Tailings Dam Breach Analysis (TDBA)

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Land Acknowledgement

- *I acknowledge and honor those Indigenous nations whose territories we are living on, working in, and gathered today for the IMWA Conference!*

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Topics to Be Discussed

i. TDBA Background
ii. Failure Modes and Scenarios
iii. TDB Process
iv. Tailings Release Volume
v. Breach Modelling
vi. Downstream Routing
vii. Recommendations and On-going Research

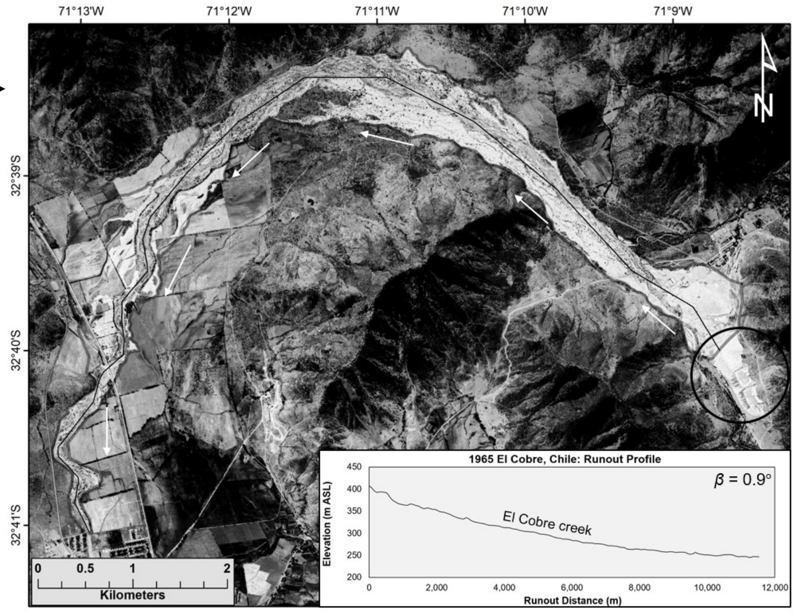
TDBA Background

- Definition: A tailings dam failure is defined as a physical breach of the dam followed by uncontrolled and typically sudden release of any or all stored materials.
- Critical to informing dam consequence classification
- Inform Emergency Response Plan (ERP) and Emergency Preparedness Plan (EPP) which are regulatory requirements in Alberta (and many other jurisdictions)

Mount Polley; image source: canadianconsultingengineer.com

TDBA Background (Cont'd)

- 1962 China, Huogudu, 3.3 Mm^3 of tailings, 171 fatalities
- 1965 Chile, El Cobre, 0.35 Mm^3 of tailings, 200 fatalities →
- 1972 US, Buffalo Creek, WV, 0.5 Mm^3 of tailings, 125 fatalities
- 1985, Italy, Strava, 0.2 Mm^3 of tailings, 268 fatalities
- 2008, China, Toashi, 0.19 Mm^3 of tailings, 277 fatalities
- 2019, Brazil, Brumadinho, 12 Mm^3 of tailings, 267 fatalities



Useful links:

Chronology of tailings dam failures: WISE Uranium Project

A comprehensive global database of tailings flows (CanBreach): CanBreach Research Data Base

TDBA Background (Cont'd)

2019, Brazil, Brumadinho, 12 Mm^3 of tailings, 267 fatalities

https://www.youtube.com/watch?v=sKZUZQytads

Location: Córrego de Feijão mine, Brumadinho, Minas Gerais, Brazil
Date: 2019, Jan. 25
Ore: Iron
Incident: Tailings dam #1 failure
Estimated Release Volume: 12 Mm^3
Impacts: The tailings wave devastated the mine's loading station, its administrative area, and two smaller sediment retention basins (B4 and B4A); it then traveled approx. 7 km downhill until reaching Rio Paraopeba, thereby destroying a bridge of the mine's railway branch, and spreading to parts of the local community Vila Ferteco, near the town of Brumadinho; the slurry was then carried further by Rio Paraopeba; 267 people were killed, and several are still reported missing.
Planet© Imagery Date: 2019, Jan. 29

Useful links:

Planet Lab Daily Earth Data: Planet Lab

TDBA Background (Cont'd)

Image Source: Mining2Me

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TDBA Background (Cont'd)

- No longer just a regulatory box to be checked
- The guidelines for TDBA are just coming out
- In 2021, the Canadian Dam Association (CDA) published the first bulletin for TDBA
- A short section in "Tailings Management Handbook – A lifecycle approach", in 2022 by SME

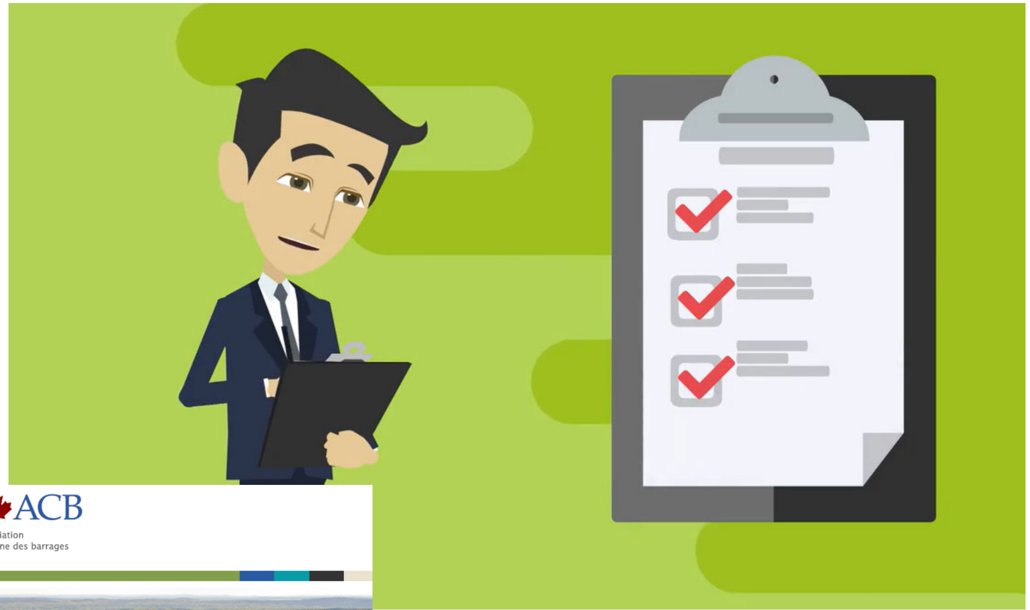

Image Source: Mining2Me

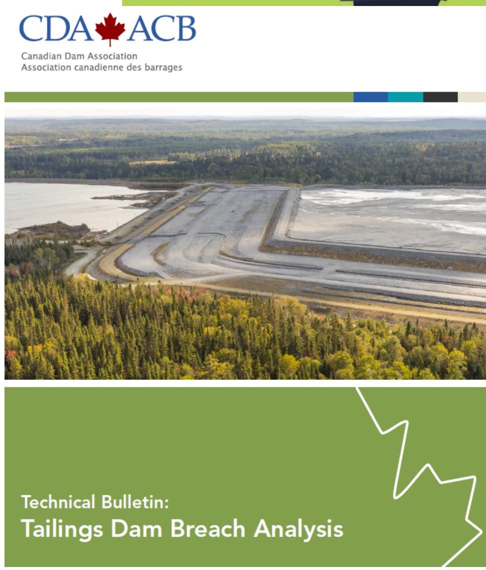

Image Source: CDA

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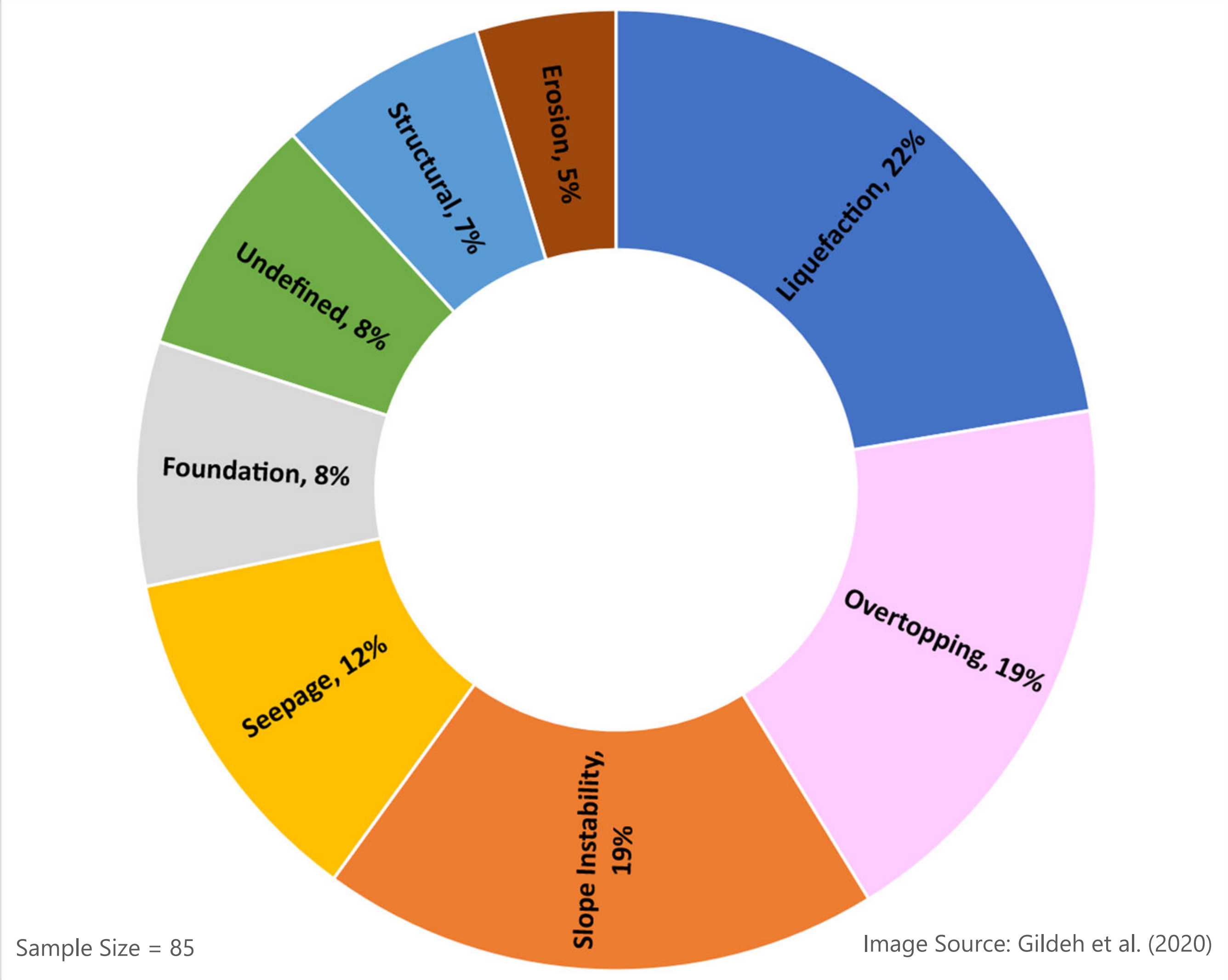
Failure Modes and Scenarios



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Failure Modes and Scenarios (Cont'd)

Two common hydrologic conditions

- Fair weather (aka sunny-day)
- Flood induced (aka wet-/rainy-day)

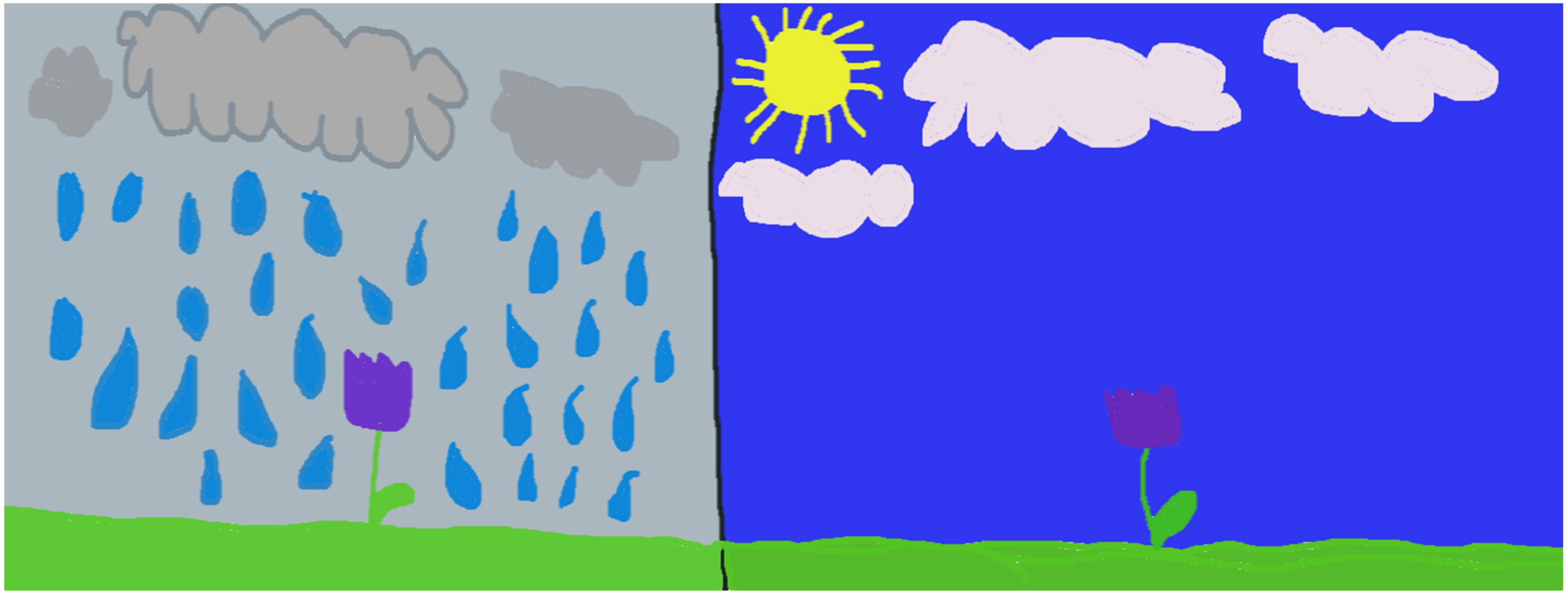
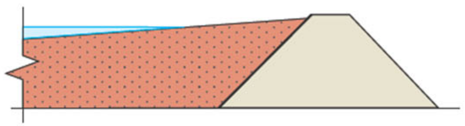
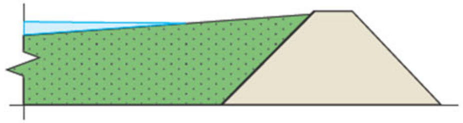
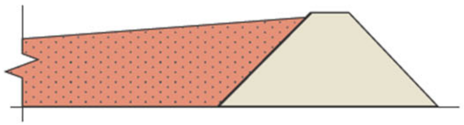
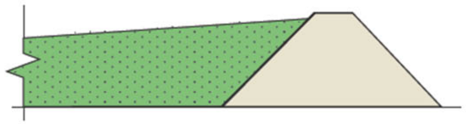


Image Source: deviantart

TDB Process

What is specific to tailings dam failures (compared to water retaining dams)

- Mobilization of tailings
- Runout characteristics (i.e., hyper-concentrated or mud/debris flows)
- Breach shape and dimensions can be very different

Supernatant pond present or pond release possible during breach	Potential for tailings runout as a result of flow liquefaction[1]	
	Yes	No
Yes	**Case 1A — Liquefiable Tailings with a Supernatant Pond:** Dam breach with flow of fluids, eroded tailings, and liquefied flowable tailings 	**Case 1B — Non-Liquefiable Tailings with a Supernatant Pond:** Dam breach with flow of fluids and eroded tailings, and tailings slumping due to retrogression of the unsupported tailings 
No	**Case 2A — Liquefiable Tailings without a Supernatant Pond:** Dam breach with liquefied flowable tailings only 	**Case 2B — Non-Liquefiable Tailings without a Supernatant Pond:** Slumping failure, or flow slide resulting from a slope failure 

Liquefiable Tailings · Non-Liquefiable Tailings · Supernatant Pond (Water, Fluid Tailings, etc.) · Tailings Dam

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.

Image Source: CDA

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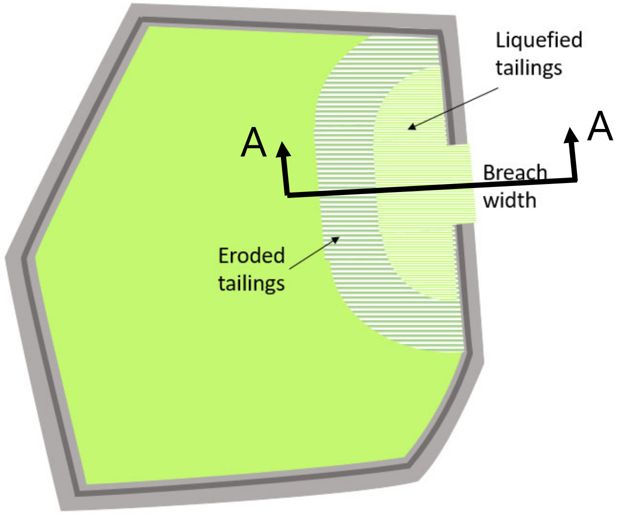
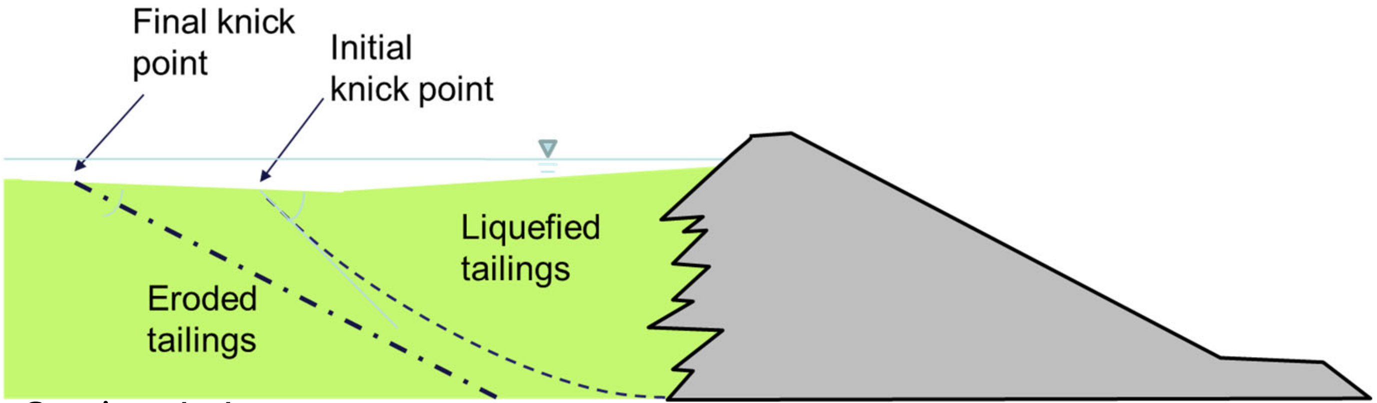
Tailings Release Volume Estimate

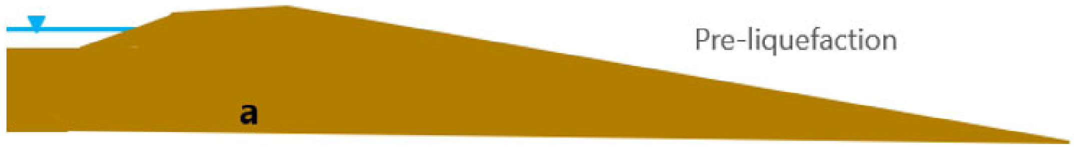
- A geotechnical analysis to determine if the tailings could liquefy (the trigger for tailings liquefaction is the dam failure)
- Estimate the <u>volume of liquefied tailings</u> from:
  - *breach geometry*
  - *basin geometry*
  - *geotechnical data and analysis*
- Estimate the <u>volume of eroded tailings</u> based on:
  - *the volume of supernatant pond*
  - *basin geometry*
  - *geotechnical data*





Section A-A

Tailings Release Volume Estimate (Cont'd) – Liquefaction Failure



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Tailings Release Volume Estimate (Cont'd)

- Other simplified methods are available!
  - *Statistical regression (e.g., Rico et al., 2008; Larrauri and Lall, 2018; etc.)*

- Flowability approximation (Fontaine and Martin, 2015)

Mine Water and the Environment
https://doi.org/10.1007/s10230-020-00718-2

TECHNICAL ARTICLE

Tailings Dam Breach Analysis: A Review of Methods, Practices, and Uncertainties

Hossein Kheirkhah Gildeh[1] · Alexandra Halliday[2] · Alfredo Arenas[2] · Hua Zhang[1]

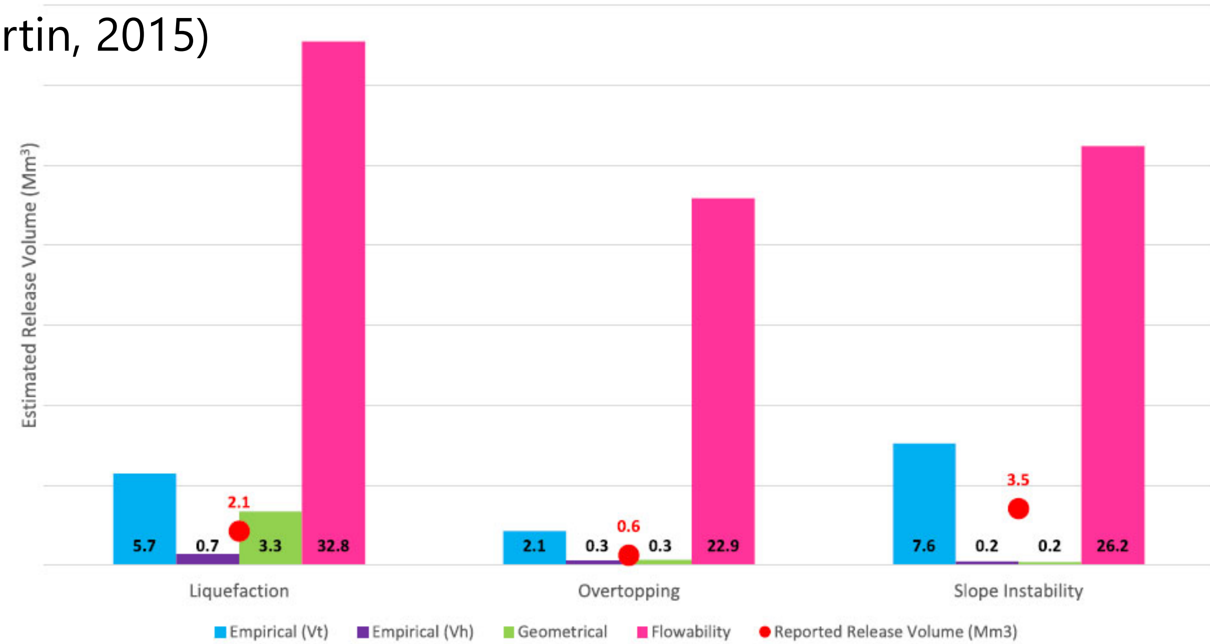

Fig. 4 Release volume by method and failure mechanism

Useful links:

Gildeh et al. (2020): Paper on TDBA

Image Source: Gildeh et al. (2020)

Breach Modelling

- Breach modelling will identify the shape of the breach hydrograph and its peak
- Breach prediction methods for earthen dams
  - parametric models
  - semi-physically based models
  - physically based models

Useful links:

West et al. (2018): [Breach Prediction Paper]

A guide to breach prediction

M. West[1], M. Morris[2] and M. Hassan[3]

[1] Student, University of Surrey, [2] Senior Consultant, HR Wallingford, [3] Senior Engineer, HR Wallingford
Editor: Craig Goff, HR Wallingford, c.goff@hrwallingford.com

Parametric Model	Time to Failure, t_f (hr)	Average breach width, $\bar{B}$ (m)	Side Slopes, z $(h{:}v)$	Peak Outflow, Q_p (m^3/s)	Number of Case Studies
Froehlich (1995a, 1995b)	$t_f = 0.00254 V_w^{0.53} h_b^{-0.9}$	$\bar{B} = 0.1803 k_o V_w^{0.32} h_b^{0.19}$ $k_o = \begin{cases} 1.4 & OT \\ 1.0 & P \end{cases}$	$z = \begin{cases} 1.4 & OT \\ 0.9 & P \end{cases}$	$Q_p = 0.607 V_w^{0.295} h_w^{1.24}$	1995a: 22, 1995b: 63
Walder & O'Connor (1997)				$Q_p = a(h_w V_w)^b$ where: $a, b = \begin{cases} 0.99, 0.40 & Landslide \\ 0.61, 0.43 & Constructed \\ 0.19, 0.47 & Moraine \end{cases}$	
Froehlich (2008)	$t_f = 0.0176 \sqrt{\frac{V_w}{g h_b^2}}$	$\bar{B} = 0.27 k_o V_w^{\frac{1}{3}}$ Where: $k_o = \begin{cases} 1.3 & OT \\ 1.0 & P \end{cases}$	$z = \begin{cases} 1.0 & OT \\ 0.7 & P \end{cases}$		74
Xu & Zhang (2009)	$\frac{t_f}{t_r} = C_5 \left(\frac{h_d}{h_r}\right)^{0.654} \left(\frac{V_w^{1/3}}{h_w}\right)^{1.246}$ where: $C_5 = b_5$ $b_5 = \begin{cases} 0.038 & HE \\ 0.066 & ME \\ 0.205 & LE \end{cases}$	$\frac{\bar{B}}{h_b} = 5.543 \left(\frac{V_w^{1/3}}{h_w}\right)^{0.739} e^{C_3}$ where: $C_3 = b_4 + b_5$ $b_4 = \begin{cases} -1.207 & OT \\ -1.747 & P \end{cases}$ $b_5 = \begin{cases} -0.613 & HE \\ -1.073 & ME \\ -1.268 & LE \end{cases}$	1	$\frac{Q_p}{\sqrt{g V_w^{5/3}}} = 0.133 \left(\frac{V_w^{1/3}}{h_w}\right)^{-1.276} e^{C_4}$ where: $C_4 = b_4 + b_5$ $b_4 = \begin{cases} -0.788 & OT \\ -1.232 & P \end{cases}$ $b_5 = \begin{cases} -0.089 & HE \\ -0.498 & ME \\ -1.433 & LE \end{cases}$	75
Pierce at al. (2010)				$Q_p = 0.0176 (V_w h_w)^{0.606}$ $Q_p = 0.038 (V_w^{0.475} h_w^{1.09})$	87
Froehlich (2016a, b)	$t_f = 60 \sqrt{\frac{V_w}{g h_b^2}}$	$\bar{B} = 0.23 k_o V_w^{\frac{1}{3}}$ Where:	$z = \begin{cases} 1.0 & OT \\ 0.6 & P \end{cases}$	$Q_p = 0.0175 k_o k_H \sqrt{\frac{g V_w h_w h_b^2}{\bar{W}}}$ Where:	2016a: 111, 2016b: 41

Breach Modelling (Cont'd)

- Comparison 1: Two Semi-Physically Based Models vs One Parametric Model

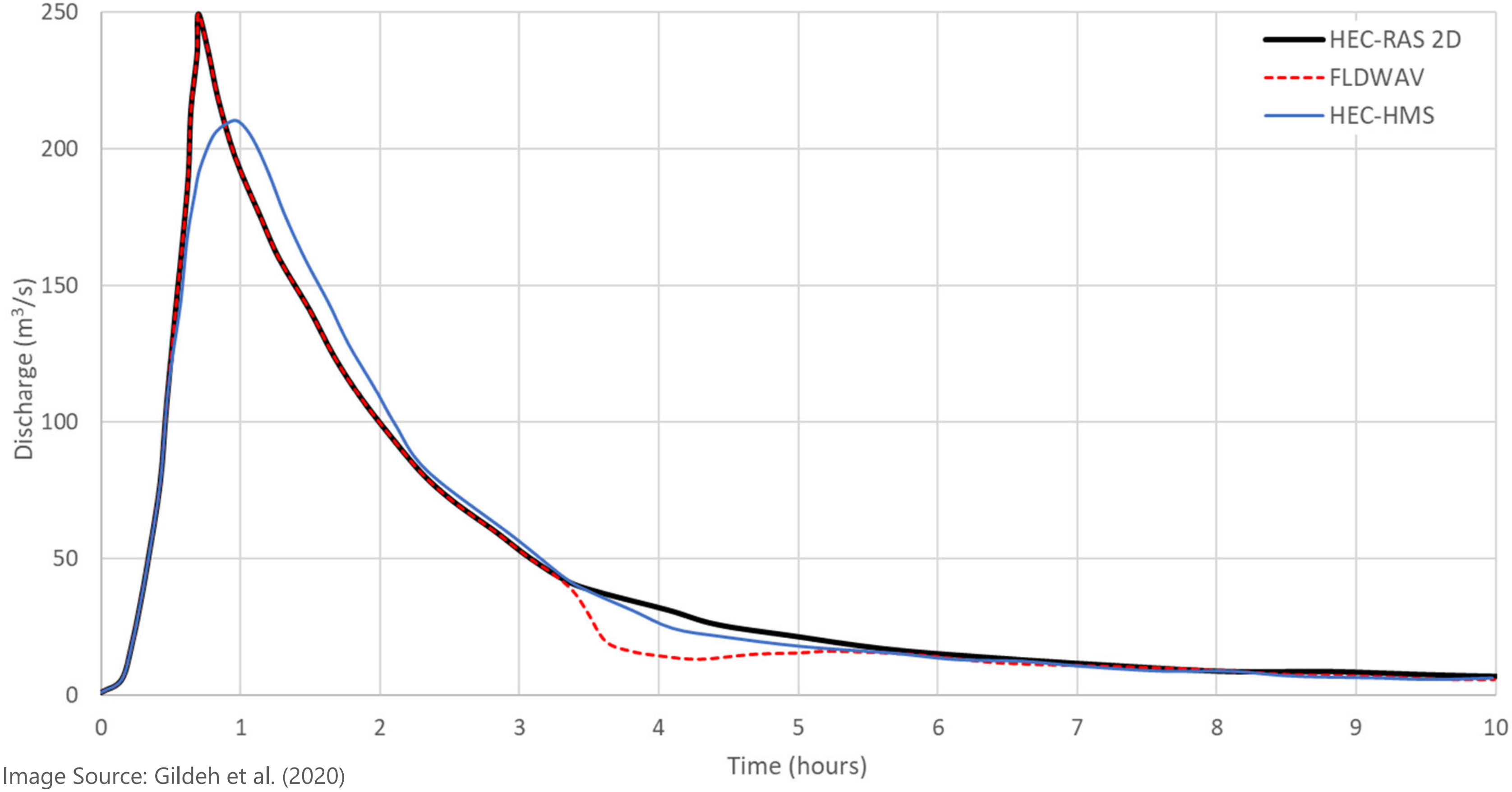

Image Source: Gildeh et al. (2020)

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Downstream Routing

- Outflow Regime

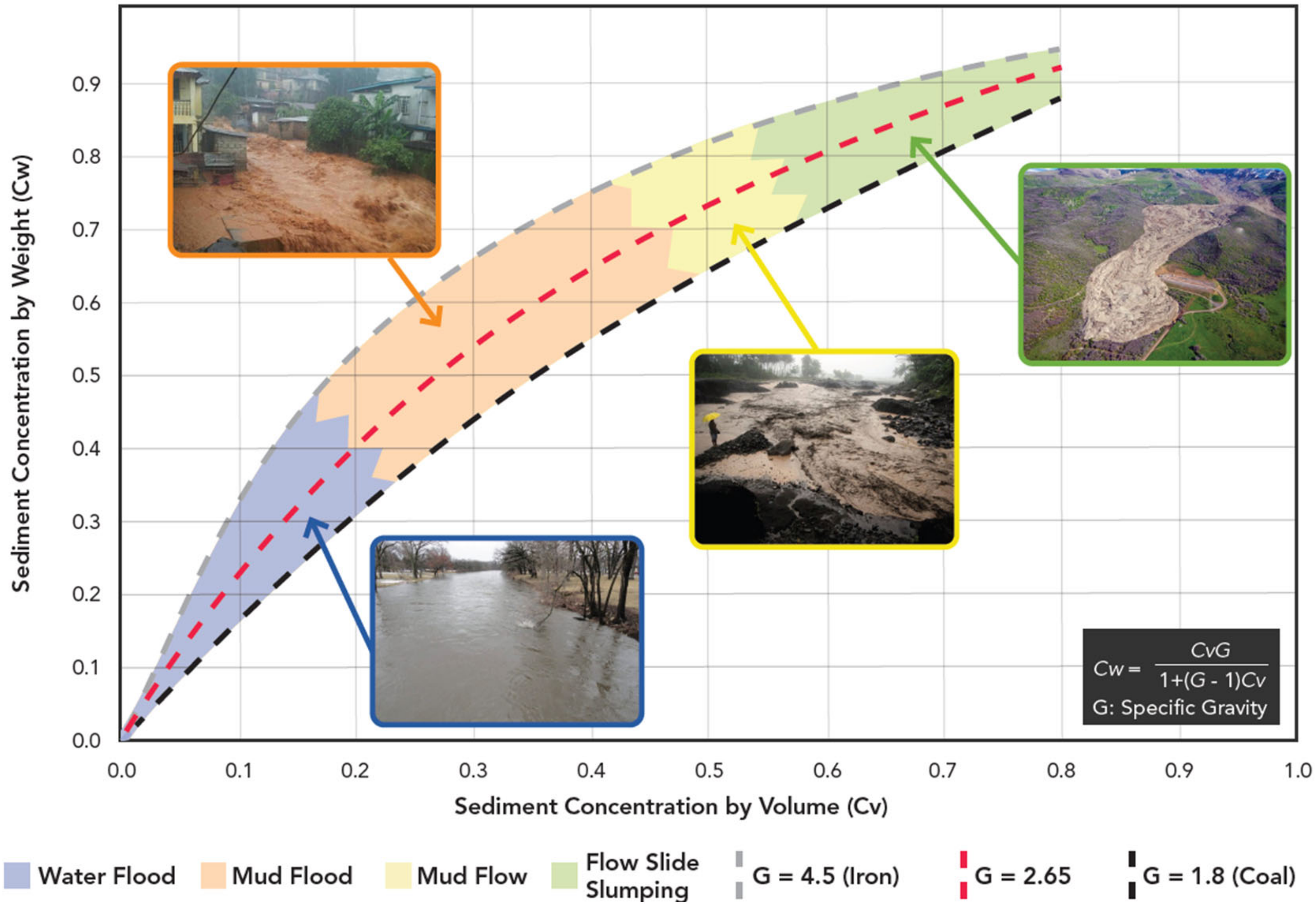

Image Source: CDA

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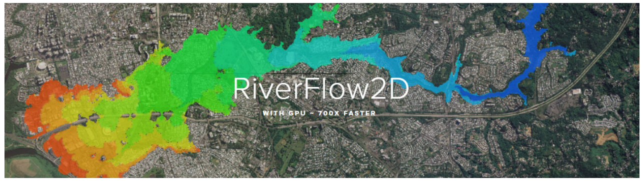
Downstream Routing (Cont'd)

- Modelling Tools



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Runout Analysis

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Useful links:

Ghahremani et al. (2022): numerical runout model paper

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

A benchmarking study of four numerical runout models for the simulation of tailings flows

Negar Ghahramani [a,*], H. Joanna Chen [b], Daley Clohan [c], Shielan Liu [d], Marcelo Llano-Serna [e], Nahyan M. Rana [f], Scott McDougall [a], Stephen G. Evans [f], W. Andy Take [g]

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Downstream Routing (Cont'd)

- Modelling Tools

Models	Type	Case 1A	Case 1B	Case 2A	Case 2B	Newtonian Fluids	Non-Newtonian Fluids	Computing Cost
DAMBRK	1D	Yes	Yes	-	-	Yes	-	Medium
FLDWAV	1D	Yes	Yes	Yes	-	Yes	Yes	
HEC-RAS	1D/2D	Yes	Yes	Yes	-	Yes	Recently released	
FLO-2D	2D	Yes	Yes	Yes	-	Yes	Yes	
MIKE 11 & MIKE 21	1D/2D	Yes	Yes	Yes	-	Yes	Yes	High
RiverFlow2D	2D	Yes	Yes	Yes	Yes	Yes	Yes	Medium to High
TUFLOW	2D	Yes	Yes	Yes	-	Yes	Recently released	Medium to High
Telemac-MASCARET System	2D/3D	Yes	Yes	Yes	-	Yes	Recently released	Medium to High
FLOW-3D	2D/3D	Yes	Yes	Yes	Yes	Yes	Yes	High
DAN3D	Quasi-3D	-	-	Yes	Yes	-	Yes	Not available commercially
MADFLOW	Quasi-2D/3D	Yes	Yes	Yes	Yes	Yes	Yes	

Image Source: CDA

Downstream Routing (Cont'd)

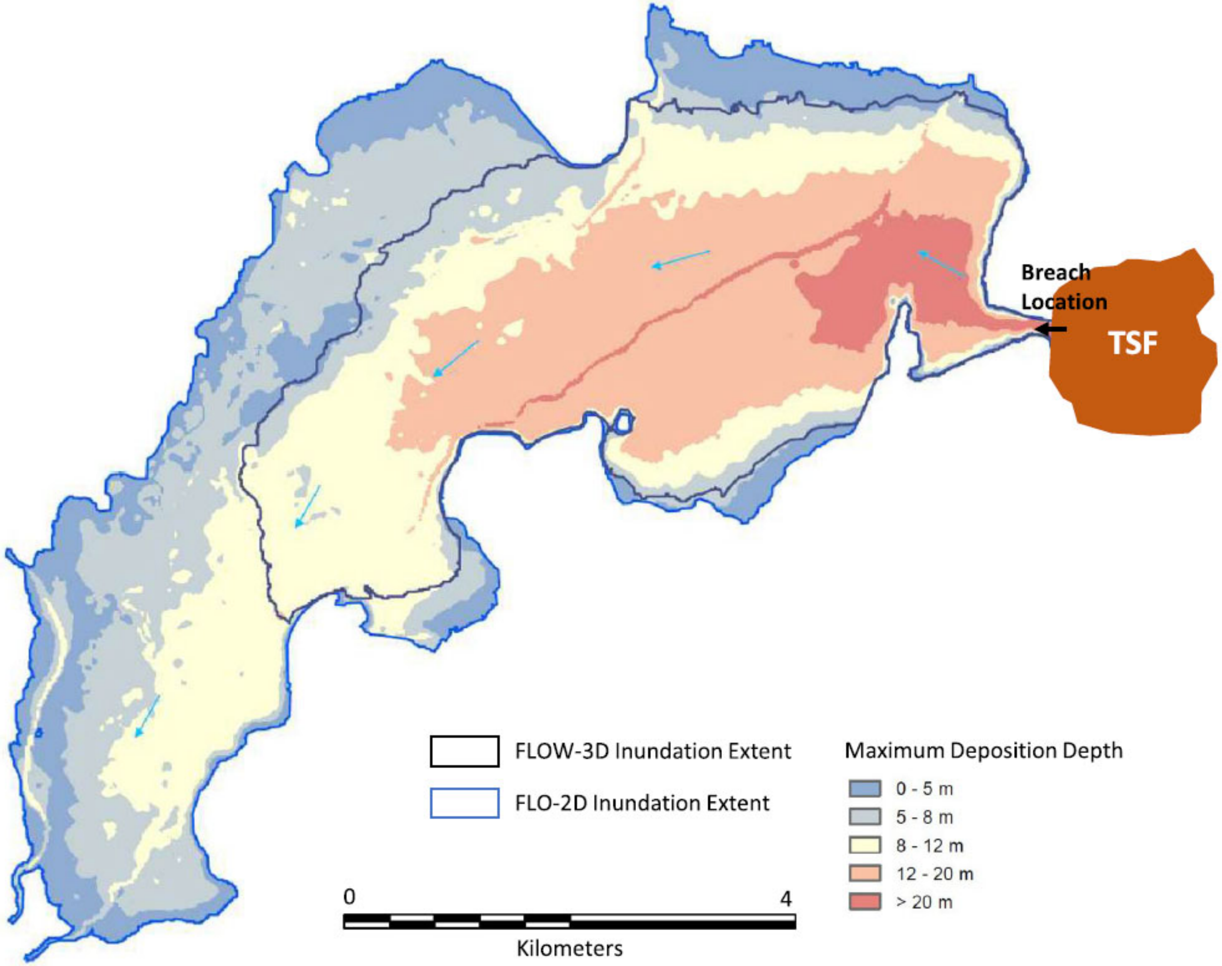

Image Source: Gildeh et al. (2020)

Fig. 10 Comparison of inundation extents between FLO-2D and FLOW-3D

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Recommendations and On-going Research

- Some Recommendations…
  - Data & Data & Data & Data…..
  - Multidisciplinary team to tackle TDBA
  - "All models are wrong, but some are useful"
  - Uncertainties! sensitivity analysis on breach parameters (mainly B and t) and tailings rheology (mainly viscosity and yield stress)
  - Stay up-to-date

Q? & A!

Image Source: scholarlykitchen

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