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Preventing fine sediment settling with jet-like inflows and intake-like outflows in reservoirs

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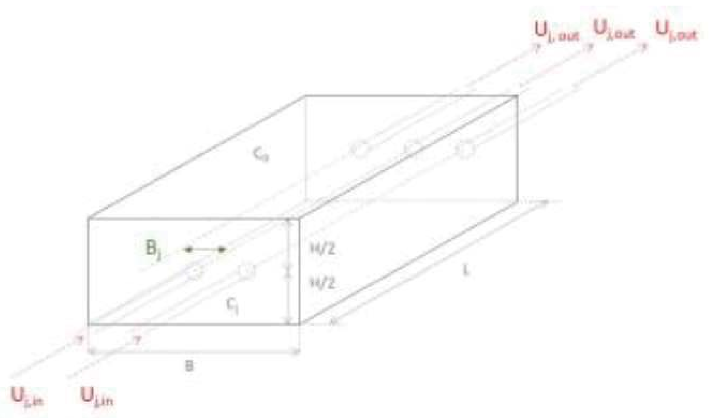
1. Indroduction and objectifs:

Reservoir sedimentation is one of the main issue in the operational management of dams. The resulting filling up of reservoirs has negative impacts on hydropower production, irrigation, flood protection and drinking water supply. New economical and sustainable solutions for sediment management in reservoirs have to be found. The latest concept suggests that the most efficient and sustainable measures consist to maintain sediment flows continuity from the tail to downstream of the reservoir. In pumped-storage plants, an adequate location and combination of inlets and outlets should generate a sediment routing through the reservoir avoiding sedimentation. This study aims to describe how the hydrodynamic of the reservoir induced by a jet-like inflow and an intake-like outflow influences the sedimentation rate of fine sediment contained within the reservoir. Moreover, the influence of various parameters, such as the relative position of the jets, the concentration of sediment entering the reservoir and the jet velocity, and their impact on sedimentation process and sediment deposition pattern are investigated. At this aim, numerical simulations were performed on a Computational Fluid Dynamic software (ANSYS-CFX). The results will allow to characterize the hydrodynamic in the reservoir and its influence on sedimentation process.

2. Methodology:

2.1. Parameters:



The sedimentation process depends on several parameters. The parameters analyzed in this study can be classified into three main groups: geometry, hydrodynamic and sediment. The deposition process of sediment can then be characterized as follow:

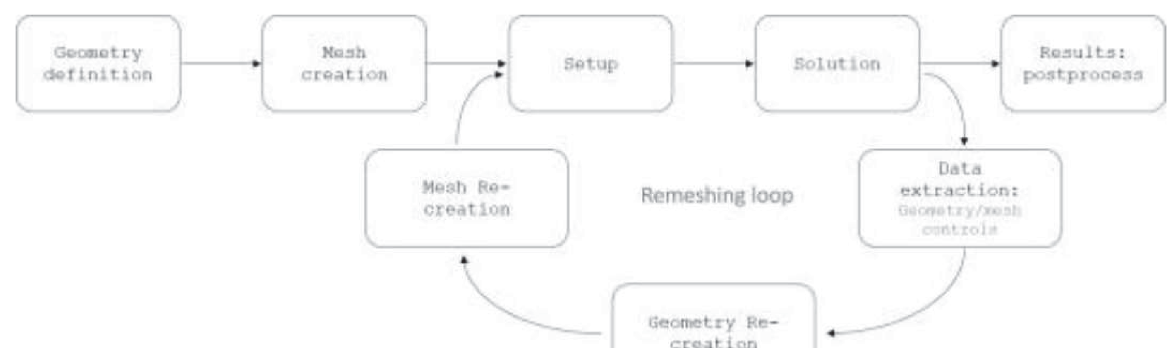
$$D = f(H, B, L, B_j, D_j, U_j, \rho_w, v_w, v_T, g, C_0, C_j, d_s, \rho_s)$$

An analysis on ten lakes situated in alpine regions allowed to obtain representative data on alpine reservoirs regarding geometry, hydrodynamic and sediment. Several of these parameters are considered constant in this study. The analysis was based on three parameters: the relative distance between the jet axis B_j, the sediment concentration entering the reservoir C_j and the jet velocity U_j. The sedimentation is then described as follow:

$$\longrightarrow \quad \frac{D}{C_0} = f\left(\frac{B_j}{B}, Fr_j, Re_j, \frac{v_T}{v_w}, \frac{w_{sm}}{U_j}, \frac{C_j}{C_0}\right)$$

2.2. Numerical model:

Numerical simulations were performed on ANSYS-CFX v.18. An adaptative time step was used, between 0.5 and 20 [s]. The mesh type applied was a fine-curvature mesh with triangular elements, refined with edge sizings and by means of inflation layers at the bottom.



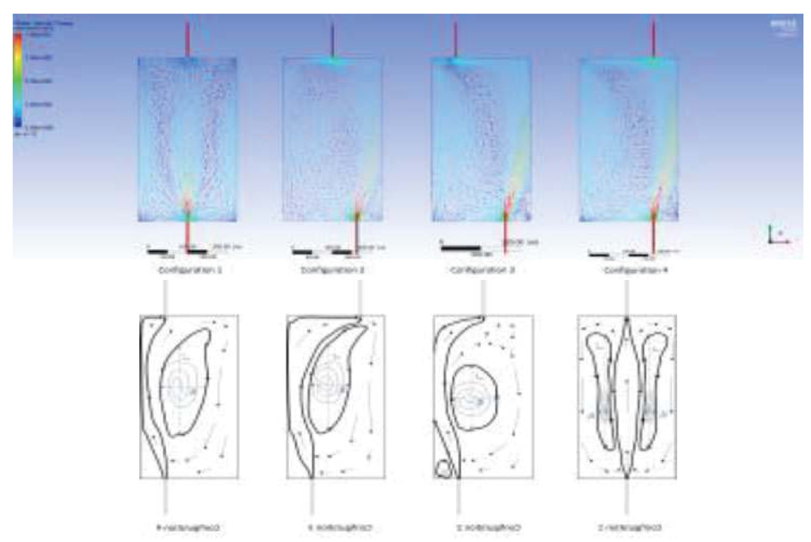
The chosen turbulence model for this study was the two-equations $K-\epsilon$, where K stands for the turbulence kinetic energy and ϵ stands for the turbulence kinetic energy dissipation rate.

To simulate the behavior of suspended sediments in the reservoir, *an Eulerian multiphase model* was chosen. More specifically, the *Particle Model* was used. In this model, the dispersed phase particles are assumed to be spherical. Finally, the *Schiller Naumann drag force* equation was used.

In total, 12 transient simulations were conducted to study the effects of the hydrodynamic induced by jet-like inflows and intake-like outflows and its influence on sedimentation in reservoirs.

3. Results:

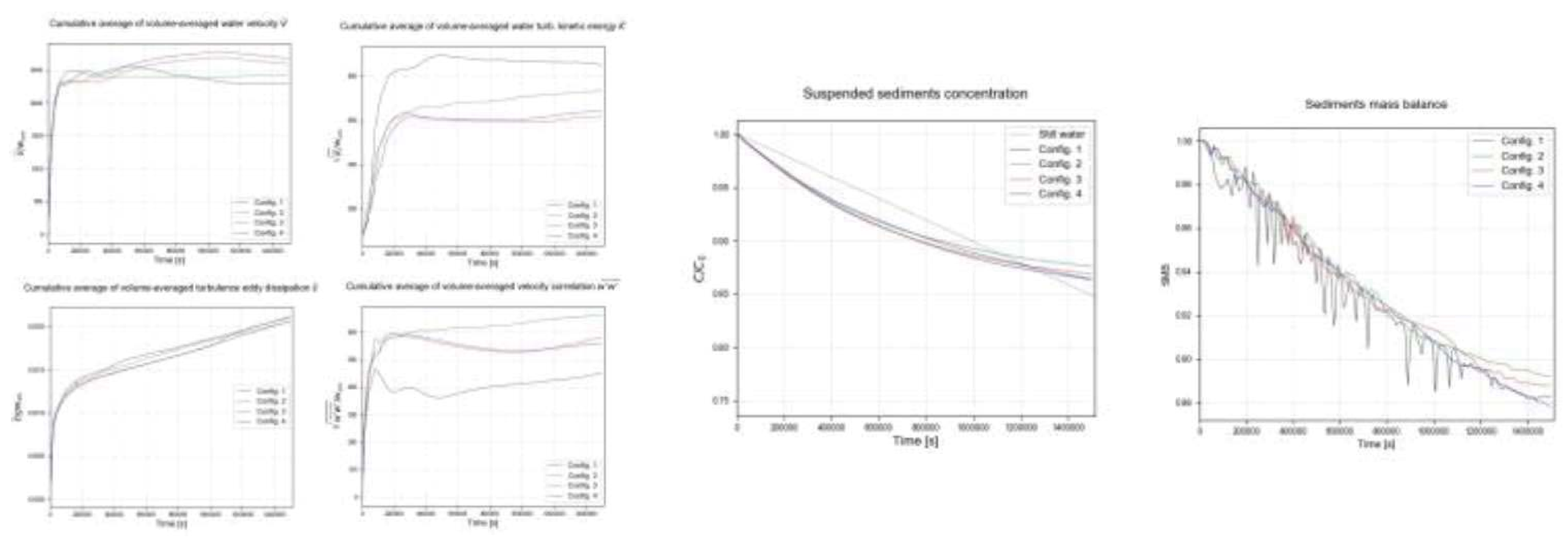
3.1. Clear water simulations:



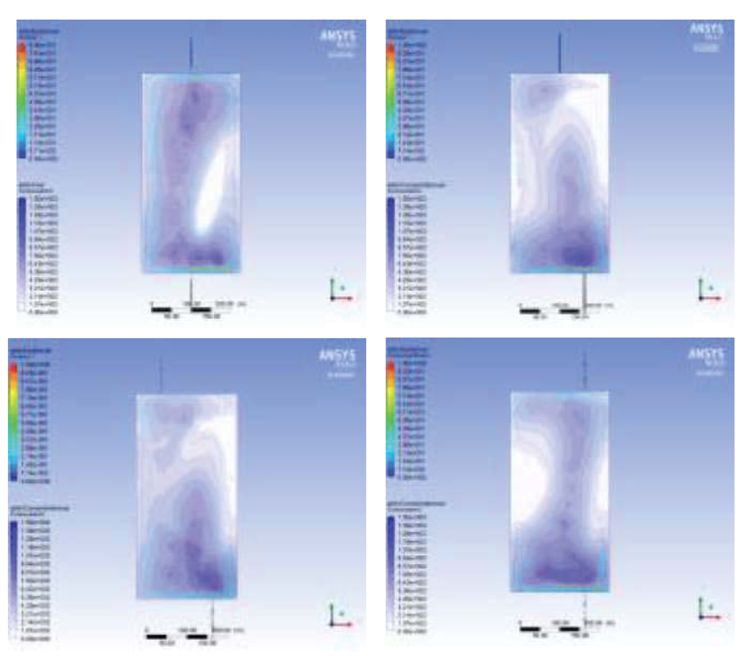
The time to reach steady state is 1'500'000 [s]. The relative position of the jets has a major impact on the hydrodynamic of the reservoir and on its flow pattern. Specifically on flow pattern, recirculation cells appear, with various size and shape, depending on the configuration.

3.2. Multiphase simulations

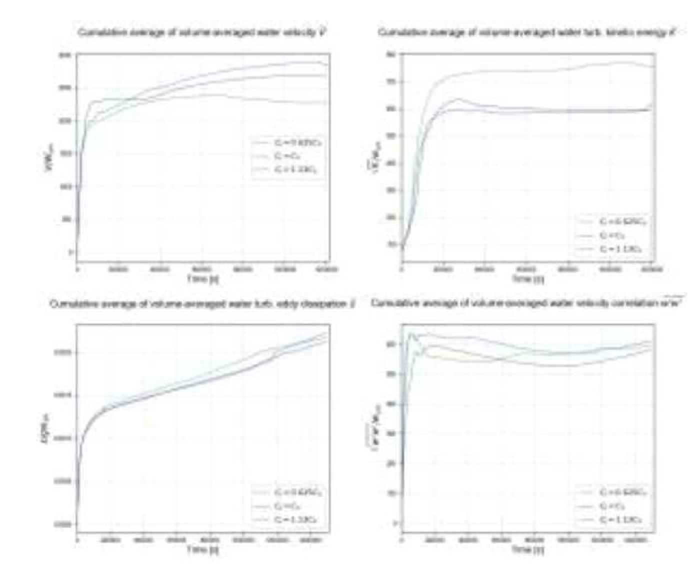
3.2.1. Influence of the configuration:



The presence of suspended sediment influences the hydrodynamic of the reservoir. The results show that the configuration 2, with $RS = \frac{B_j}{B} = 0.25$, has the lowest sedimentation (i.e. the highest suspended concentration) and the highest sediment mass balance (i.e. sediment routing through the reservoir. Moreover, the turbulence kinetic energy dissipation rate ϵ influences the sediment deposition pattern. The highest local deposition was observed in the vicinity of the jet, where a high energy dissipation occurs due to the velocity difference between the jet and the reservoir ($Re_j \gg Re_0$).

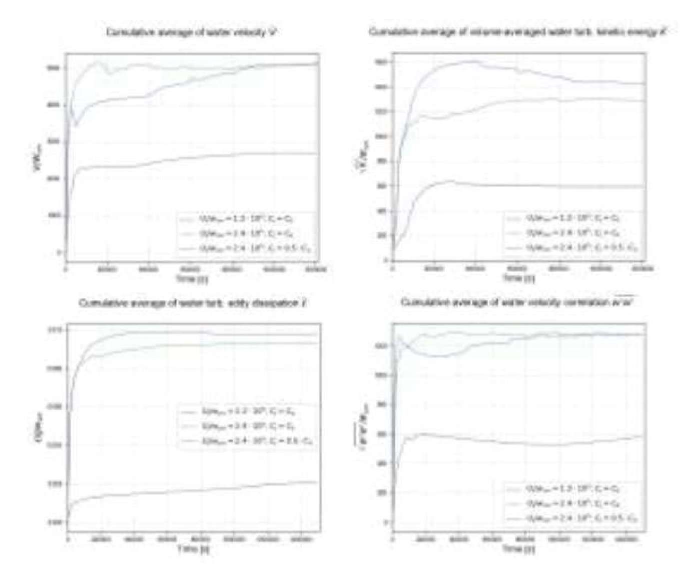


3.2.2. Influence of the concentration:



The variation of suspended sediment concentration has an impact on the hydrodynamic of the reservoir. Indeed, the drag effect of sediments on water increases the velocity in the reservoir, which means that for higher sediment concentration, higher velocities are observed. The total energy in the reservoir is smaller, as it occurs at the interphase between water and sediment.

3.2.3. Influence of the velocity:



The jet velocity has an influence on the hydrodynamic of the reservoir. Higher jet velocity induces higher turbulence kinetic energy in the reservoir. Moreover, it was seen that the influence of the jet velocity overtakes the influence of the sediment concentration entering the reservoir.

4. Conclusions:

The influence of the jets relative position was investigated. It was shown that the configuration has a clear impact on the hydrodynamic, with different behavior regarding the water velocity and the turbulence parameters for each configuration. Furthermore, it has an impact on the suspended sediment concentration, the sediment mass balance and the sediment deposition pattern. Indeed, the deposition pattern was found to correlate to the turbulence kinetic energy dissipation rate ϵ.

Furthermore, the sediment concentration entering the reservoir also influences the hydrodynamic of the reservoir. It was shown that the highest sediment concentration induced the highest water velocities in the reservoir, the highest turbulence kinetic energy dissipation rate and the smallest turbulence kinetic energy, due to energy dissipation at the interphase between sediment and water.

Finally, it was shown that the jet velocity has an influence on the hydrodynamic of the reservoir. Indeed, as expected, highest velocities induce highest velocities in the reservoir, highest turbulence kinetic energy and highest turbulence kinetic energy dissipation rate. Moreover, the influence of the jet sediment concentration at high water velocity is overtaken by the influence of the jet velocity.