EMBREA-Web: a tool for the simulation of breach through dams and embankments

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ABSTRACT: The failure of dams and embankments can have catastrophic impacts on people, properties and environment. Therefore, dam and embankment breach modelling is a fundamental stage of any flood risk assessment. EMBREA-Web has been developed to help researchers and practitioners undertake this task more easily via an online interface that is built upon the well-known simulation engine of the EMBREA breach model. EMBREA-Web is available in two versions 'Lite' and 'Pro'. The Lite version is free and allows the modelling of the failure of homogeneous dams or embankments initiated by overtopping or internal erosion. The Pro version has advanced features such as modelling of non-homogeneous and layered dams and embankments and the ability to undertake Monte Carlo simulations to account for data and modelling uncertainties.

In this paper, a description of the EMBREA simulation engine is given with a detailed presentation of the 'Lite' and 'Pro' versions of EMBREA-Web. Examples of undertaking modelling runs with EMBREA-Web are also given showing how it guides and simplifies the task of undertaking breach modelling.

RÉSUMÉ: La défaillance des barrages et des remblais a des répercussions catastrophiques sur les personnes, les propriétés et l'environnement. Par conséquent, la modélisation des ruptures de barrages et de remblais est une étape fondamentale de toute évaluation des risques d'inondation. EMBREA-Web a été mis au point pour aider les chercheurs et les praticiens à entreprendre cette tâche plus facilement au moyen d'une interface en ligne qui repose sur le moteur de simulation bien connu du modèle d'ouverture de brèche de l'EMBREA. EMBREA-Web est disponible en deux versions « Lite » et « Pro ». La version Lite est gratuite et permet de modéliser la défaillance de barrages ou de remblais homogènes par déversement intempestif ou par tuyauterie. La version Pro présente des fonctionnalités avancées telles que la modélisation de barrages et de digues non homogènes et en couches, ainsi que la possibilité d'effectuer des simulations Monte Carlo pour prendre en compte les incertitudes relatives aux données et à la modélisation

Dans cet article, une description du moteur de simulation EMBREA est donnée avec une présentation détaillée des versions "Lite" et "Pro" EMBREA-Web. Des exemples de brèche de modélisation avec EMBREA-Web sont également présentés pour montrer ses puissantes fonctionnalités et sa simplification en ce qui concerne la modélisation des brèches.

1 INTRODUCTION

The failure of dams and levees can have catastrophic impacts on people, properties and environment. To assess the risk arising from dam or levee failure, it is necessary to predict how the failure may develop and the rate at which water might be released. This data may then be used in different ways - for example, to underpin the development of emergency action plans, to assess potential flood risk (both in terms of economics and risks to people), and to provide guidance on how a breach might develop and hence also be repaired. The way in which this information is used affects the significance of the uncertainty in prediction. Recognizing and addressing the degree of uncertainty in breach prediction results is essential for any application.

Selecting the right approach for modelling breach can be confusing and is often steered by a lack of available data and a tendency to undertake a quick analysis at minimal cost without perhaps assessing the degree of uncertainty inherent in that approach. By developing a (free) online version of the EMBREA breach model we are providing users with the opportunity to undertake a more realistic analysis of breach, using a physically based predictive model that takes into account the dam or levee soil type and hydraulic load conditions rather than just using a simple 'peak discharge' equation.

This paper first discusses why we have developed an online breach model, followed by an explanation of the how the EMBREA breach model works. Differences between the online 'Lite' and 'Pro' model versions are explained and future development steps outlined.

2 WHY DEVELOP AN ONLINE BREACH MODEL?

The difficulty with predicting breach formation is that it requires an assessment of several different interacting processes, including hydraulics, soil erosion and structure response. This in turn requires expert judgement and as data detailing hydraulic loading, soil type and state and structural behaviour. The degree of uncertainty inherent in any prediction will be affected by how the model or method represents the breaching process, the data used and the expertise of the person undertaking the analysis.

In practice, there are a range of different ways in which breaching processes may be predicted. These vary from simple judgement, to simple equations to physically based models (of varying complexity). Details of the different breach formation processes and breach prediction approaches can be found in publications such as by West (West et al, 2018) and Hassan (Hassan et al, 2019). Broadly, the degree of uncertainty in the prediction decreases as the complexity of analysis, and amount of data used, increases. As the complexity increases, so does the time and hence the cost of analysis. Without an appreciation of the uncertainty inherent in the different processes, and hence the implications for any particular end use, there is a tendency to predict breach using the simplest and most readily available approach – typically using peak discharge equations.

By creating a free to use online version of the EMBREA physically based breach model, we are encouraging users to 'play' with the model in the same way that simple discharge equations are used. In this way the real differences in predicted breach results and hence the real advantages for using physically based models should become clearer. For example, a peak discharge equation such as Froehlich's equation (Froehlich, 2008) will typically provide the same answer regardless of whether the dam or levee is made from sand or clay, and whether failure occurs during flood or non-flood conditions. The effects of drowning of the breach as flood water downstream of the breach backs up into the breach would also be ignored. This would not be the case when using the online version of EMBREA.

3 THE EMBREA BREACH MODEL

The EMBREA breach model is a physically based breach model that has evolved over the past 20 years from the original HR BREACH models, developed by Mohamed Hassan (Mohamed, 2002). The HR BREACH model was developed at HR Wallingford (Mohamed, 2002) and validated through a series of European research projects, including the CADAM (Morris, 2000), IMPACT (Morris, 2005), FLOODsite (Samuels et al, 2010); (Morris et al, 2009) and FloodProBe (www.floodprobe.eu) projects. Performance of the model was also assessed through participation in the CEATI Dam Safety Interest Group, breach modelling project. Conclusions from this performance evaluation work can be found in the US Bureau of Reclamation technical report DSO-2017-02: Evaluation of numerical models for simulating embankment dam erosion and breach processes (USBR, 2017).

Figure 1. Breach erosion research undertaken through the European IMPACT project.

The HR BREACH model was further developed in 2011, refining the prediction processes and including the ability to model zoned dams and levees (Morris, 2011). The model name was also then changed from HR BREACH to EMBREA.

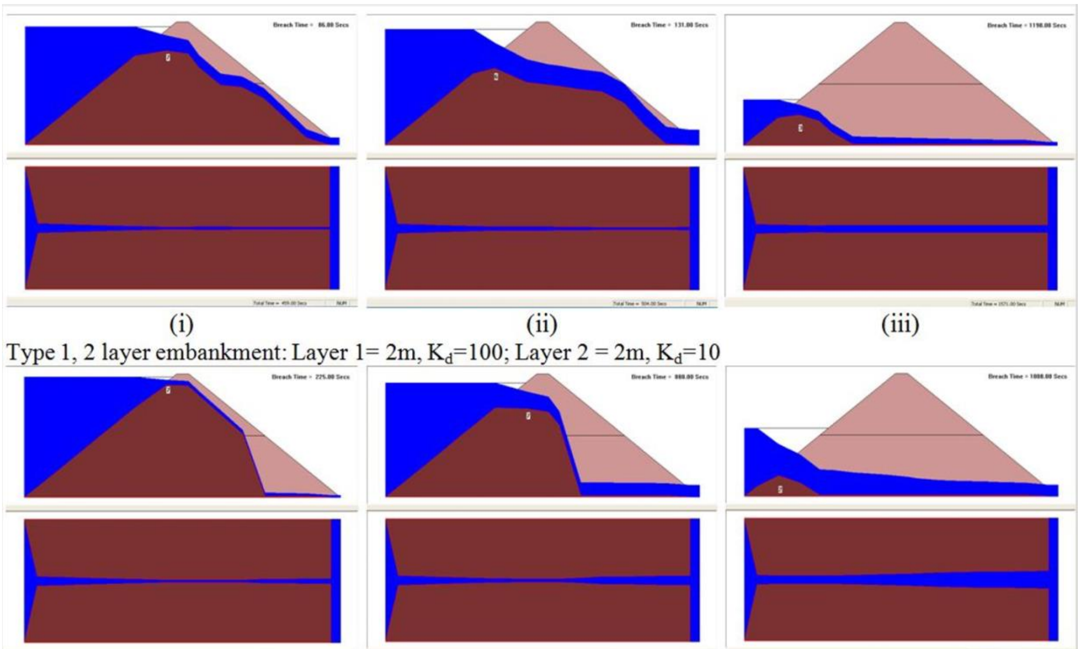

Figure 2. Example outputs from the EMBREA breach model showing breach erosion progression (in this example, showing erosion of a layered embankment with different zones of erodibility)

The core model processes analyse potential breach formation by simulating the physical processes that have been observed for a range of soil types.

The model integrates hydraulics, soil mechanics and structural failure processes to a broadly consistent degree of complexity. The model undertakes analysis on a section by section basis through the model (Figure A1-1) and, unlike many other models does not predefine the breaching process in terms of stages and geometry. The 'penalty' for this more detailed approach to analysis is that the model takes some minutes to run rather than seconds.

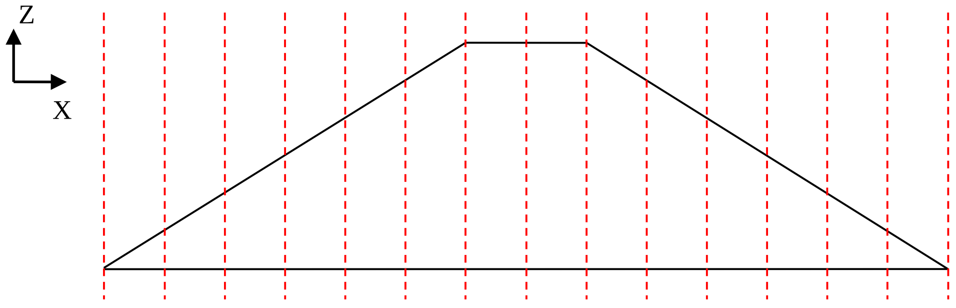

Figure 3 Modelling embankment breach by division of the embankment into sections

Figure 4 provides a flow chart showing the order in which the hydraulic, soil and structural processes are analysed.

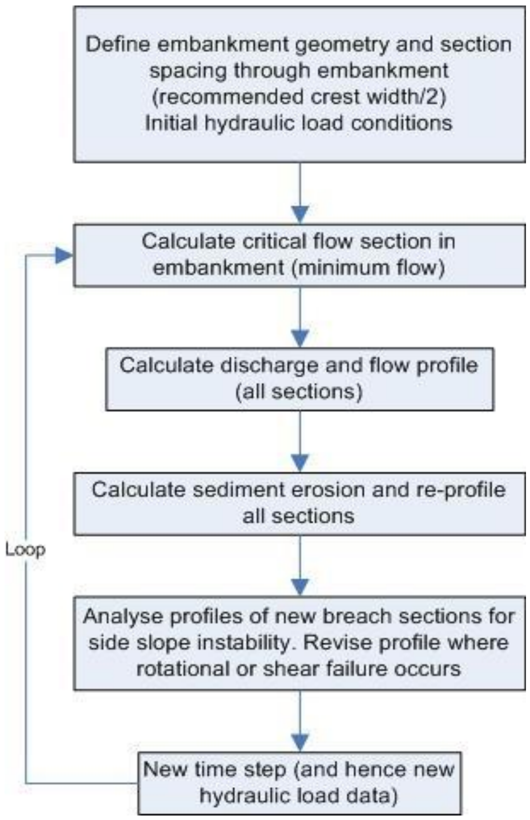

Figure 4 EMBREA breach modelling calculation process

In adopting this approach, the model combines the analysis of flow, soil erosion and side slope (and core) instability within the overall breach prediction process. More specifically:

- Flow is calculated using a weir flow equation at the critical flow section
- A form of the non-uniform flow equation (Chow, 1959) maps the flow profile
- Various soil erosion equations may be selected by the modeller for the estimation of soil erosion; each section through the embankment is allowed to erode (below the waterline) according to the erosion relationship and hydraulic load conditions
- The stability of the breach side slopes (which are undercut by the erosion) are assessed for shear and rotational failure, and failure allowed section by section
- Where a dam core is indicated, soil is permitted to erode either side and failure scenarios including shear and various fracture lines assessed at each time step.

Prior to this process being implemented the modeller may also define a protective surface layer of grass or rock. Under these conditions the layer prevents any erosion from being calculated until the hydraulic load exceeds the level of protection being offered. At this point the layer is assumed to fail entirely, and the breach erosion process begins.

This process therefore combines 1D and 2D analyses along different axes to reflect the physical processes that can be observed during breach formation.

4 EMBREA ONLINE: LITE AND PRO MODEL VERSIONS

The online breach models may be accessed via www.dambreach.org

Both EMBREA Lite and EMBREA Pro use the same modelling process, but the available functionality varies as shown in Table 1 below.

EMBREA model version	EmbreaLite	EmbreaPro
Structure	Homogenous embankments	Homogenous, composite and layered embankments
Failure mode	Overtopping and piping available in both versions	
Probabilistic representation of variability in embankment material properties and construction quality	Not included	Included
Simulation mode	Single	Single and Monte Carlo
Output type	Simplified	Detailed
Price	Free	User Licence Required
	Access online tool	Purchase a subscription

Table 1 Different breach modelling options included in EMBREA Lite and EMBREA Pro

EMBREA Lite:
When you access the EMBREA Lite model area, you are presented with a data entry screen (see Figure 5 below).

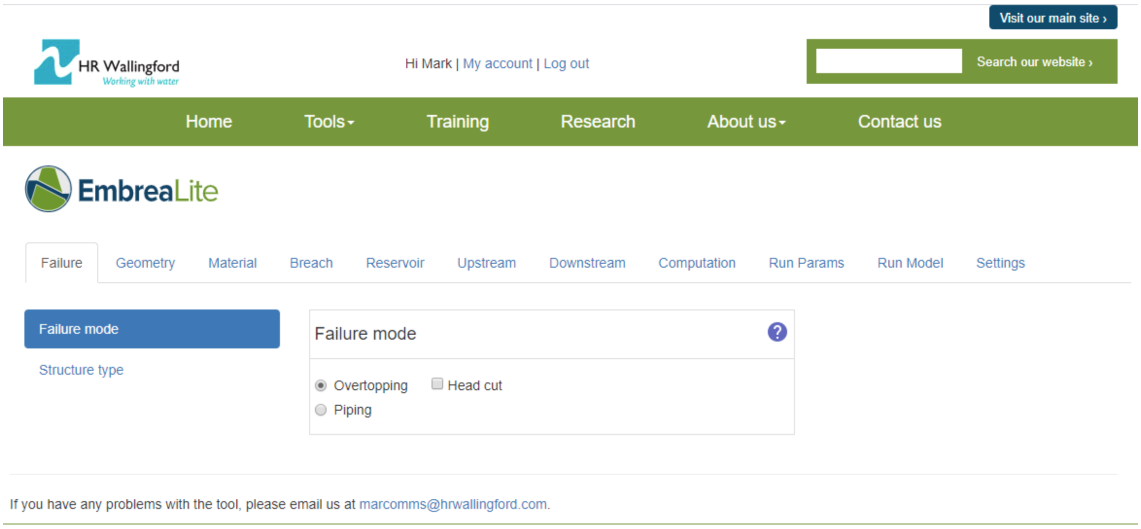

Figure 5 EMBREA Lite home screen

As you work through each tab for data entry, you are guided through the process of describing the dam or levee geometry, soil conditions, hydraulic load conditions and how you would like to simulate the breaching process. Each data entry page has a help function where you can find an explanation of the data needed.

Whilst the model is running online, you see the screen shown in Figure 6. The model runs on a server remotely, and once the results are complete, they are made available (Figure 7).

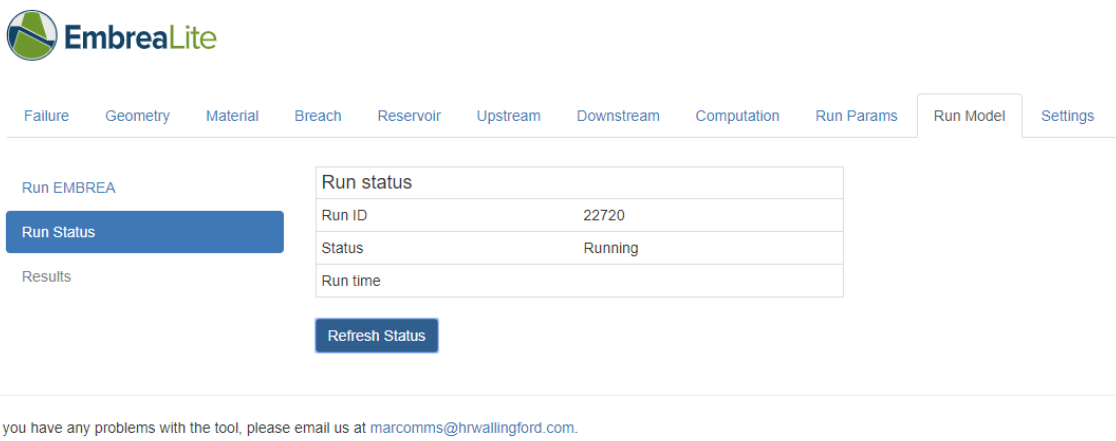

Figure 6 EMBREA Lite modelling running screen

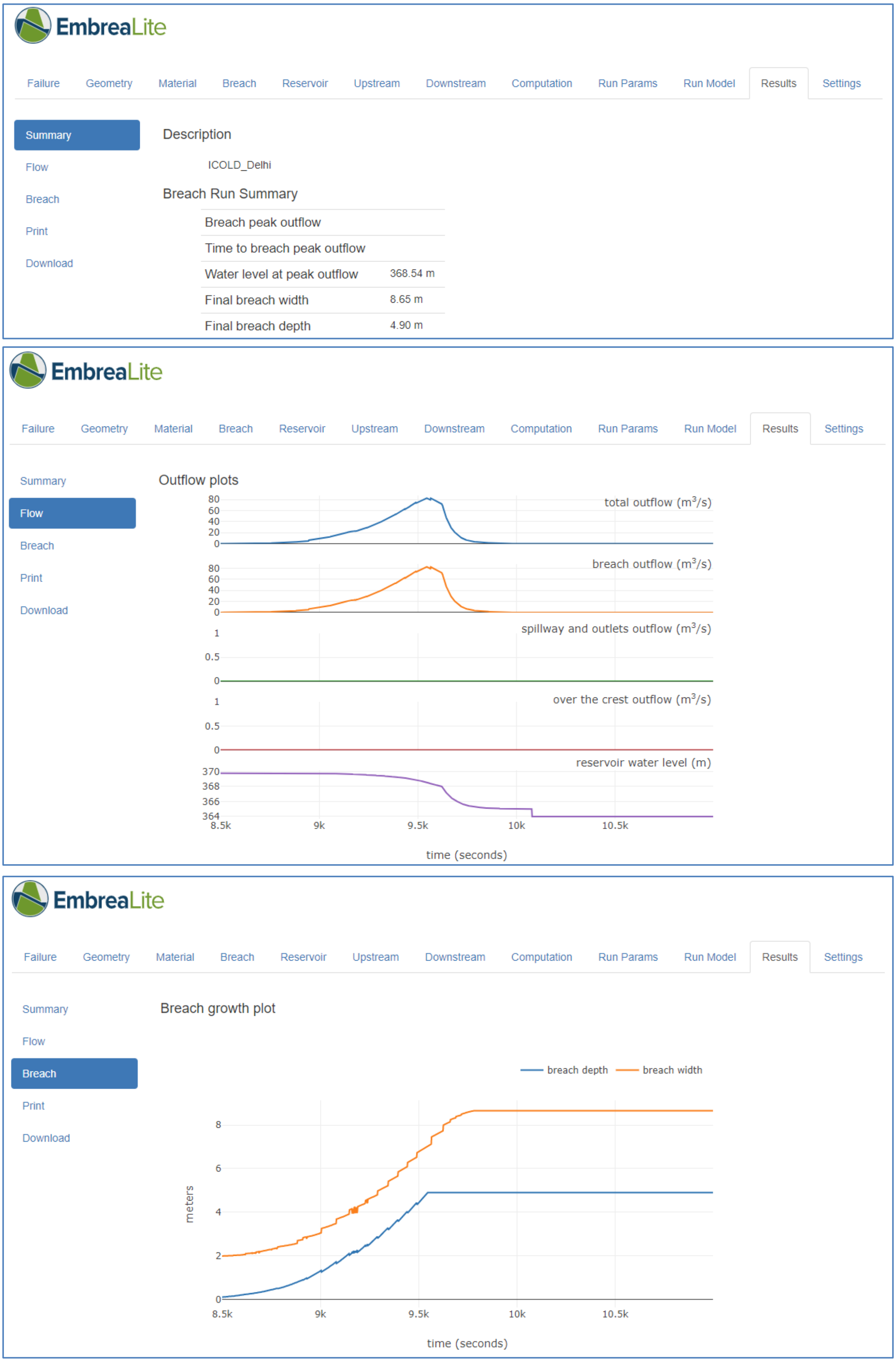

Figure 7 EMBREA Lite modelling results screens

The modelling results are presented as (i) a summary of key parameters; (ii) plots showing breach and reservoir outflow, along with upstream water level variation and (iii) plots showing the predicted breach width and depth growth over time. These results may be downloaded (EMBREA Pro version) or printed (both versions).

EMBREA Pro:
Running the EMBREA Pro model version is undertaken in a similar way to EMBREA Lite, but the pro version offers increased model functionality and run options. Access to EMBREA Pro requires payment.

5 FUTURE DEVELOPMENTS BUILDING UPON RESEARCH ACTIONS

The current EMBREA Lite model is an initial model version developed for online use. As the EMBREA model functionality continues to be developed, so too will the online version, although the EMBREA Pro version will always remain advanced in relation to the free access lite version.

Both online models are developed from the original, stand alone EMBREA model version, which will continue to be developed as part of ongoing programmes of research at HR Wallingford. Two current lines of research and development include:

(1) Dam and Levee Surface Erosion Research

(2) Internal erosion-initiated breach model performance validation

Both of these research programmes have been initiated by Electricté de France (EDF) and involve wider international research cooperation on breach processes. In particular, the surface erosion research will investigate when and why macro erosion processes change (for example, when headcut changes to surface erosion or slope slumping); the internal erosion model validation programme will review and assess the performance of current breach models in simulating breach formation which is initiated by internal erosion. More information on both of these research projects can be found in Morris et al, 2019.

In addition to breach modelling for water retention stuctures, EMBREA-MUD, a physically-based numerical model for simulation of tailings dam breaching has been developed at HR Wallingford as part of the DAMSAT project which is funded by the UK Space Agency. It predicts the outflow rates of water and tailings and growth of the breach opening as a result of flow erosion. EMBREA-MUD builds upon the upon the functionality of the EMBREA model and considers the interactions between three layers: water (Newtonian fluid, corresponding to supernatant water stored above tailings), mud (non-Newtonian fluid, corresponding to liquefied tailings) and the dam itself (subject to erosion by the other two components).

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