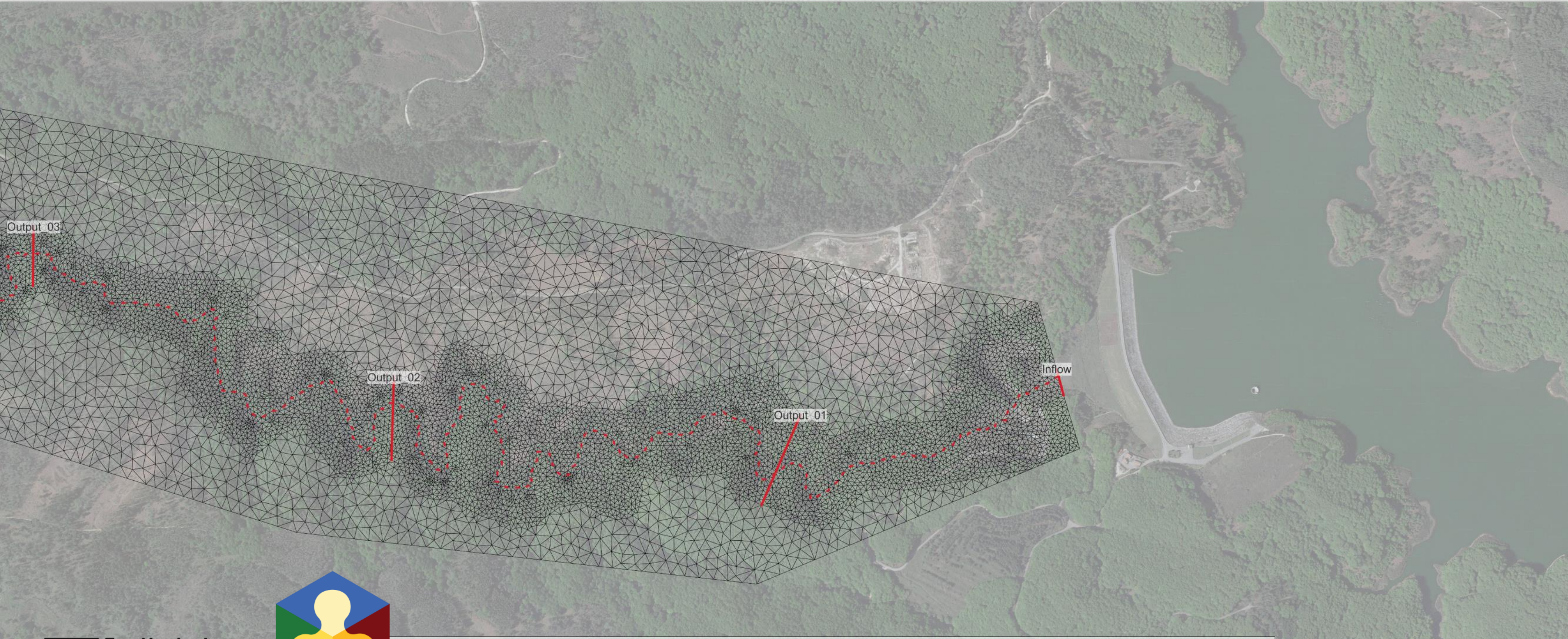
Downstream propagation of water and sediment hydrographs due to the hypothetical failure of a real earthen dam



ETH zürich

VAW
Laboratory of Hydraulics, Hydrology and Glaciology

BASEMENT Users' Meeting - January 25th, 2024

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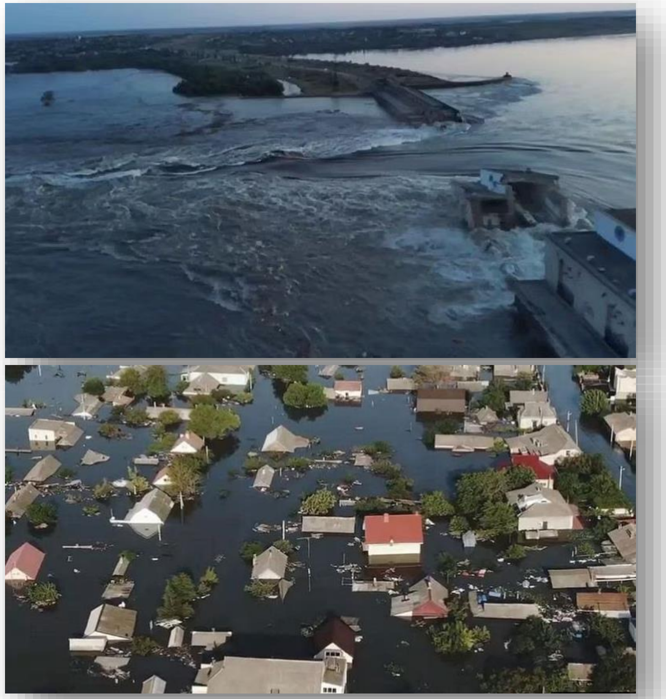
UNIVERSITÀ DELLA CALABRIA

Laboratorio di Modellistica Numerica per la Protezione Idraulica del Territorio
LaMPIT

Introduction

Dam failures → Artificial floods → Catastrophic events!



Kakhovka Dam failure (Ukraine),
June 2023

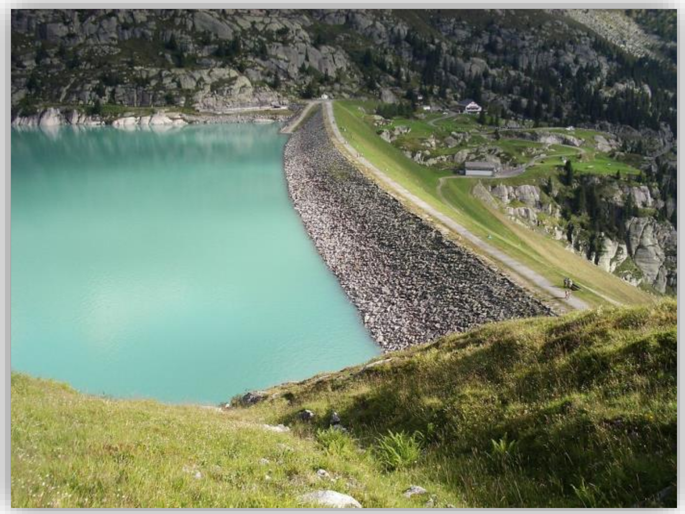
Derna Dams failure (Libya),
September 2023

Introduction

Concrete dams

DAM-BREAK:
sudden collapse
(partial or total) of
the dam body

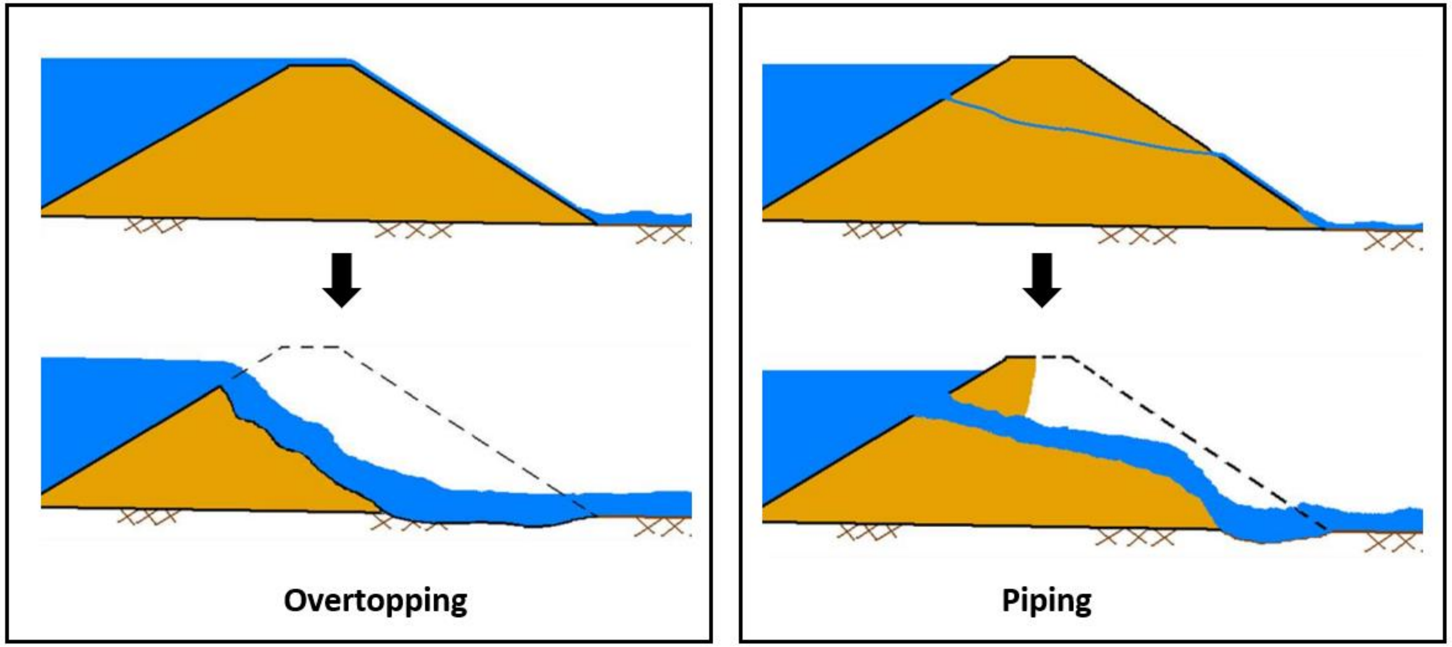
Earthen dams



DAM-BREACH:
progressive erosion
of the dam body

Introduction

Triggering mechanisms



- Different initial phase
- Formation of a top **breach** in both cases
- Breach enlargement governed by the **transport capacity** of the outflow discharge

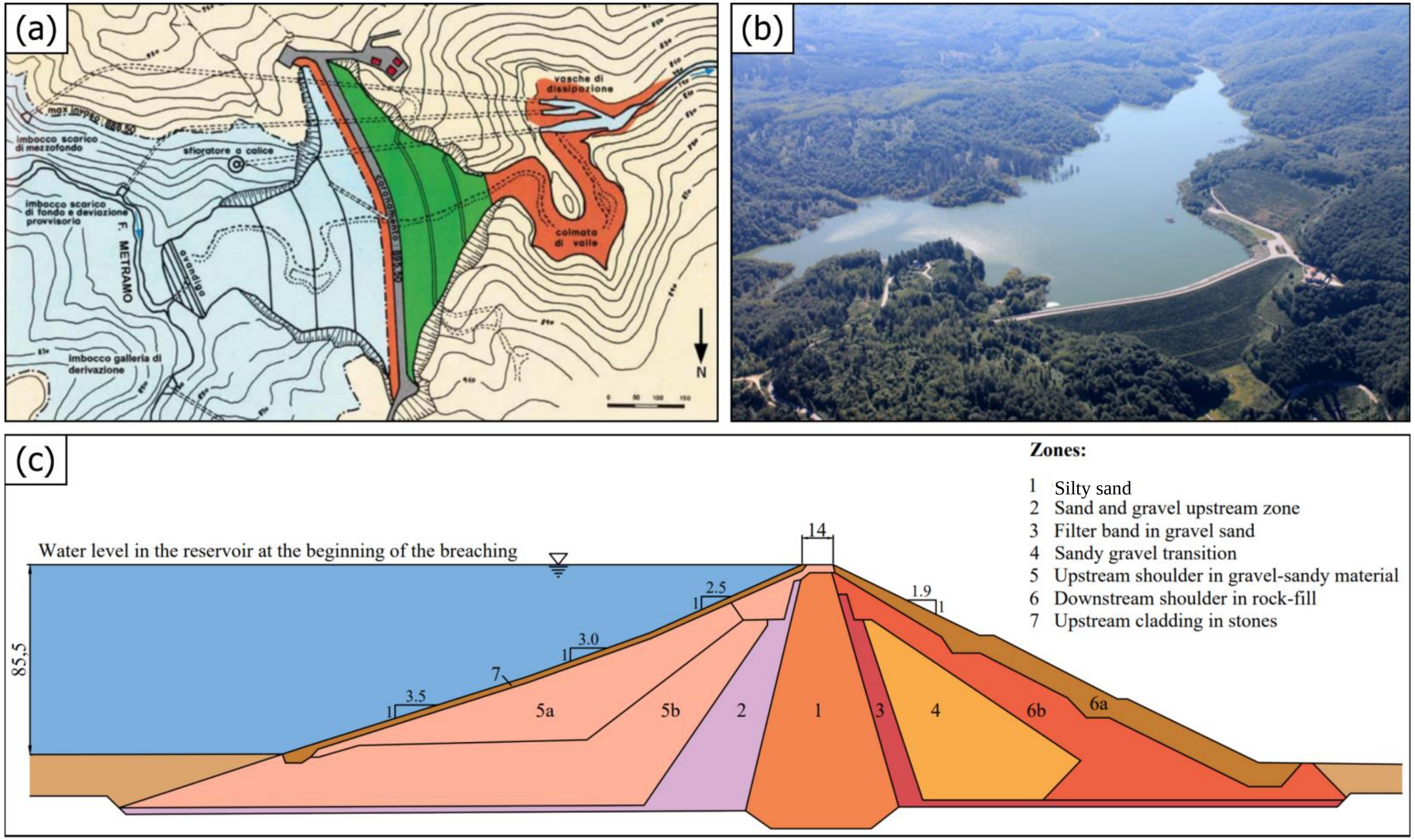
Dam-breach numerical modelling

Aimed at:

1. **Outflow hydrograph generation**
2. **Downstream flood wave propagation**

…addressed separately

Case study: Castagnara Dam (Calabria, Italy)



Characteristics of the dam-reservoir system:

- Dam height:

$$Z_M = 85.5 \text{ m}$$

- Water volume stored up to the dam crest:

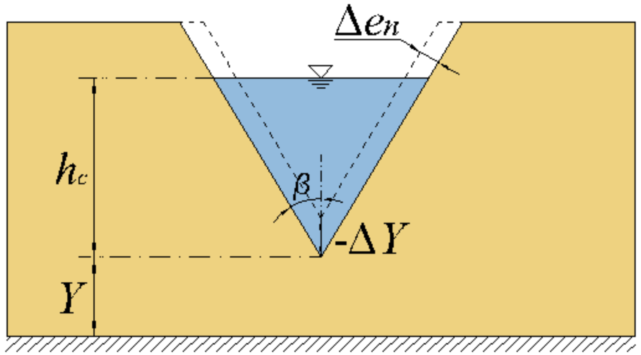
$$W_M = 38 \text{ Mm}^3$$

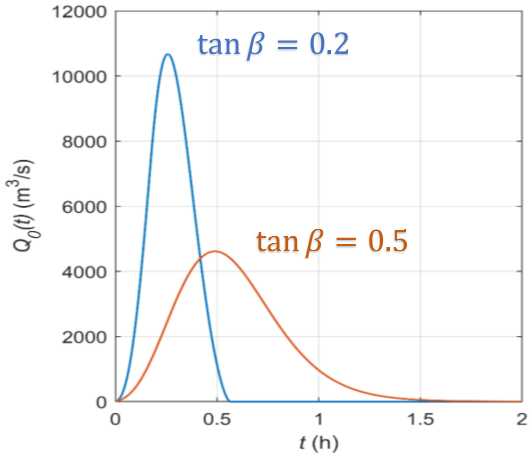
Outflow hydrograph generation

Macchione (2008) simplified physically based model

→ **Main assumptions**:

- Shear stress-based erosion law dependent on parameter $v_e = 0.07$ m/s
- Triangular breach characterized by shape parameter $\tan\beta$

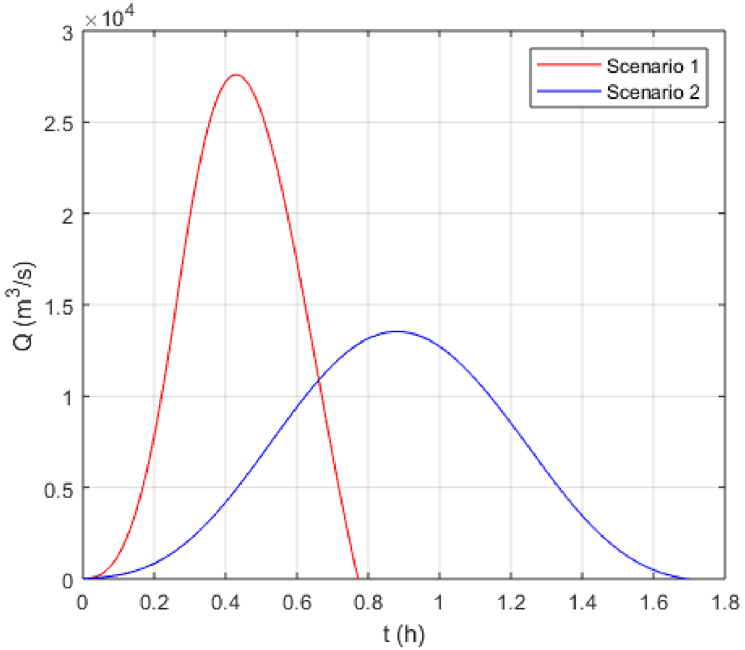




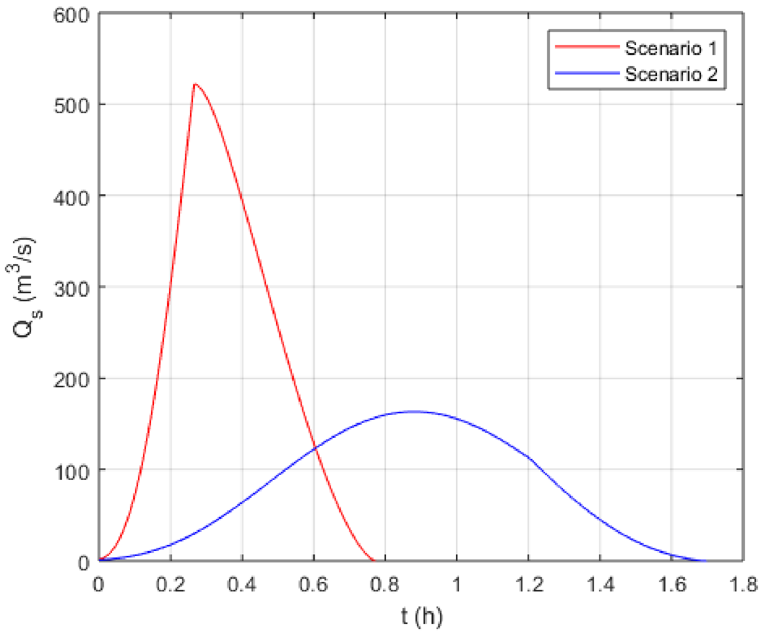
Breach shape scenarios assumed for the case study

- Hypothetical failure simulated according to different breach shape scenarios: (1) $\tan\beta = 0.2$; (2) $\tan\beta = 0.5$

Water outflow hydrographs



Sediment outflow hydrographs



Upstream boundary conditions for a 2D morphodynamic model

BASEMENT High-Performance Computing (**BASEHPC**)

- Same released water volume: 38 Mm^3
- Different total volume of sediments (without porosity): 614218 m^3 vs 491309 m^3

Goal

- Evaluate the changes in bed elevation due to input sediment deposition
- Compare the results given by the assumed breach shape scenarios
- No data to calibrate the model
- Sensitivity analysis of the results to the variability of some crucial parameters

Bedload transport formula → **Meyer-Peter and Muller** (1948)

$$q_B = \psi 8(\theta - \theta_{cr})^{1.5}\sqrt{(s-1)gd^3}$$

$\theta = \dfrac{h\sqrt{S_{fx}^2 + S_{fy}^2}}{(s-1)d}$ → Shields parameter (dimensionless bed shear stress)

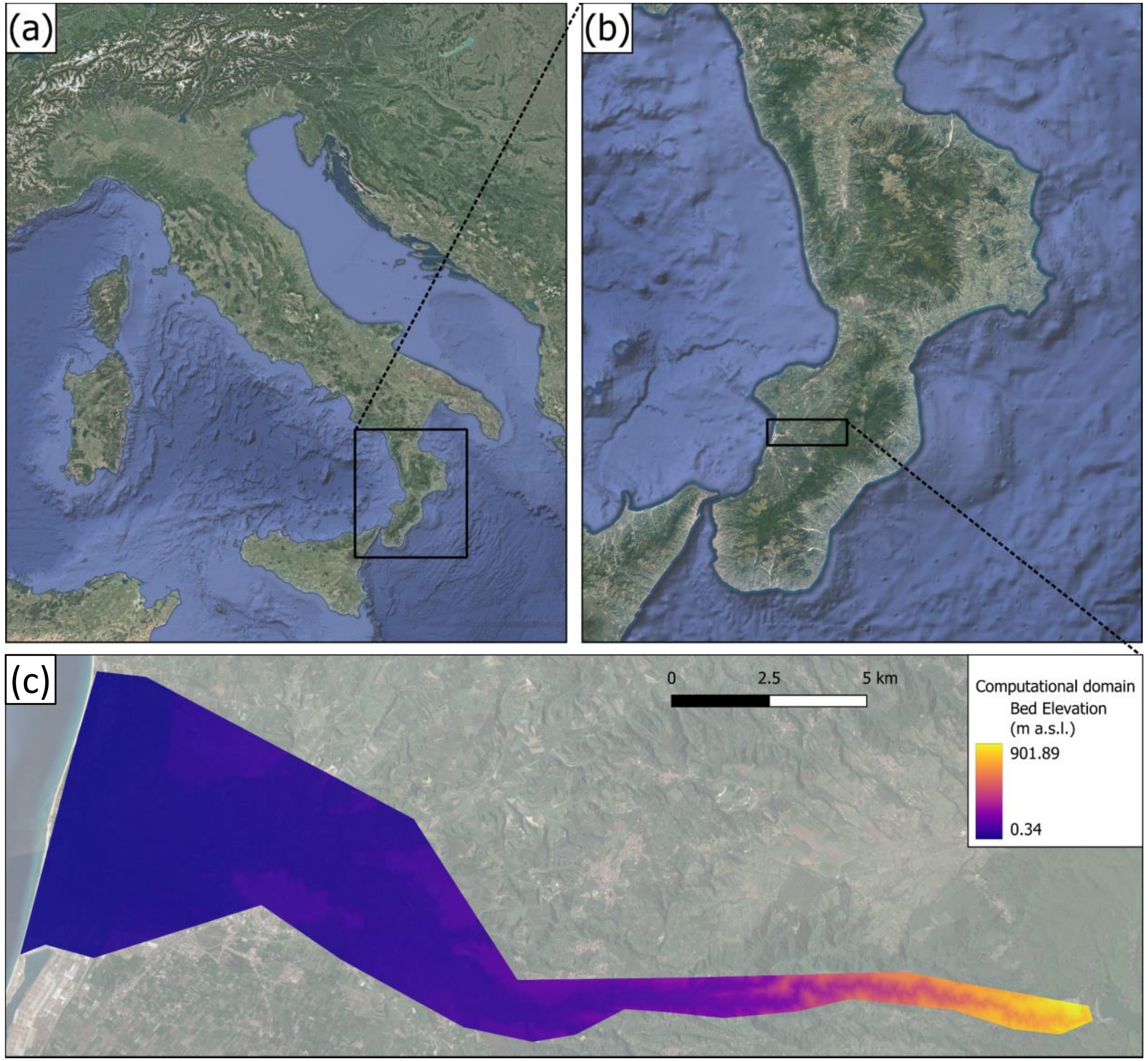
$\theta_{cr} = 0.047$ → Critical value of the Shields parameter

$s = \rho_s/\rho_w$ → Sediment density coefficient

- d is the sediment diameter (average diameter of the Castagnara dam body: $d = 0.05$ m)
- ψ is a pre-factor used to scale the bedload transport formula

→ Sensitivity analysis of the results to the Meyer-Peter and Muller pre-factor:
MPM factor (ψ) = 1, 2, 3, 4, 5, 7, 10

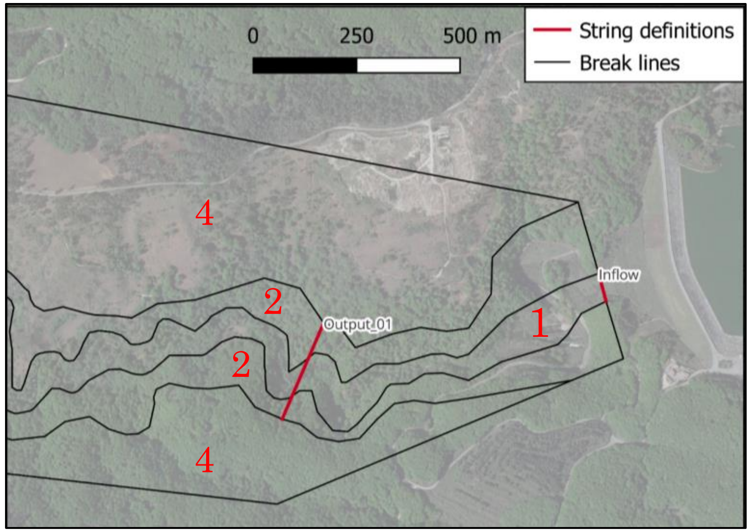
Case study location and potential flooded area



Computational domain

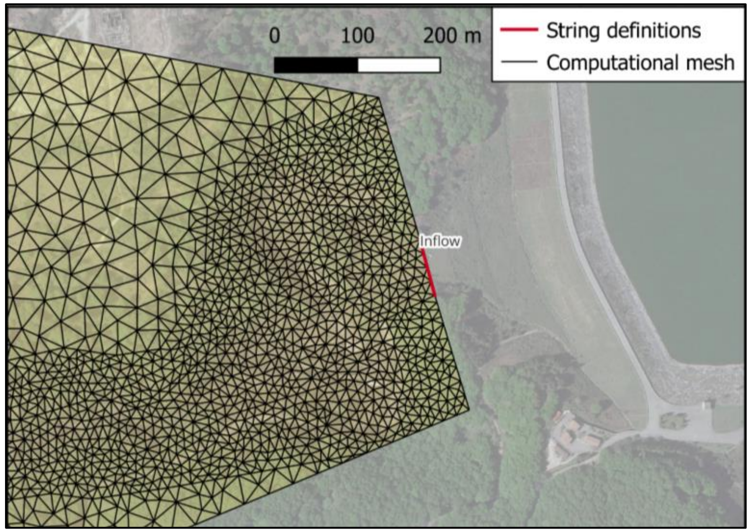
- From the dam toe to the seashore
- Area: 72.4 km^2

Model set up



Set up of **break lines** and **string definitions**

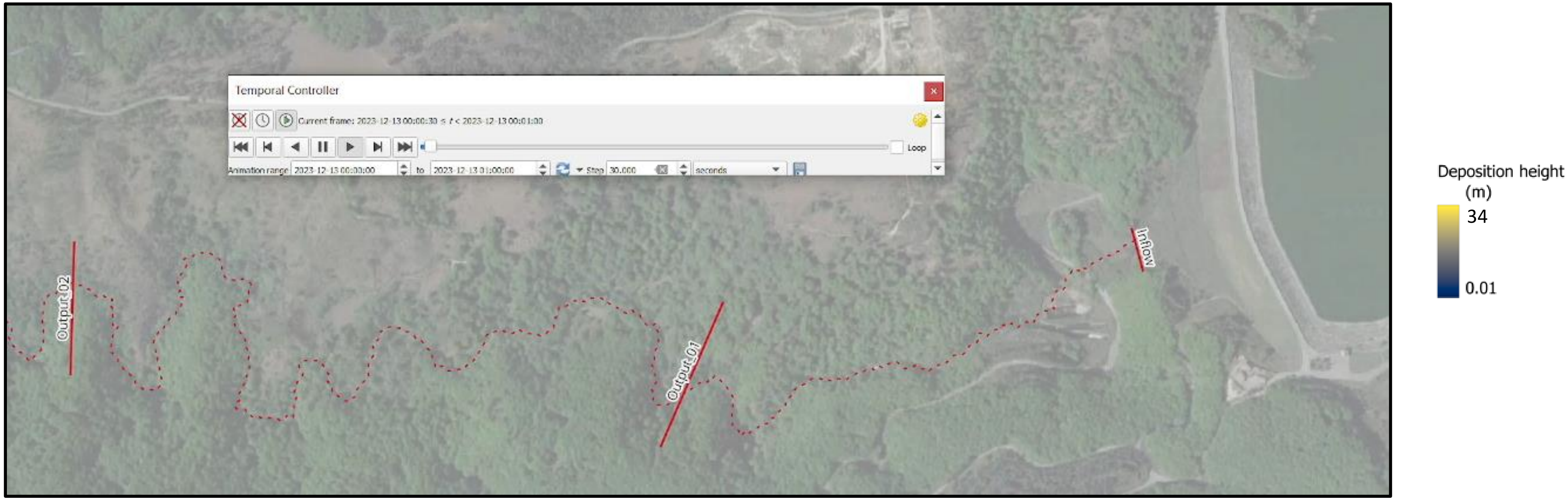
- Break lines set up in order to create four regions:
  1. Thalweg region
  2. Main channel
  3. Floodplain
  4. Rest of the domain
- Set up of 29 string definitions (1 Inflow XS; 27 Output XS; 1 Outflow XS)



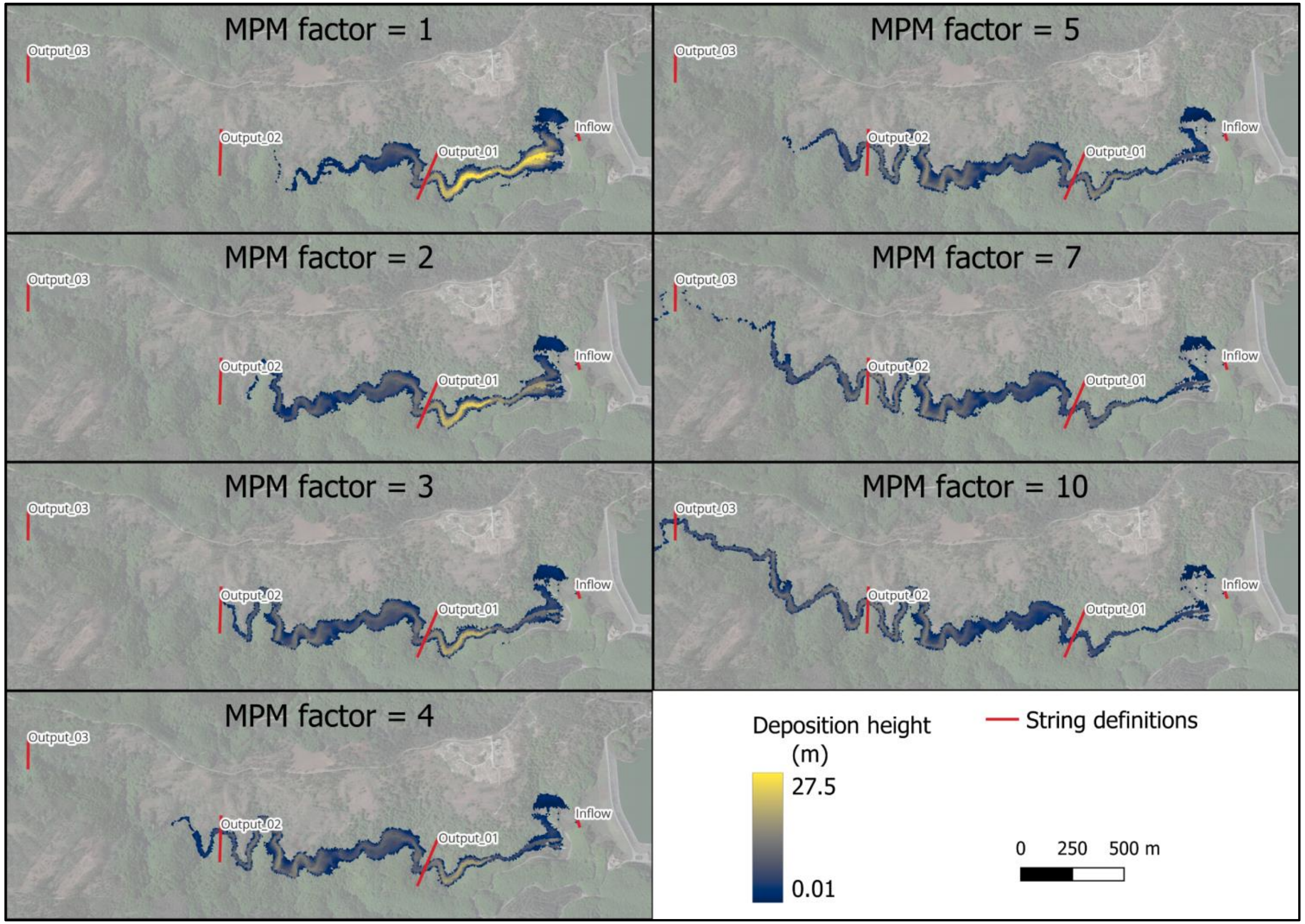
Computational mesh

- 380582 cells
- Maximum area of cells: 100 m^2 (regions 1 and 2), 400 m^2 (region 3), 700 m^2 (region 4)

Results – Temporal evolution of sediment deposition



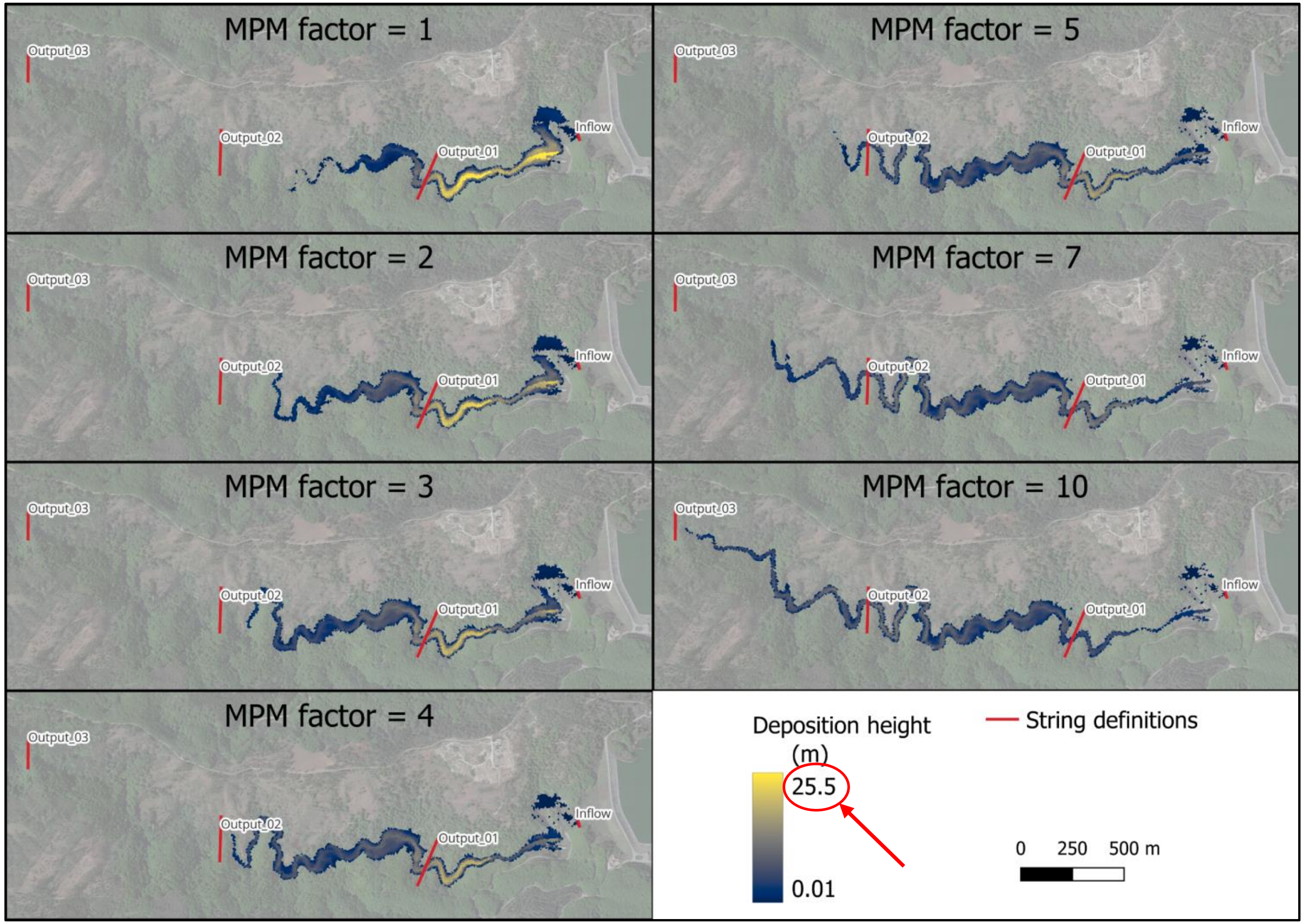
Results – Final sediment distribution



Scenario 1

- **No** deposition at the Inflow XS
- Maximum deposition height of **27.5** m given by MPM factor =1
- As MPM factor increases:
  - ➢ Deposition heights decrease
  - ➢ The sediment is transported more and more downstream

Results – Final sediment distribution

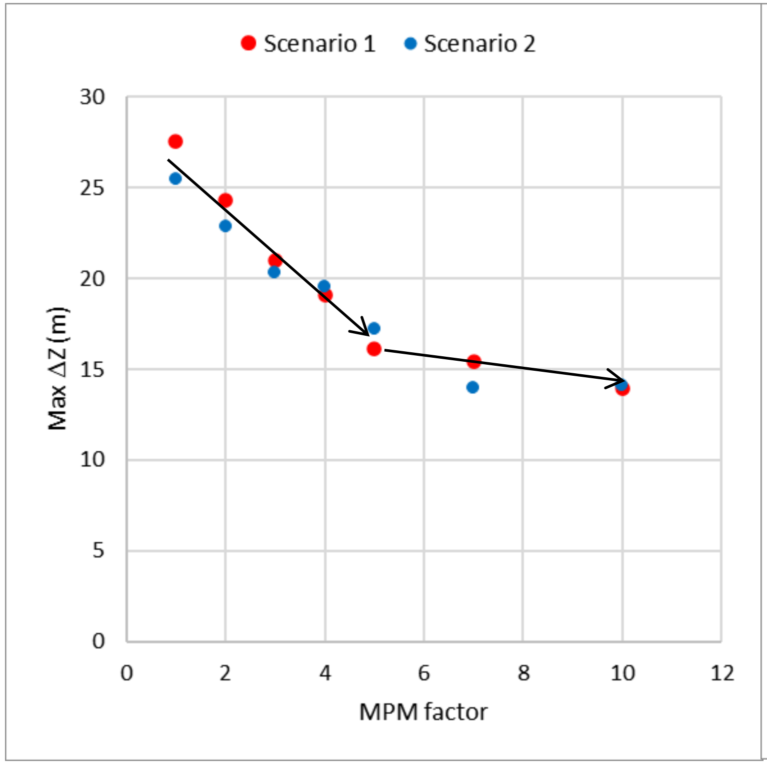


Scenario 2

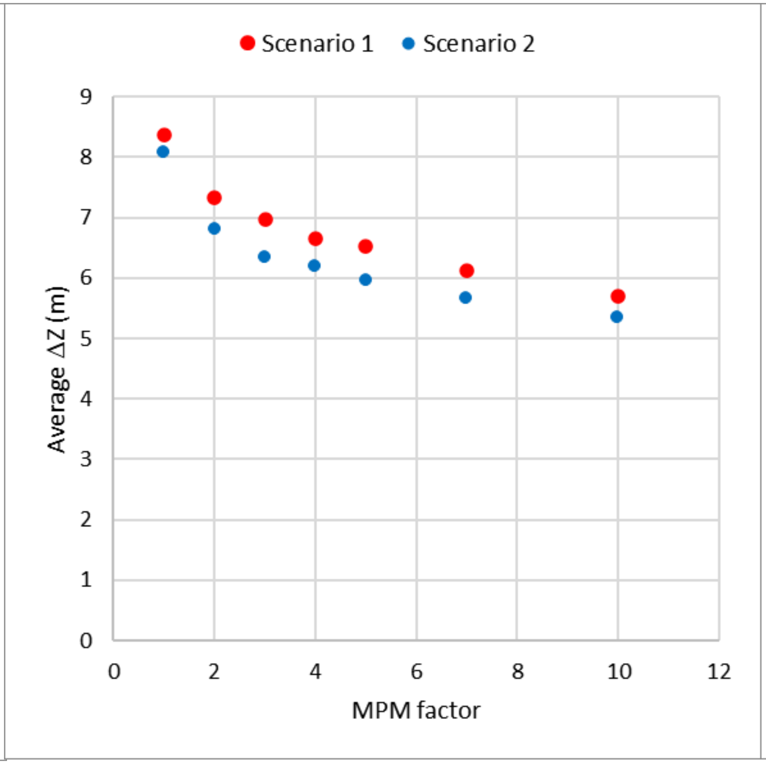
- **Small** depositions at the Inflow XS
- Maximum deposition height of **25.5** m given by MPM factor =1
- As MPM factor increases:
  - Deposition heights decrease
  - The sediment is transported more and more downstream

Results – Final sediment distribution

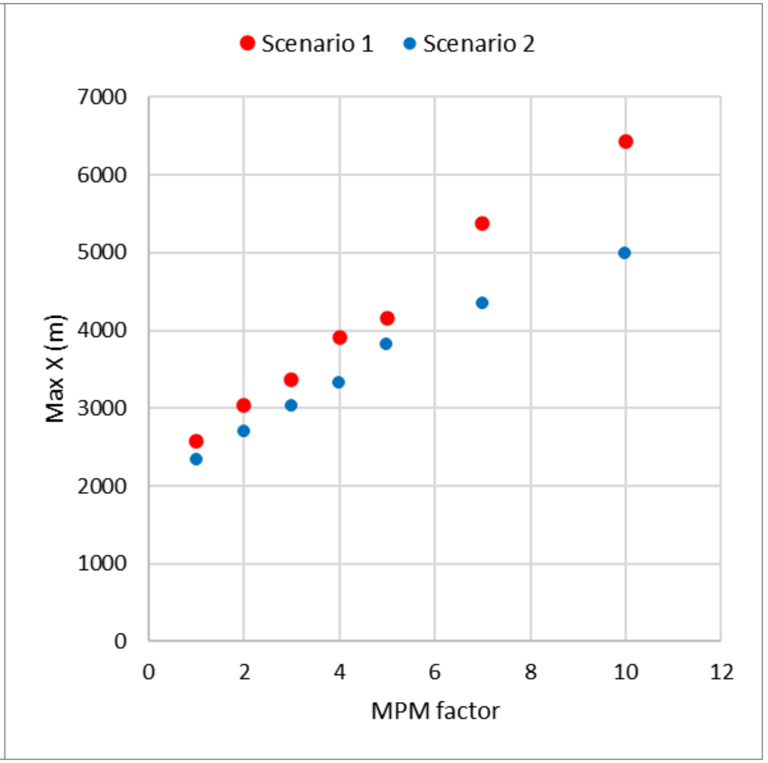
Maximum deposition height



Average deposition height

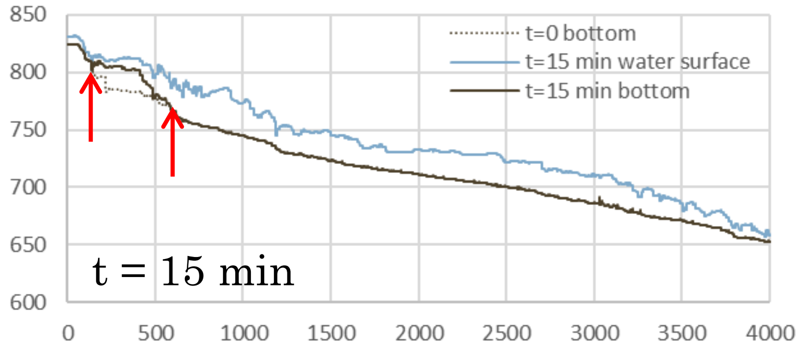


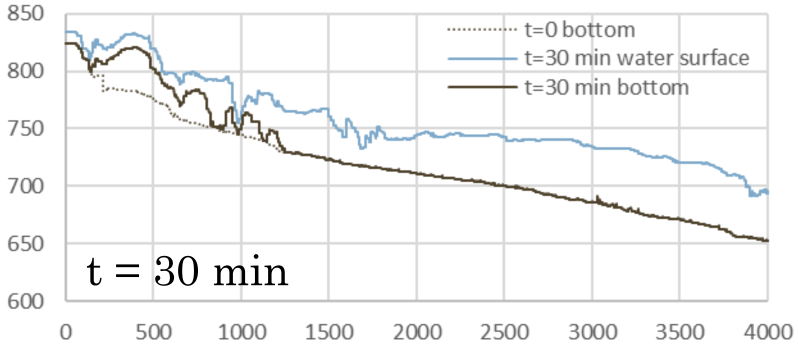
Maximum deposition distance from the dam

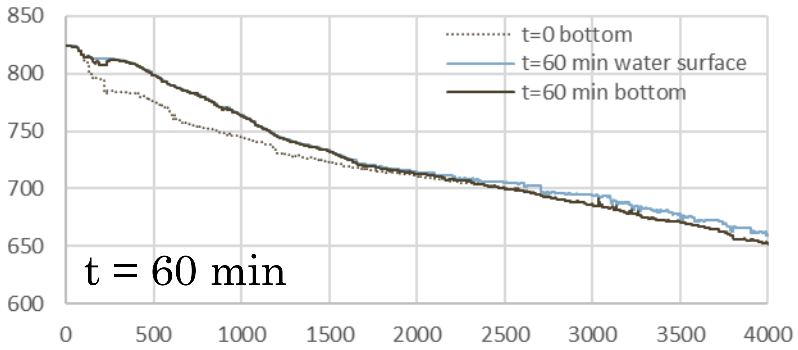


Results – **Bottom and water surface longitudinal profiles** – Scenario 1

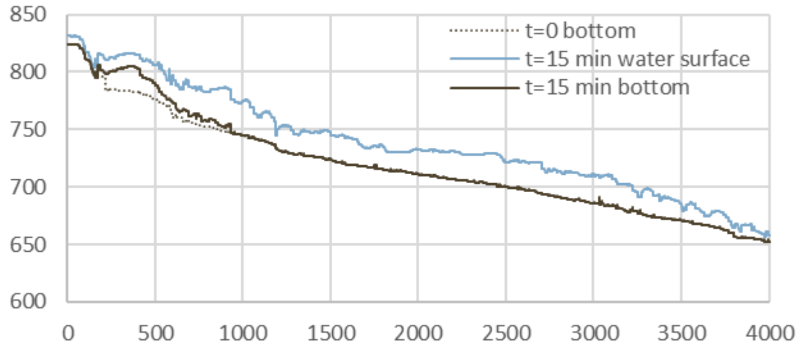
MPM factor = 1

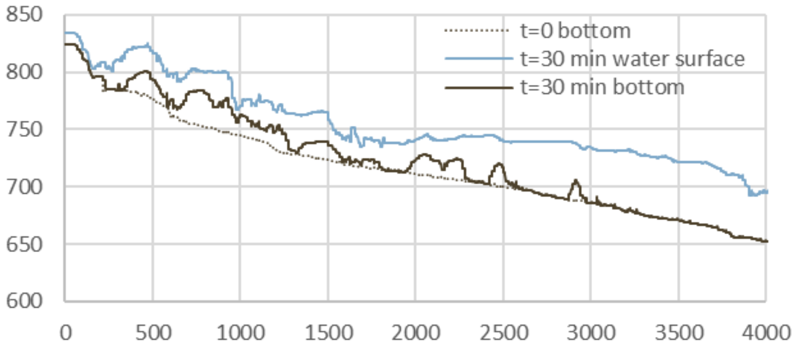


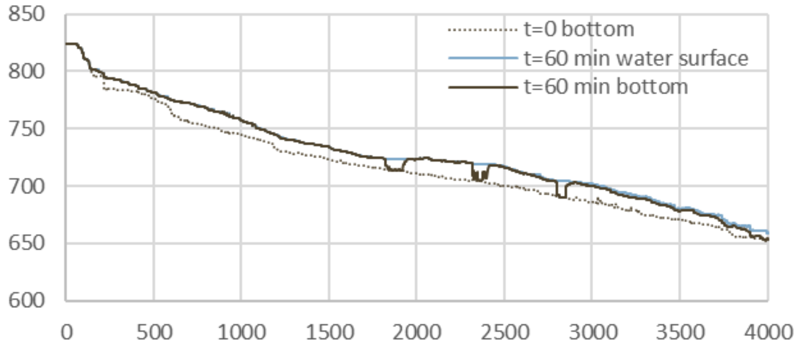




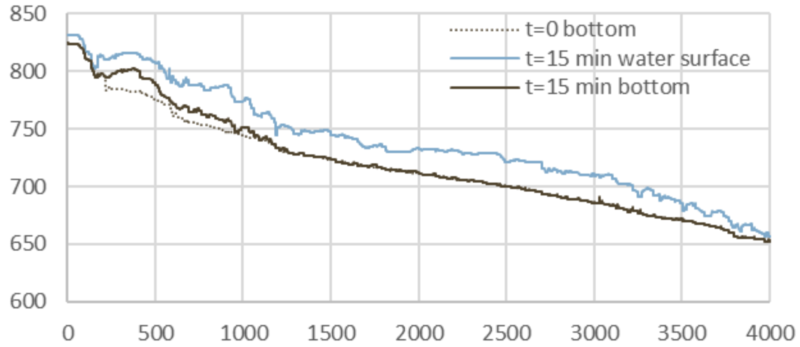
MPM factor = 5

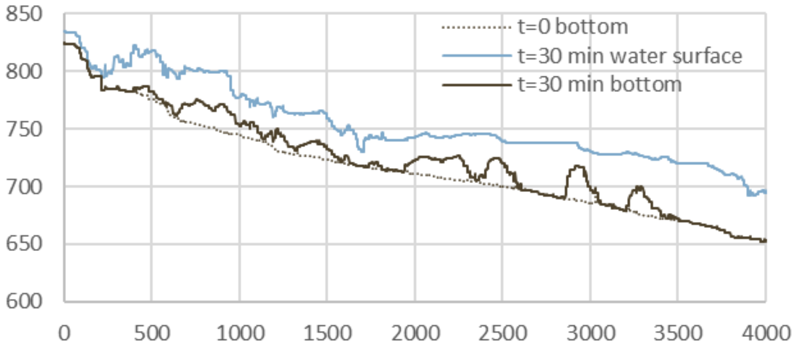


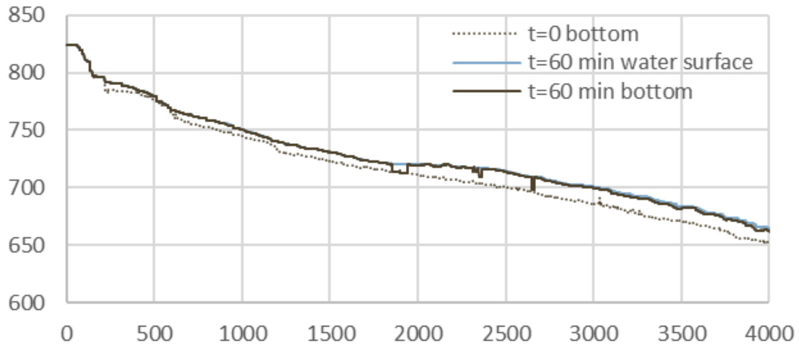




MPM factor = 10

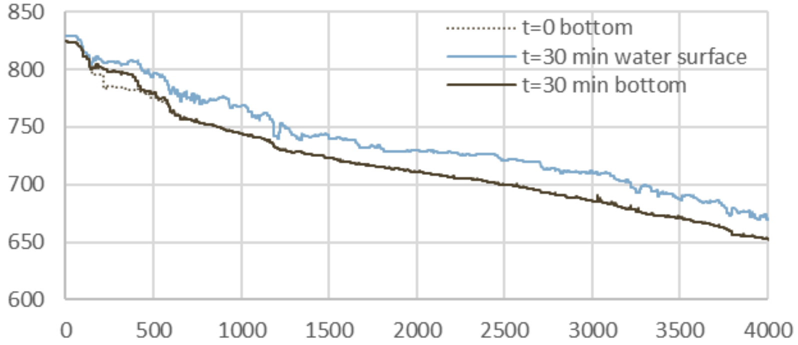


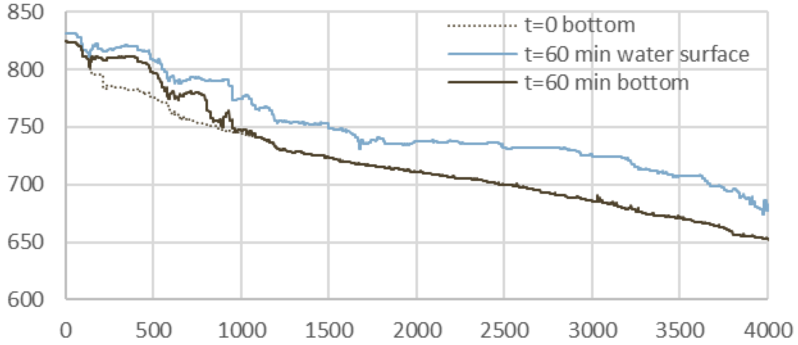


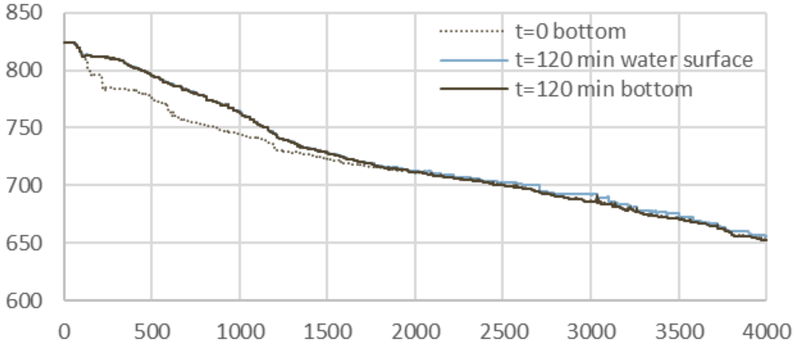


Results – **Bottom and water surface longitudinal profiles** – [Scenario 2]

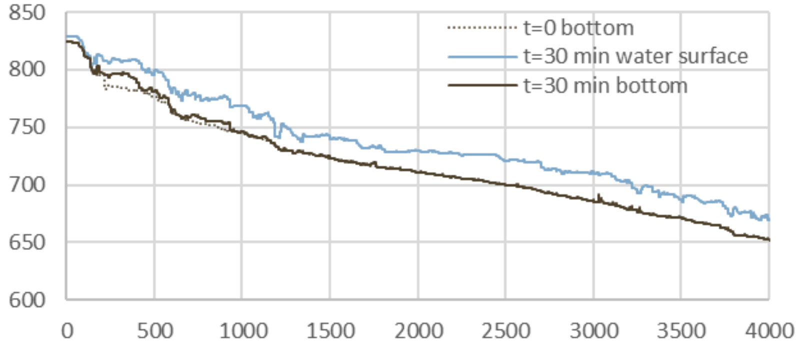
MPM factor = 1

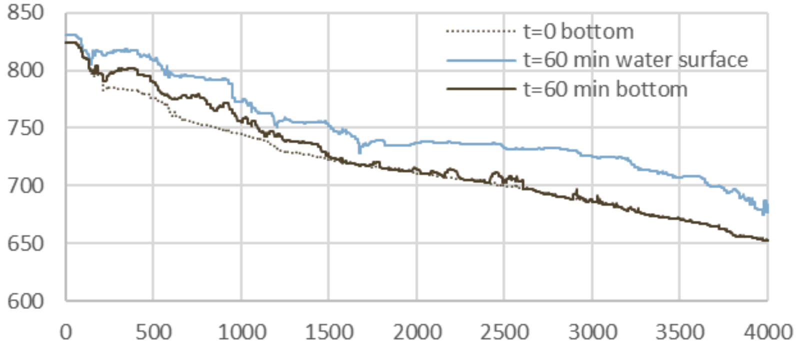


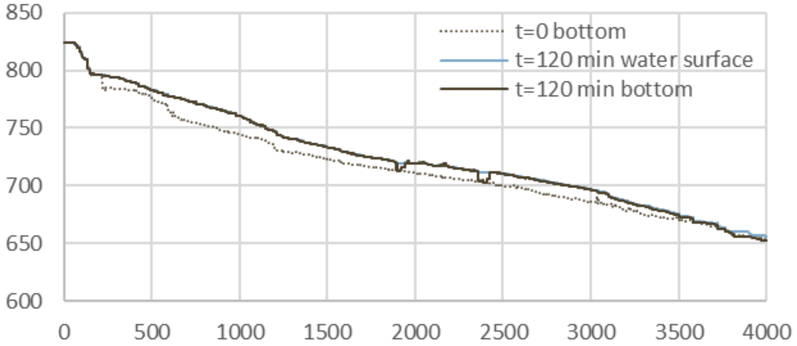




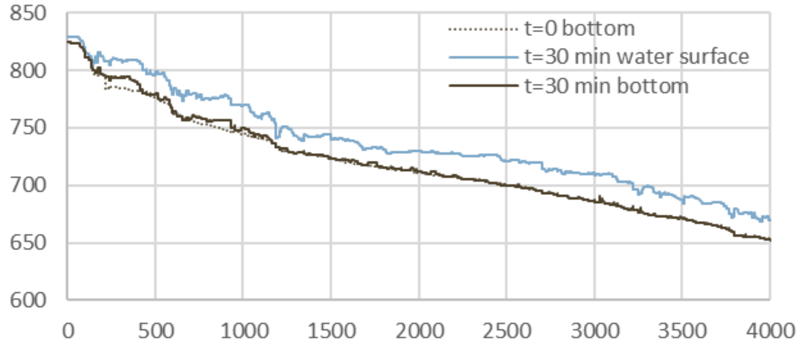
MPM factor = 5

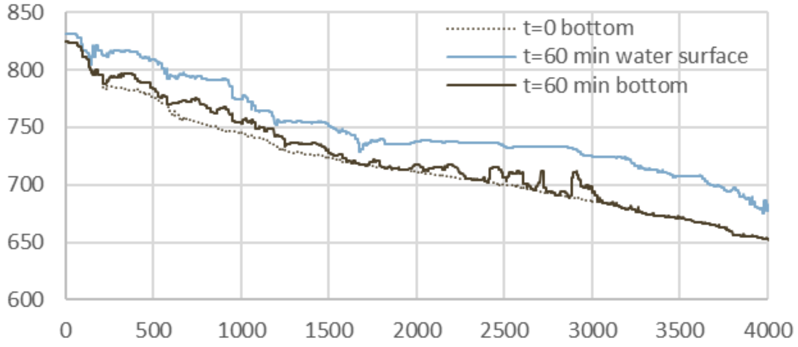


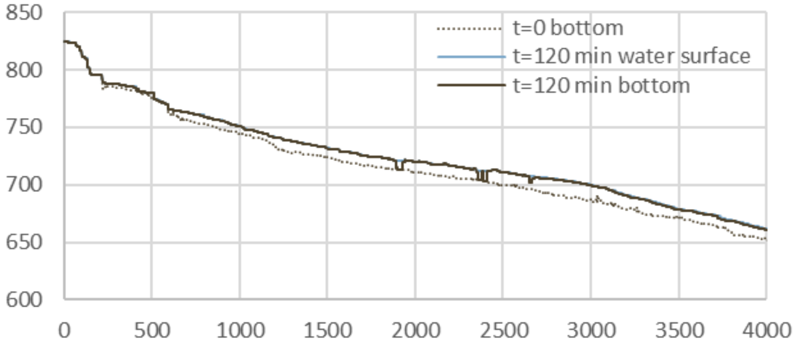




MPM factor = 10



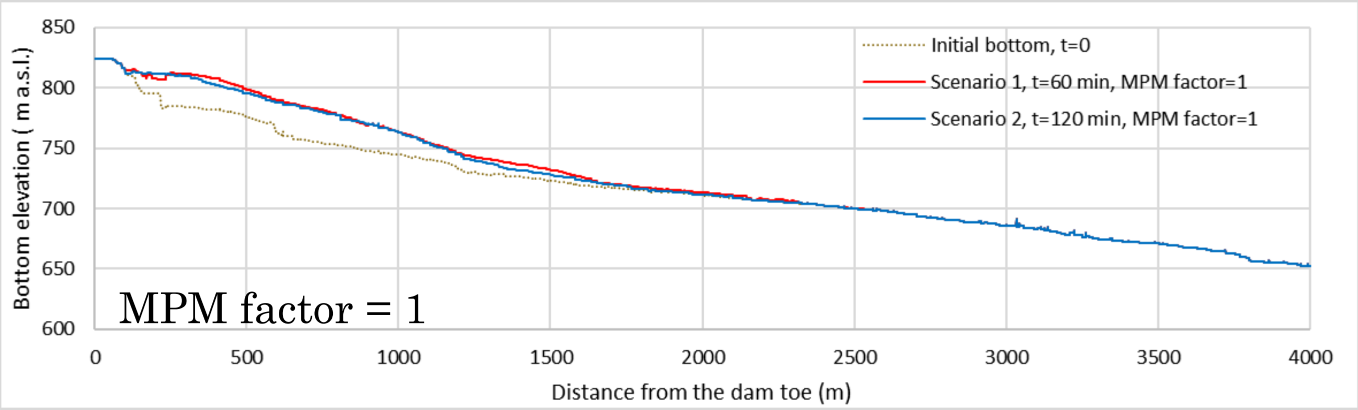


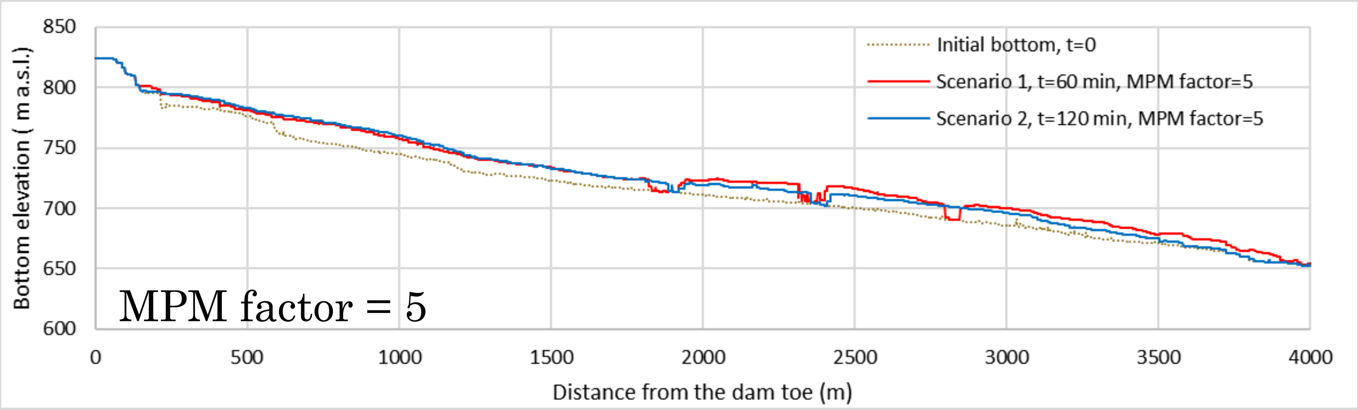


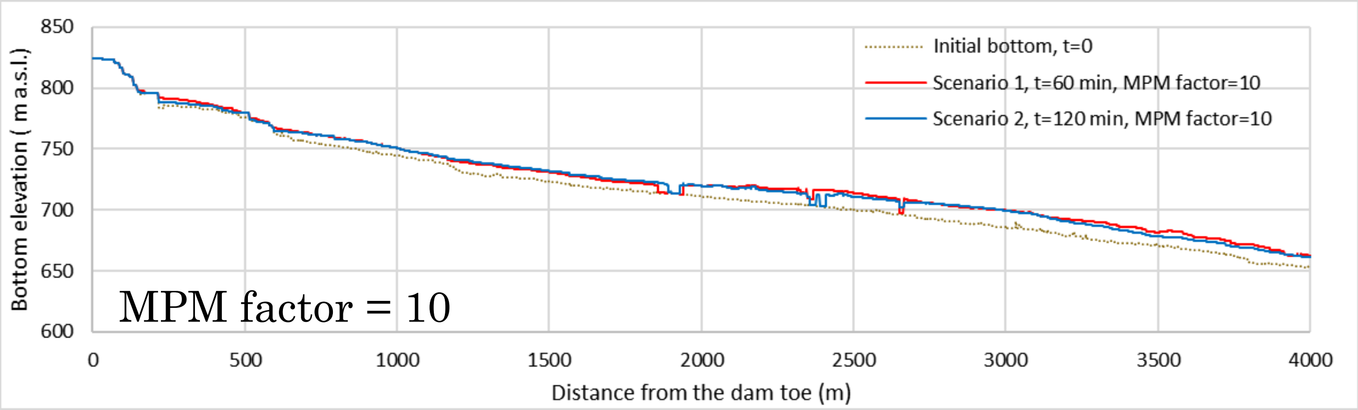
Results – Final bottom longitudinal profiles

Scenario 1 compared to **Scenario 2**

Results more sensitive to the MPM factor than to the breach shape scenario







Thank you for listening!

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