# Dynamic Dam Breaches: Predicting sediment laden dam breach flood wave propagation for future conditions using FLO-2D

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## Abstract

Dam breaches are a critical factor in floodplain, emergency, and reservoir management but rarely account for the impact of sediment storage within the reservoir on the flood wave propagation. Moreover, the volume of the impounded sediment typically increases over time; thus, influencing the potential for dam failure, the water level behind the dam, and the failure characteristics of a breach, should it occur. This aspect is particularly important for predictions of tailings dam failures, wherein both the sediment storage and the physical characteristics of the dam structure itself are in constant flux. To account for this dynamic influence of sediment inflow and dam characteristics on flood wave propagation, a dynamic modeling system was developed that utilizes the dam breach and subsequent downstream 2D flood routing capabilities of FLO-2D. This unique model provides a methodology wherein the user can specify how the impounded sediment and water storage volumes and the dam / levee bank height and width change over time. The user then selects any future time scenario and executes the FLO-2D breach model for the corresponding predicted dam and sediment characteristics. This paper describes this model and provides an example of its application to a hypothetical tailings facility. The modeled implications of floodplain changes over time are discussed, and suggestions for future applications of the model to other, related facilities such as coastal levees and sediment basins are provided.

## Introduction

A breach can occur at any point during the life of a tailings storage facility (TSF), whether by overtopping given a significant enough hydrologic event [i.e., probable maximum flood (PMF)], a piping failure, foundation failure, or earthquake (O'Brien, 2015). Because the tailings facility is dynamic, growing both from incoming sediment load as well as from periodic structural improvements (Figure 1), the likelihood of these hydrologic and piping failure modes, in particular, changes over time, as does the progression and severity of the ensuing breach. It can, thus, be useful for tailings facility management and design to understand this dynamic relationship and the corresponding downstream consequences of failure. To assist in that regard, a new modeling approach was developed. This approach utilizes the dam breach and subsequent downstream 2D flood routing capabilities of FLO-2D in conjunction with a "Tailings Dam Tool", or TDT, wherein the user can specify how the impounded sediment and water storage volumes and the dam / levee bank height and width are changing over time. This allows the user to identify the worst-case failure scenarios over a time period of interest. The TDT, thus, allows mine engineers/planners to identify an optimum program for expanding the TSF that accommodates mine operations and costs and, simultaneously, minimizes downstream consequences of failure.

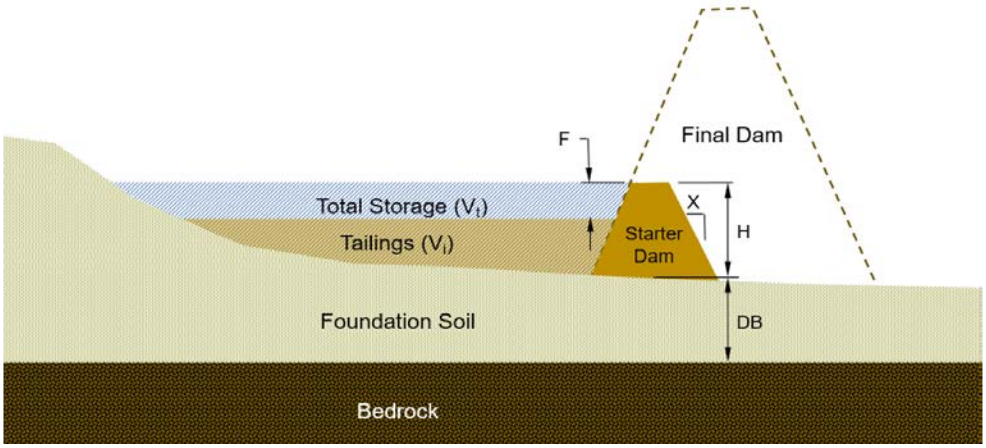


**Figure 1.** Tailings dam definition sketch.

## Approach

The overarching approach to executing the combined TDT / FLO-2D model within the context of TSF operation and / or design is as follows:

1. Couple the developed TDT with FLO-2D to route the breach hydrograph at any given point in time for any given condition of tailings volume and TSF embankment due to a PMF inflow.
2. Run the TDT at a specified time interval over the desired duration of operation. Inputs to the Tailings Dam Tool are varied according to operational inputs (annual tailings production rate, total tailings storage volume, and TSF embankment raises). Geotechnical properties for the embankment along with hydrologic data for the PMF are used to determine the failure mode and the corresponding breach hydrograph and volume of tailings material released.
3. Import the resulting breach hydrograph into FLO-2D for computation of the downstream inundation area and corresponding depths, velocities and travel times at critical facilities.
4. Use the results to refine the TSF operation plan, if necessary, to minimize the adverse downstream consequences based on an understanding of the corresponding risk of failure.

At present the particular tailings factors must be relayed to FLO-2D directly, but development is currently underway (expected completion in spring, 2019) to allow general project input via a single GUI (Figure 2).

| Physical/Site Data: | Initial | Final | |
|---|---|---|---|
| Tailings Dam Height (H): | 50 | 270 | feet |
| Total Impoundment Volume ($V_t$): | 7,783,951 | 51,772,000 | cubic yards |
| Tailings Volume ($V_i$): | 0 | 46,720,000 | cubic yards |
| Freeboard (F): | 100 | 280 | feet |
| Tailings Dam Slope (X:1): | 2 | 2 | |
| **Hydrologic Data:** | | | |
| Probable Maximum Precipitation: | 14 | inches | |
| Watershed Area: | 3 | sq. miles | |
| Runoff Volume: | 3,613,867 | cubic yards | |
| **Geotechnical Data:** | | | |
| Depth to Bedrock (DB): | 40 | feet | |
| Foundation Soil Character: | Granular | | |
| SPT Blow Count: | 3 | | |
| Unit Weight of Foundation Soil ($\gamma_b$): | 120 | pcf | |
| Unit Weight of Dam Material ($\gamma_D$): | 110 | pcf | |
| Cohesion of Dam Material: | 100 | pcf | |
| Friction Angle of Dam Material ($\Phi$): | 25 | degrees | |

**Figure 2.** Proposed Tailings Dam Tool (TDT) GUI interface. (Currently under development.)

With the overall project information entered into the TDT, variable dam construction conditions can be considered (e.g., how high to build the dam and when to do so). The program then automatically executes FLO-2D with this information, and provides critical results including peak hydrograph flowrate, total volume released, and total sediment released.

## Example

As an example of how the proposed TDT could be used, consider a hypothetical tailings facility with the soils, hydrologic, and geometric data, as specified in Figure 2. Assuming a continuous production rate of 1 cfs, then a 50-foot height increase of the dam every six years results in the failure scenarios shown in Figure 3.

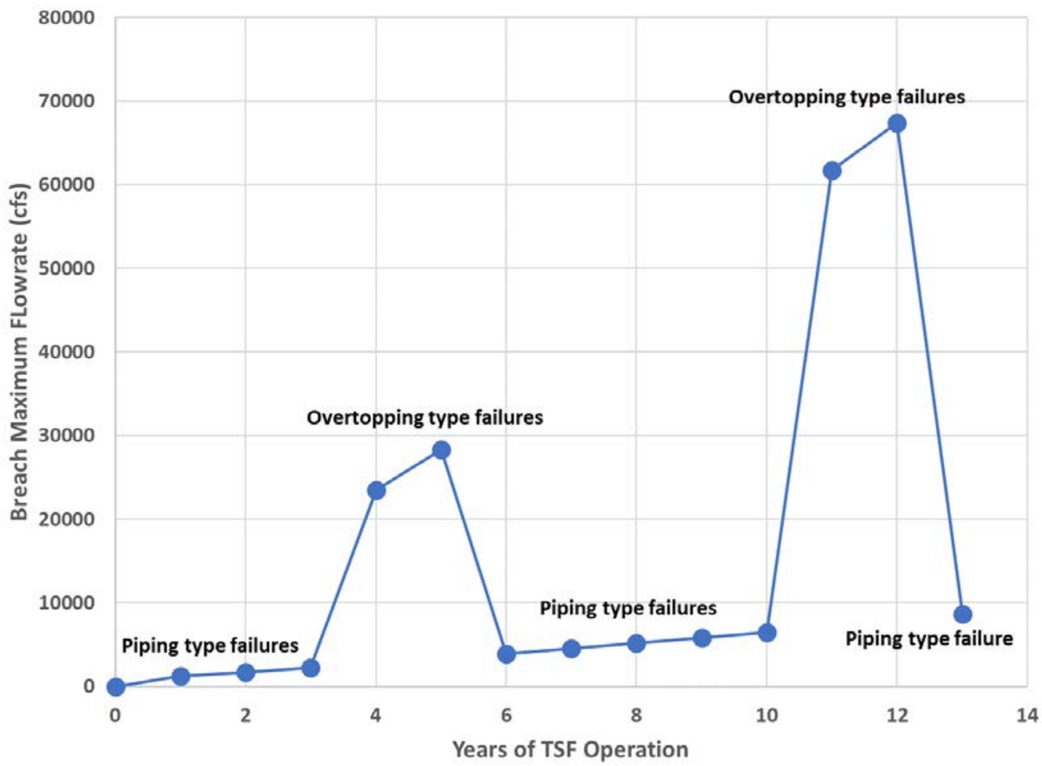


**Figure 3.** Breach Maximum Flowrate versus Years of TSF Operation

The transition between piping type failures and overtopping type failures is considerable, with overtopping resulting in much higher maximum breach flowrates. The difference in overall sediment outflow is also substantial.

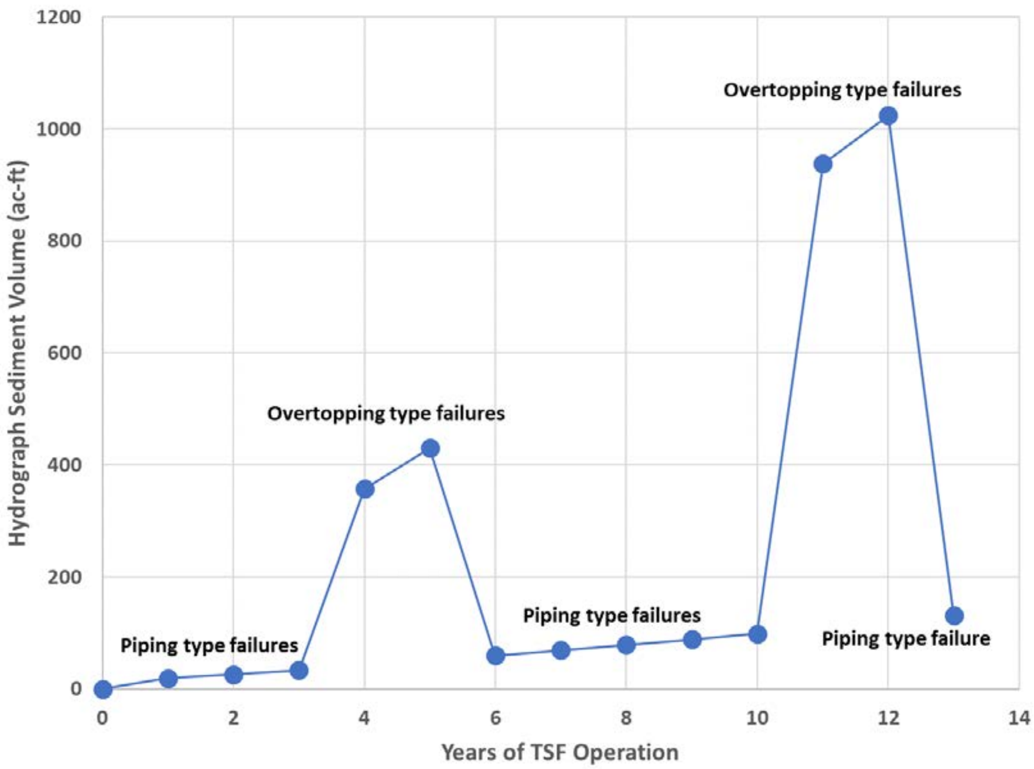


**Figure 4.** Breach Maximum Flowrate versus Hydrograph Sediment Volume

# Conclusion

The TDT is a useful tool for tailings management, operations, and design. By combining the disparate aspects of breach failure (geotechnical, hydrologic, geometric) into one integrated algorithm, the consequences for operations and design decision making becomes immediately apparent. Here, the example shows that an overtopping-type failure is of much greater consequence compared with the piping failure, suggesting that the original construction plan (a 50-foot increase every 6 years) be revisited. Of course, other TSF may have different outcomes. A facility with weaker material and a more aggressive construction schedule may experience greater piping failure consequences compared with overtopping. Indeed, it is the nonlinearity of this process that justifies application of the TDT and its continued development.

## Reference

O'Brien, J.S., Gonzalez-Ramirez, N., Tocher, R.J., Chao, K.C., and Overton D.D. (2015). "Predicting Tailings Dams Breach Release Volumes for Flood Hazard Delineation," Proc. of the Association of State Dam Safety Officials Conference, New Orleans.