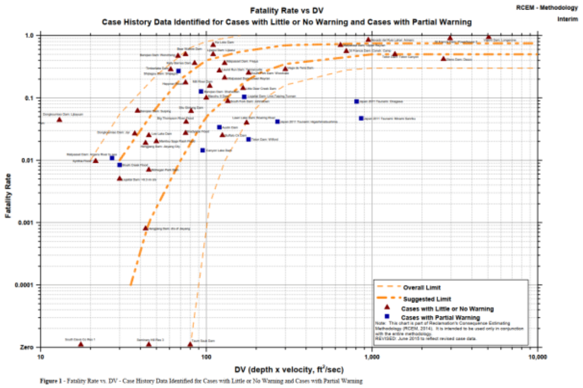
Credible failure mode

- Define credible failure mode (CFM)?
- Is CFM is the correct term? Do you use any other terms for same purposes
- Does all technically feasible PFM be consider as CFM?
- Does consequence and likelihood in addition to technical feasibility be considered to define CFM?
- Does a PFM with very low likelihood be considered CFM?
- If there is no CFM in a TSF do you need a TDBA
- Do you need an emergency plan for a TSF with no CFM?
- How does CFM used for the risk assessment purposes?
- Does your local regulator defines CFM or set expectation for CFM?

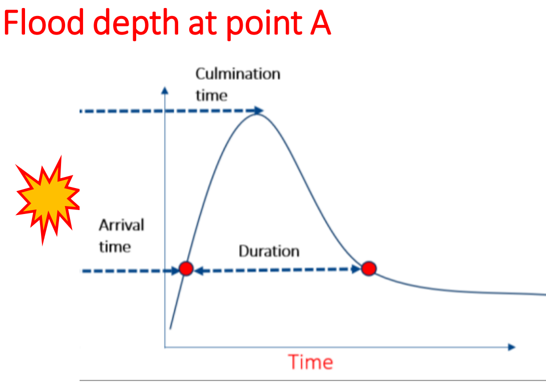
Part 2 Group discussions
3. Consequences - Estimating potential loss of life

Discussion on methods and aspects to consider

- What are the advantages/drawbacks of available methods to estimate potential loss of life?
- What are the most important aspects to consider when estimating potential loss of life due to failure in a tailings facility?
- When is it reasonable to take credit of available warning systems when estimating potential loss of life?
- How do you assess the risk for temporary or permanent work force on the tailings dam or in the facility?



(USBR, 2014)



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0.6 – 0.8		Extreme Hazard; Dangerous to all	Moderate Hazard; Dangerous to some[2]
0.8 – 1.2			Significant Hazard; Dangerous to most[3]
> 1.2			Extreme Hazard; Dangerous to all

(ARR, 2010)

Part 2: Group discussions
4. Open questions / discussions

Round-up and conclusion

- Summary of group discussions
- Conclusion

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