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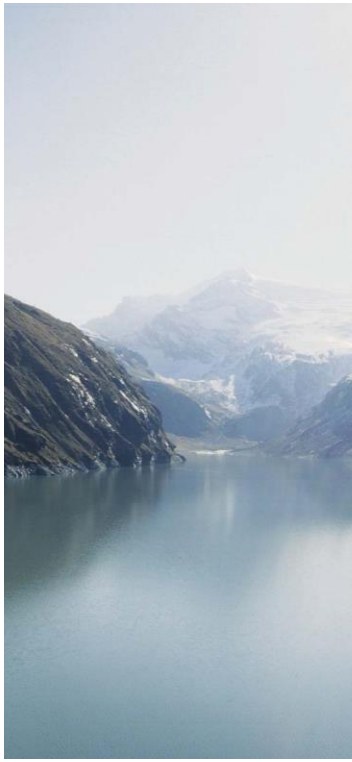
Numerical Modelling of Gravel Transport during Flushing Processes in an Alpine Reservoir



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Overview

- Introduction and motivation
- Sedimentation in reservoirs
- Sediment transport
- Reservoir flushing
- Numerical modeling

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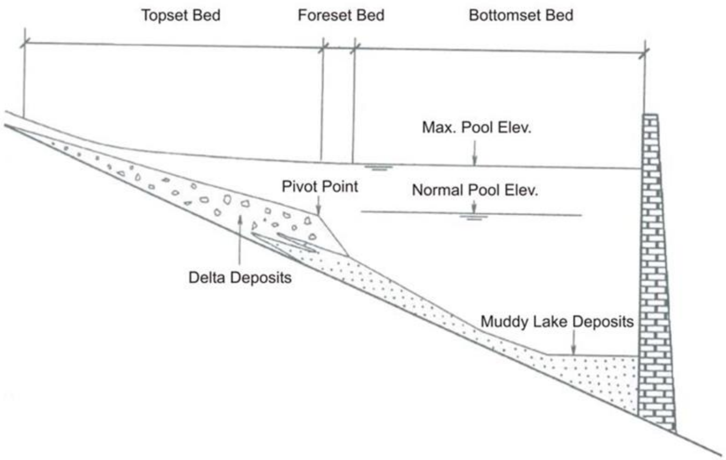
Introduction and Motivation

- Reservoir sedimentation is a problem in many Alpine reservoirs
- Alpine reservoirs of run-off river or diversion power plants have a small storage volume compared to the annual inflow and often a high sedimentation rate
- Literature focus on hydrological large reservoirs with large water depth at the dam
- Reservoir sedimentation can create problems regarding flood protection and reduces the downstream sediment supply



Source: Morris and Fan, 1998

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Aim of the Project

The aim was the analysis of the bed load transport processes during a flushing event in an Alpine reservoir.

The reservoir is approximately 1 km long with an initial storage volume of about 250.000 m^3 and an mean annual inflow of 60m3/s.

The annual bed load input is rather high, thus the remobilization of the sediment in the reservoir in case of flood events was investigated.

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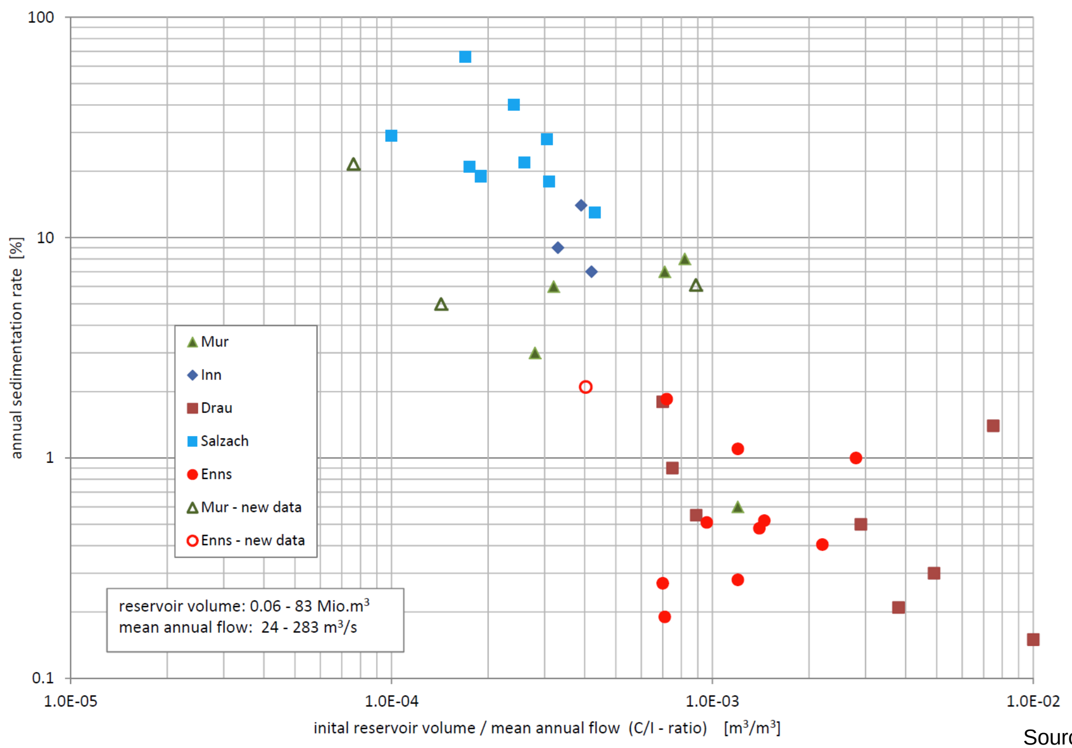
Sedimentation in Reservoirs

- Huge amount of the sediment load is trapped in reservoirs
- World‘s total sediment deposit is between 8 km^3 – 16 km^3 / year
- Loss of inital storage volume is between 0.5 and 1%

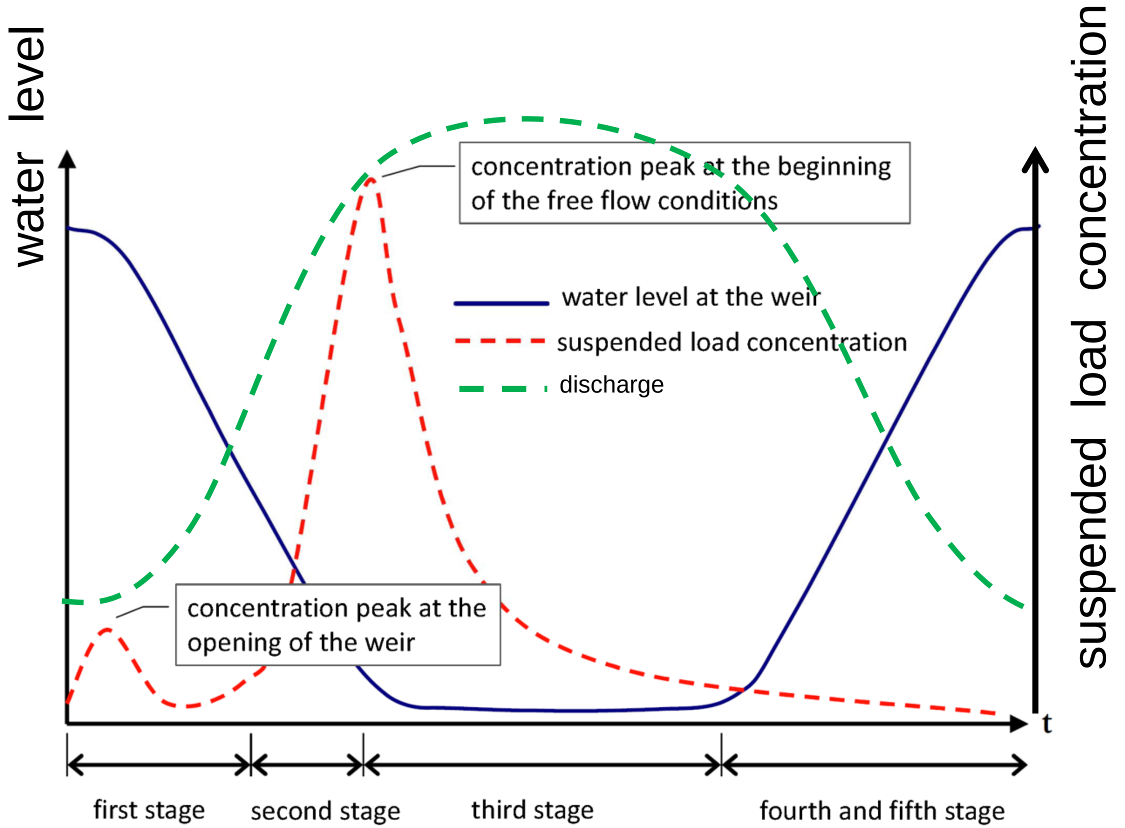


Source: Lempiere and Lafitte, 2006
White, 2001, Mahmod, 1987
Yoon, 1992, Bruk, 1996

Source: Harb, 2013

Reservoir Flushing

Usually lowering of the water level at higher discharges to increase the erosion processes in the reservoir



Source: Harb, 2013

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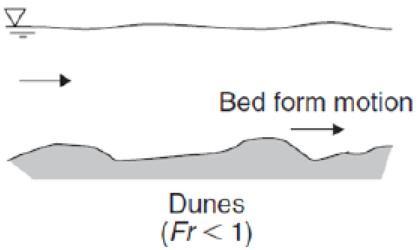
Sediment Transport

Several factors influence sediment transport processes, for example

- grain sizes
- bed forms
- effective grain shear stress
- armoring and pavement processes
- hiding/exposure effects
- graded and cohesive sediments



Source: Chanson, 2004,
Institute of Hydraulic Engineering, TU Graz

Numerical Modeling

CFD- Model: Telemac

$$\frac{\partial U_i}{\partial x_i} = 0$$ continuity equation

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = \frac{1}{\rho_w} \frac{\partial}{\partial x_j} (-P\delta_{ij} - \rho_w \overline{u_i u_j})$$ RANS equation

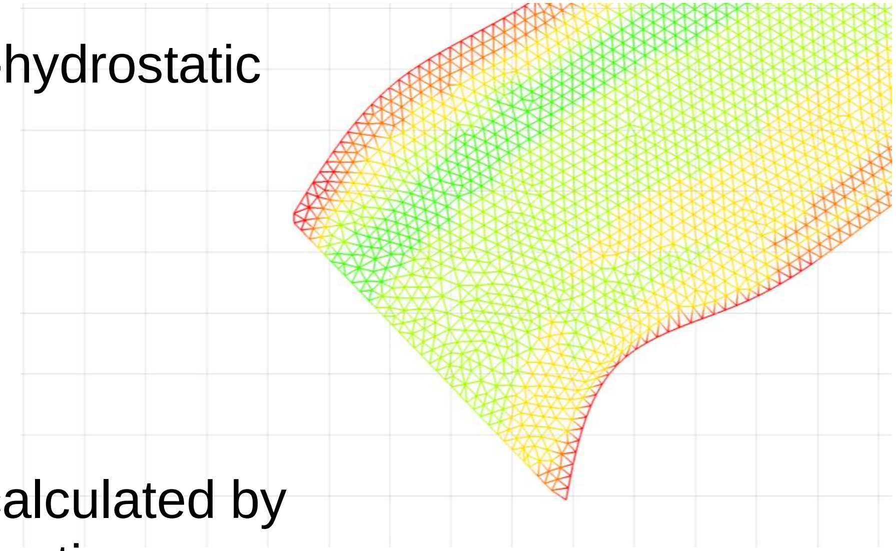
$$-\overline{u_i u_j} = \nu_t (\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}) - \frac{2}{3} k \delta_{ij}$$ Bussinesq approximation

$$k = \frac{1}{2} \overline{u_i u_i}$$ turbulent kinetic energy

v_t is the turbulent eddy viscosity and is calculated using a turbulence model

Telemac 2D und 3D

- Constant eddy viscosity, standard k-ε turbulence model, mixing length model
- Pressure with hydrostatic and non-hydrostatic pressure model
- Wall laws by Schlichting
- Unstructured, triangular grid



- Suspended sediment transport is calculated by solving the convection-diffusion equation
- Bed load is calculated using the formulas of van Rijn, Meyer-Peter-Müller and Engelund-Hansen

Source: Hervouet, EDF – R&D, 2012

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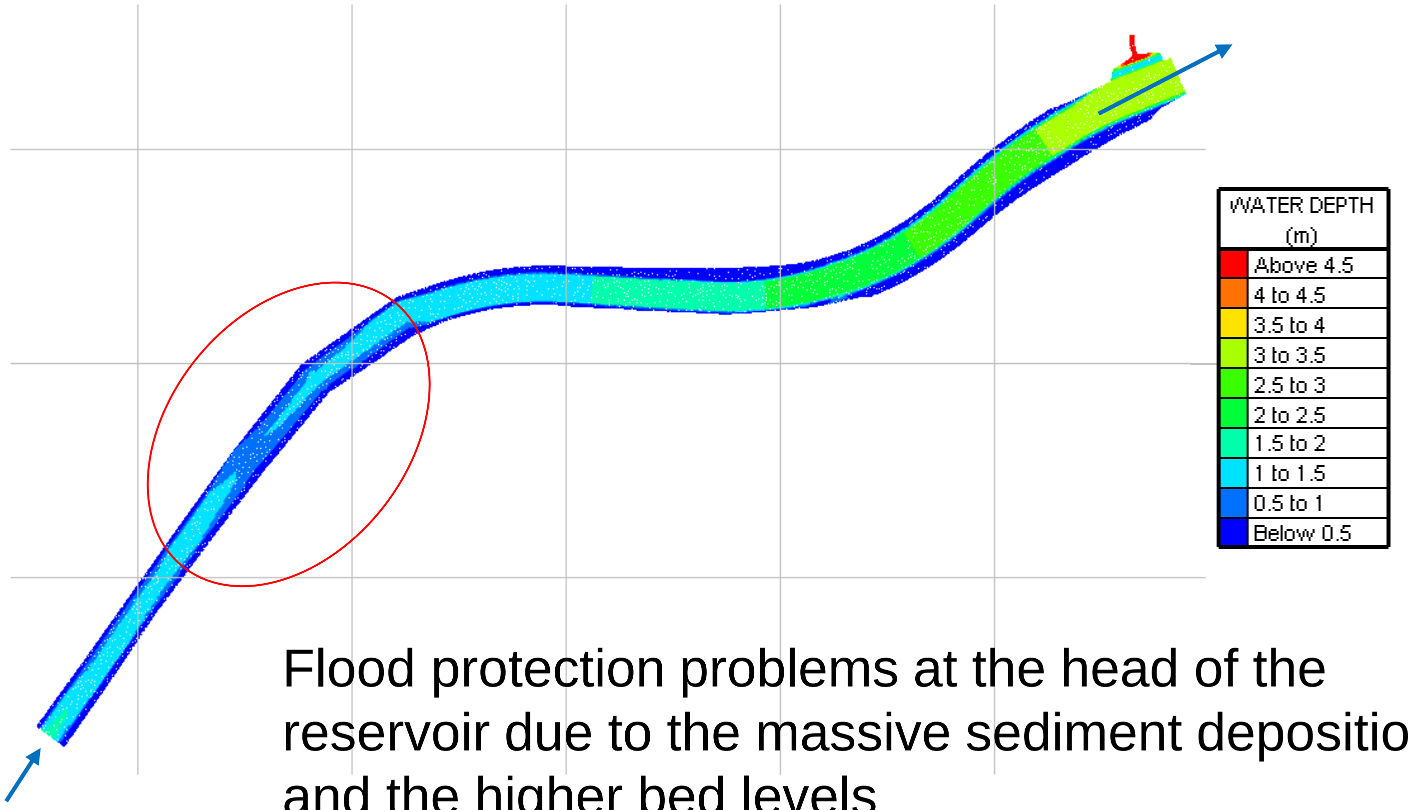
Problems - Case Study



Flood protection problems at the head of the reservoir due to the massive sediment depositions and the higher bed levels

Fishery do not like flushing events, but sediment connectivity is necessary, because fish need mobile gravel for spawning

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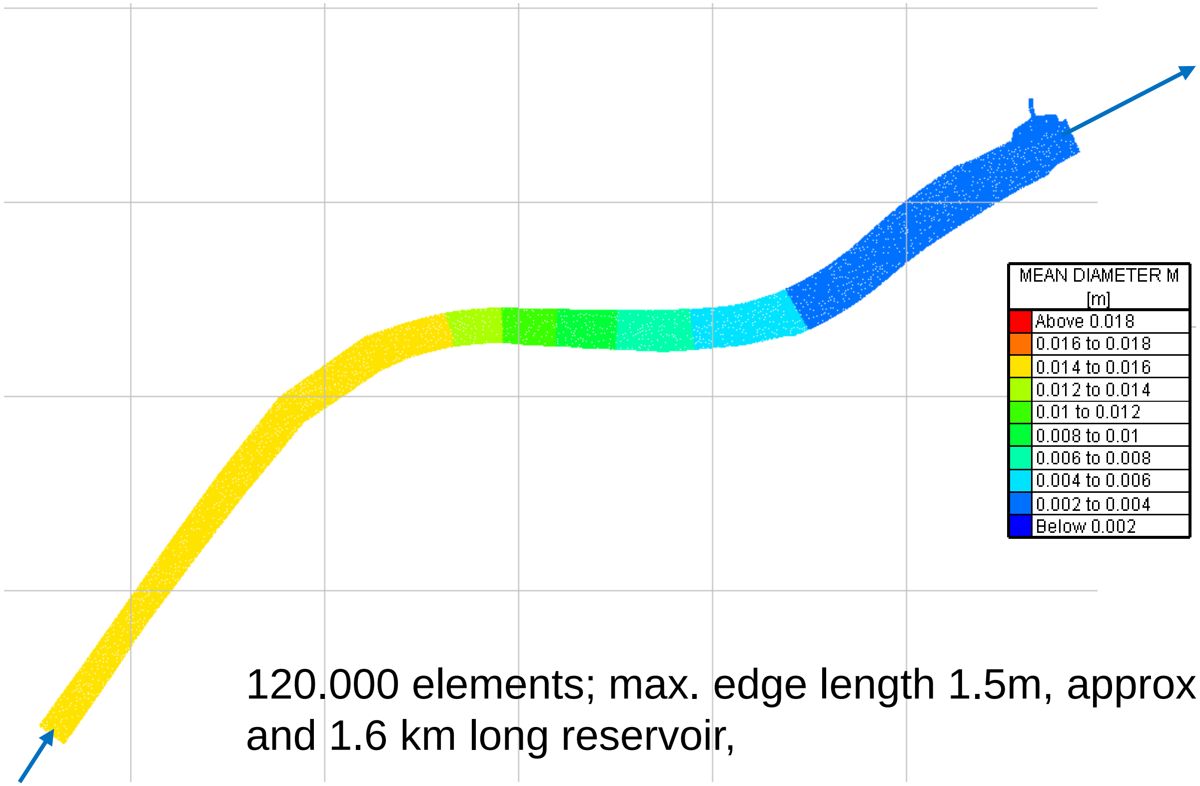
Numerics - Case Study



120.000 elements; max. edge length 1.5m, approx. 50m wide and 1.6 km long reservoir,

time step 1s, 1-year flood wave over 24h

7 sediment size classes

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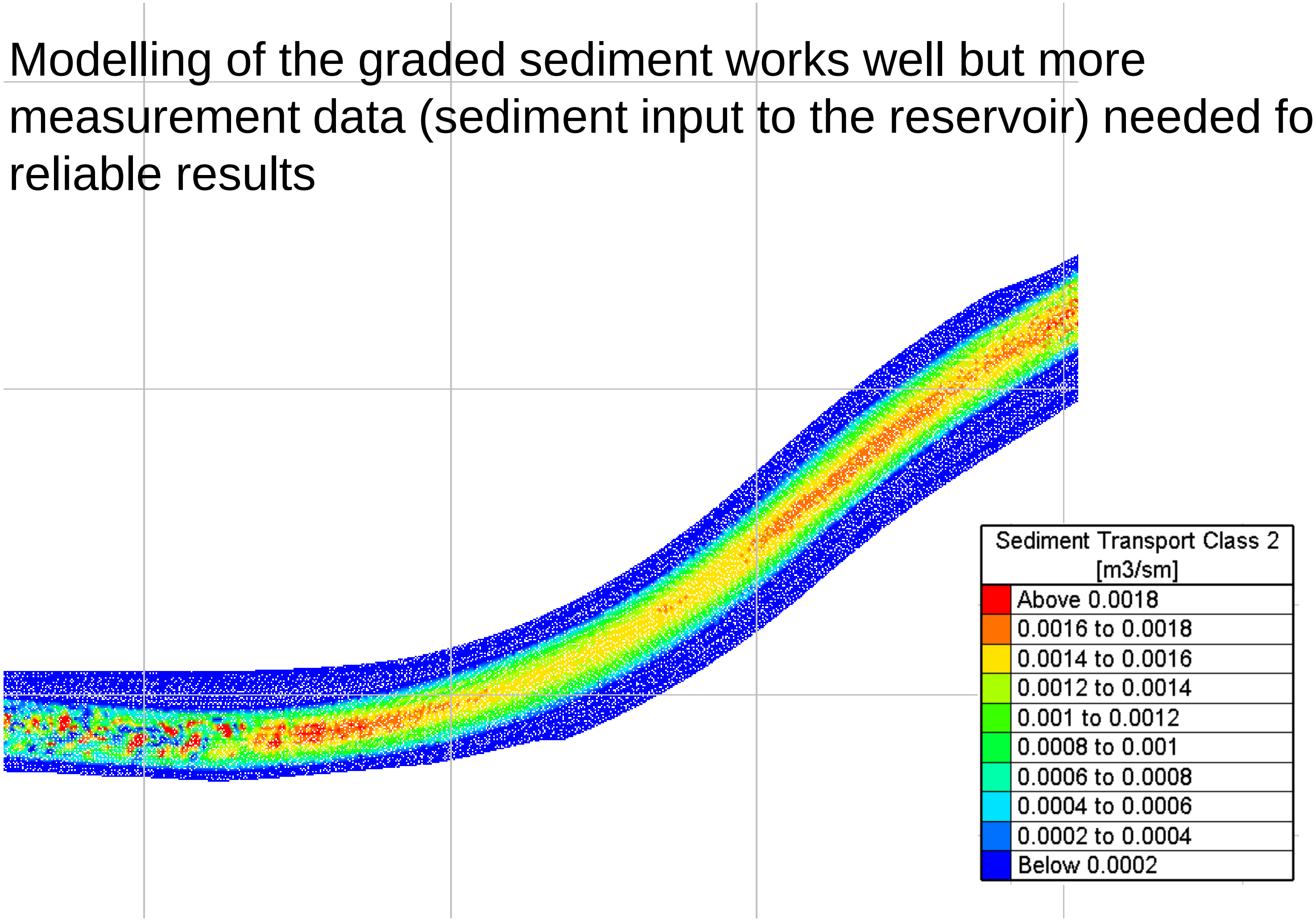
Results Numerics

Modelling of the graded sediment works well but more measurement data (sediment input to the reservoir) needed for reliable results



Sediment transport - Flushing

Calibration of the sediment transport und test of parameters

- Sediment transport formulae
- Skin friction correction
- Hiding/exposure factor
- Deviation formula
- Slope effect formula
- Number of layers (5 layers – 8 layers – 10 layers)
- Several non erodable bed configurations

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Conclusions

- Reservoir sedimentation is a problem in many Alpine reservoirs
- Reservoir flushing is one of the most common and most effective ways to remove sediment depositions
- Reservoir flushing and opposite interests of stakeholders may be difficult to manage
- Interval between two flushing events should not be too long to limit the sediment deposition in the reservoir
- Numerical simulations can reproduce sedimentation and erosion processes, but simulation of sediment transport processes can be challenging