Chapter 73
Numerical Simulations of an Innovative Water Stirring Device for Fine Sediment Release: The Case Study of the Future Trift Reservoir

Azin Amini, Anass Chraibi, and Pedro Manso

Abstract Reservoir sedimentation and consequently lack of storage volume and perturbation of the operation of intakes and bottom outlet is a key challenge affecting both hydropower production as well as dam safety and flood management. In the framework of a peer-reviewed research project [8] an innovative countermeasure, called SEDMIX, was proposed allowing to keep in suspension or re-suspend the fine particles near the power water intakes, thanks to an optimized arrangement of four water jets producing an upward whirling flow like produced by a mixer. With such a system, the suspended particles can be conveyed downstream at acceptable rates through the power waterways during the normal operation of the hydropower plant. Although experimental studies have shown the very promising efficiency of such a device in simple cases and by numerical simulations in a laboratory reservoir, SEDMIX performance has not been investigated yet in a real-life reservoir under prototype conditions.

The aim of this study is therefore, to analyze the performance of a real-sized SEDMIX operating in the future Trift reservoir via numerical analyses. This study allows to validate or to improve SEDMIX optimal configuration experimentally determined.

The numerical simulations are performed for different positions and heights for the SEDMIX device. The performance of SEDMIX in each position has been evaluated and tested for different jet discharges. The analysis of the numerical simulation results shows that the presence of SEDMIX does create a vortex flow pattern and sediment movement upward. The sediment volume fraction in the higher layers of the reservoir increases and consequently the evacuated volume of fin sediments increases for simulation using the SEDMIX device comparing those without the device.

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73.1 Introduction

When a new dam is built, the continuity of sediment transport is interrupted [1]. Moreover, low flow velocities upstream the dam are favorable conditions for sediment deposition in the reservoir. Sediments are therefore trapped. The reservoir silts up which results in a loss of storage capacity. An example is shown in Fig. 73.1.

In Alpine reservoirs, turbidity currents are the main process for the deposit of sediments [2]. Turbidity currents mainly occur during floods and are characterized by a higher density than the ambient water in the reservoir due to the high sediment concentration. This density difference results in the plunge of the turbidity current to the bottom of the reservoir which then follows the thalweg towards the deepest regions with a velocity dependent on the slope.

Reservoir sedimentation threatens the sustainability of hydropower plants due to loss of useful storage volume as well as shortage in flood control [3]. On the other hand, clogging of bottom outlets may cause safety problems for dams [4–6]. The sustainable design of storage reservoirs requires dams to be hydraulically pervious as much as possible to sediment fluxes. Many technical solutions exist for sediment management in reservoirs although with very different effectiveness, efficiency and environmental impacts. De Cesare et al. [7] presented some innovative measures to cope with fine sediment deposition problem in reservoirs.

Fig. 73.1 Sedimentation of Sufers reservoir, Grisons, Switzerland

In the framework of a peer-reviewed research project an innovative countermeasure, called SEDMIX, was proposed allowing to keep in suspension or re-suspend the fine particles near the power water intakes, thanks to an optimized arrangement of four water jets producing an upward whirling flow like produced by a mixer [8]. It was shown that the SEDMIX device is not only efficient in evacuating sediments from the reservoir but it is also economically attractive and environmental friendly [9, 10]. With such a system, the suspended particles can be conveyed downstream at acceptable rates through the power waterways during the normal operation of the hydropower plant. Although experimental studies have shown the very promising efficiency of such a device in simple cases and by numerical simulations in a reservoir, SEDMIX performance has not been investigated yet in a real-life reservoir under prototype conditions.

73.2 Background Study

The current study is based on a solution elaborated by the Laboratory of Hydraulic Constructions (LCH) which allows to set or keep in motion fine sediments [4].

The disposition of four jets in a circle on a horizontal plane was studied in a 2 m wide, 4 m long and 1.5 m deep rectangular tank (Fig. 73.2) both experimentally and numerically by Jenzer-Althaus [8]. These jets create a rotational current which plays the role of a radial or axial mixer depending on various characteristics of the jets and the geometry of the tank. When the rotational flow creates an upward motion, the circular jet arrangement can be beneficial for sediment release as it enables the mixing of sediment and can even lead to resuspension in certain cases. The sediment in suspension in front of the water intakes into the power plant can then be sent downstream, thus increasing the sediment release.

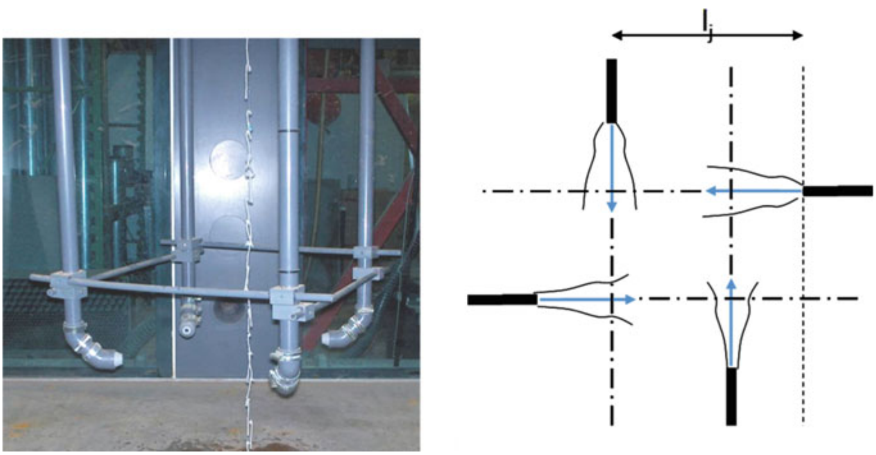

Fig. 73.2 Experimental set-up of SEDMIX physical model [8]

The efficiency of such a system is assessed by the Evacuated Sediment Ratio, ESR, defined as the ratio between the total evacuated sediment weight, $W_{s,out}$, and the initially supplied sediment weight, $W_{s,in}$:

$$ESR = W_{s,out}/W_{s,in} \tag{73.1}$$

The best jet configuration enabled to reach in the laboratory tank an evacuation efficiency of 73% after four hours against only 37% without jets in the same conditions.

This new device was therefore found to be effective, sustainable but also environmentally friendly as the sediments can be released during the normal operation of the hydropower station. In other terms, this system would allow to come closer to the natural conditions downstream without the dam regarding the sediment transfer to downstream. Moreover, the water in neighboring catchments can be transferred in order to provide the energy for the jets thanks to the drop height. This innovative device could meet the different requirements for an optimal management system which justifies the current interest in this innovative technology. Finally, recommendations on optimal jet geometry and characteristics are provided for upscaling the results to a real- life case.

Later on, in the framework of Swiss Competence Center for Energy Research (SCCER) some numerical studies were carried out to evaluate the efficiency of such a device in real size reservoirs [11].

73.3 Up-Scaling and Preliminary Design of the Sedmix Device

73.3.1 Trift Reservoir

Taking advantage of the withdrawal of some glaciers, several new dams will eventually be constructed in Switzerland in the coming years as a part of the 2050 energy strategy. The Trift dam, located in Berner Oberlands in Switzerland, is one of these new projects (Fig. 73.3). Reservoir sedimentation is however one of the main challenges for long-term sustainable operation of dam reservoirs that requires mitigation measures. Settling of suspended sediment may reduce reservoir live storage available for hydropower production and hamper operation of the bottom outlets.

73.3.2 Up-Scaling the SEDMIX Device

To guaranty a similar efficiency as in the physical model, the scaling factor, l_L, is considered to design a real-sized SEDMIX. The up-scaling should satisfy two conditions:

Fig. 73.3 Withdrawal of Trift glacier during the last century and an eventual dam project in coming years

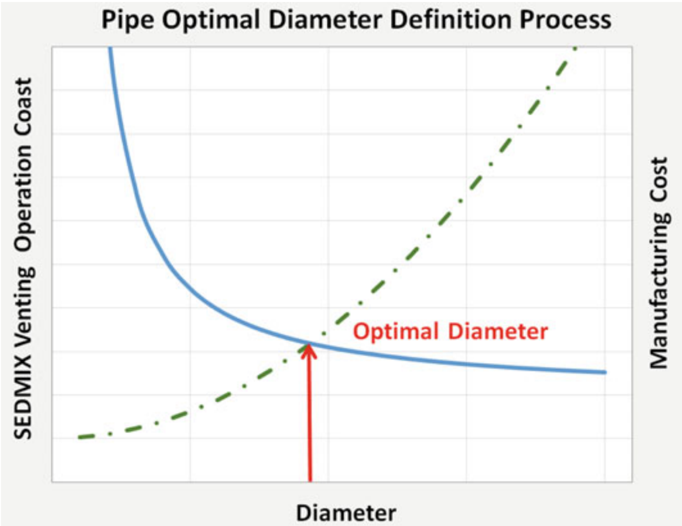

Fig. 73.4 Optimal diameter of the SEDMIX tubes

- Froude similarity, expressed by a relationship between the jet discharges used in the test and those of the real case.
- The circulation velocity compared to the settling velocity which should at least be the same as in test conditions.

To design the device in the case of the Trift reservoir, the optimal values found empirically by Jenzer-Althaus [8] are used. These are normalized by the reservoir width. The upscaling relies on Froude similarity which leads to the definition of the geometrical scale factor, l_L, as

$$l_L = l_Q^{2/5} \tag{2}$$

with l_Q referring to the discharge ratio between the real case and the experimental prototype. For the presented prototype, a total jet discharge of 5 m^3/s is considered. This leads to a scaling factor of $l_L = 38$.

73.3.3 Preliminary Design of SEDMIX

The design of SEDMIX prototype has been performed to fulfil the following objectives:

- Minimise head losses and consequently the required power during operation.
- Minimize fabrication and installation costs, especially for the manifold pipe diameter (Fig. 73.4).

As such, an optimal diameter of 100 cm is obtained.

In order to install the device, the multi-nozzle manifold frame is kept in place using a floating platform at water surface elevation and a ballast at the reservoirs' bottom. The manifold is mobile along the vertical chains which allows to locate it at its optimal position, derived from numerical simulations, and even change the position during the same operation (Fig. 73.5).

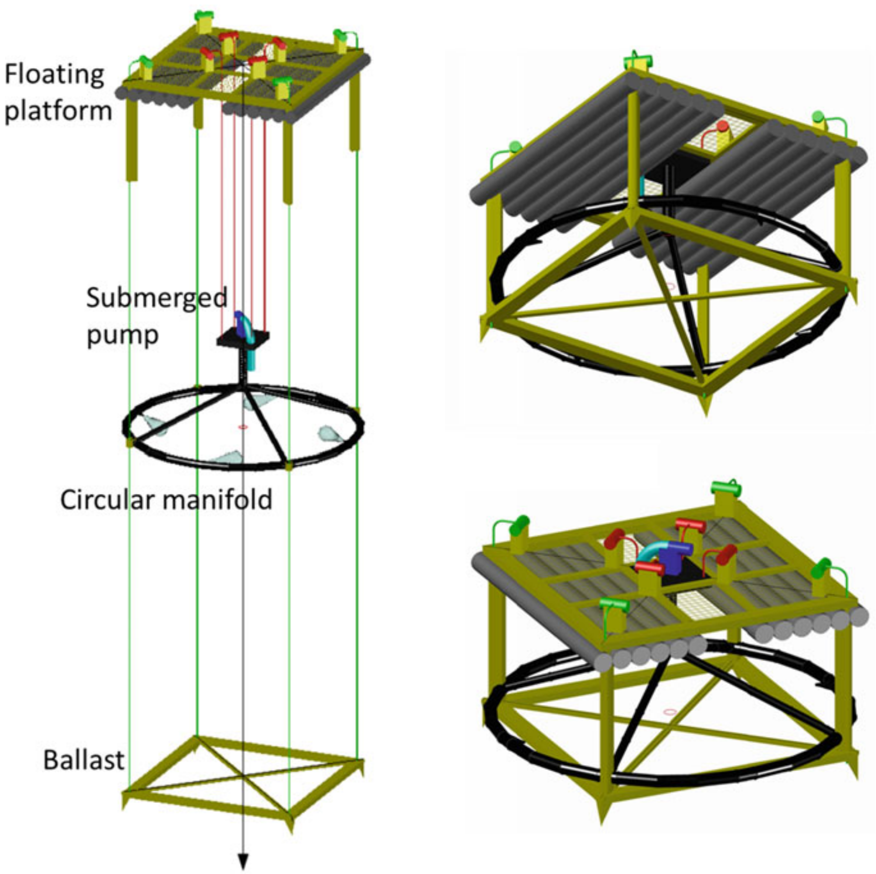

Fig. 73.5 SEDMIX device installed in a reservoir with help of a floating platform and a ballast

The device can be assembled and installed in a given dam reservoir then dissembled and moved to another. All the system components can be displaced by moving the floating platform which is anchored onshore.

73.4 Numerical Simulations

73.4.1 Geometry Modeling of the SEDMIX Device in the Trift Reservoir

The ANSYS-CFX (v 18.0) three-dimensional finite volume model for multiphase flows is used to simulate the SEDMIX device in the Trift reservoir (Fig. 73.6).

In a preliminary phase, over 30 trial simulations have been done with/without sediments both in steady state and transient flow conditions. Once the model parameters were adjusted, the SEDMIX device was implemented into the model. The device location is presented Fig. 73.7. It is placed close to the dam at a distance of about 100 m from the water intake. The results are then compared to the reference case, i.e. identical conditions but without jets.

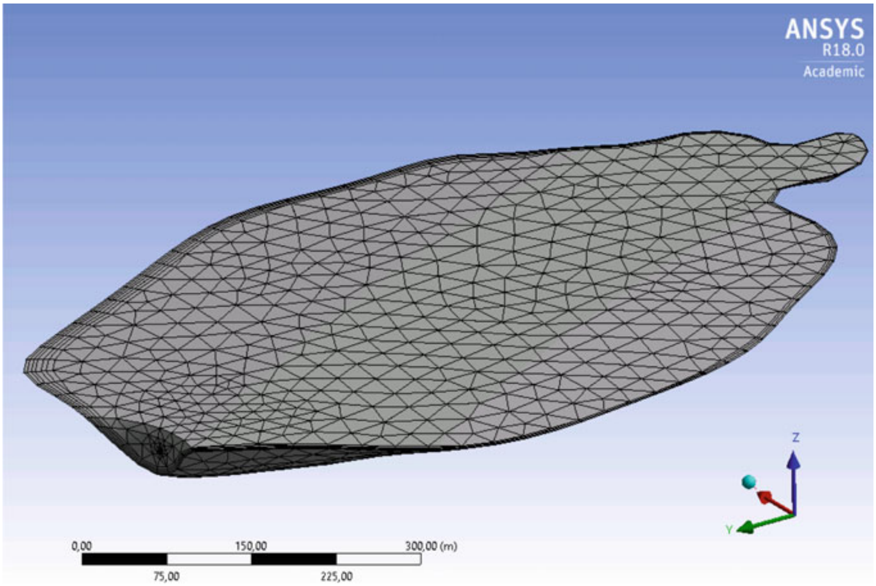

Fig. 73.6 Numerical model of the Trift reservoir

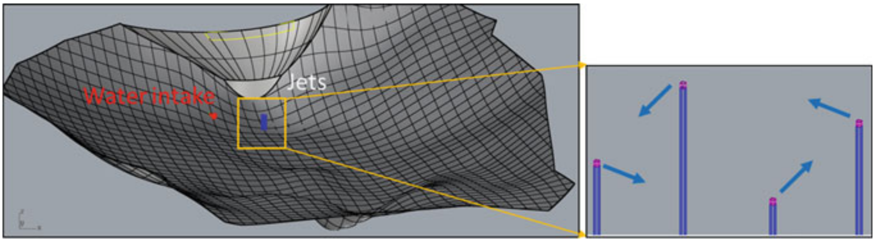

Fig. 73.7 SEDMIX jets location (in front of the power water intakes)

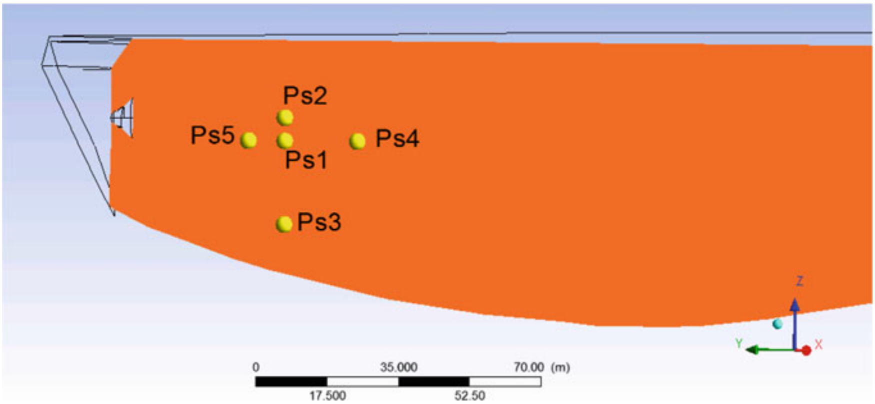

Fig. 73.8 SEDMIX tested positions

73.4.2 Numerical Model Set-Up

The numerical simulations were performed for five different positions of SEDMIX device (Fig. 73.8). Steady state simulations as well as transient simulations were computed for the same boundary conditions, namely, the mass flow rate for the inlet ($M_{in} = 21002.7$ kg/s), the relative pressure for the outlet ($P_{outlet} = 0$ Pa) and 4 Source points (SEDMIX jets) with specific discharge and directions +1 source point with negative discharge (submerged SEDMIX supplier pump) (Fig. 73.5). All the simulations are multiphase since they include sediment ($D_s = 0.1$ mm, $\rho_s = 2600$ kg/m^3, $C_s = 0.7$ g/L). The chosen turbulence model was the $k - \varepsilon$ model combined with inhomogeneous Eulerian model. The performance of SEDMIX in each position has been evaluated and tested for different jet discharges.

73.4.2.1 Boundary Condition

For all simulations the bottom of the reservoir, the front of the dam, the sides of the outlet, the front of the dam, and the sides of the outlet are set to no slip. For the inlet a value of flow rate of $Q_{in} = 21$ m^3/s has been chosen. At outlet boundary a 0 relative

Table 73.1 Boundary conditions of the numerical model

Boundary	Boundary condition
Reservoir bottom	No slip wall, roughness: 0.1 m
Dam	No slip wall, roughness: 0.1 m
Top	No slip wall, smooth surface
Inlet	Qin = 21 m^3/s
Outlet	$P_{outlet} = P_{Hydrostatic}$

pressure is defined ($P_{outlet} = P_{Hydrostatic}$). Such configuration gives more flexility to the software and allows to avoids convergence issues. Table 73.1 summarizes the boundary conditions:

73.5 Results and Analysis

To evaluate the efficiency of the operation of the jets, the latter are launched to run for approximately 30 h to overcome the stagnation inertia of the reservoir, in parallel with the flood event. Figure 73.9 illustrates the flow pattern in the reservoir for the simulation with SEDMIX after 30 h. By that time the flood discharge is very low and the flow pattern is mainly influenced by the operation of the jets. The figure highlights the role of SEDMIX device in producing rotational flow in the

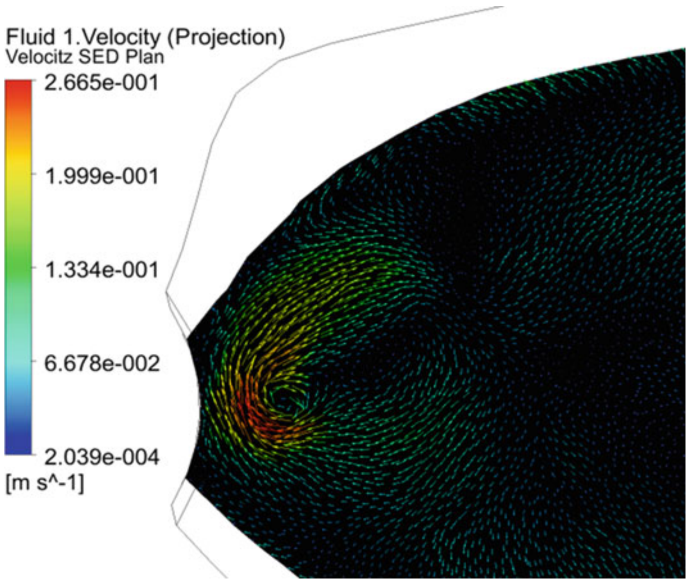

Fig. 73.9 Rotational flow generated by SEDMIX

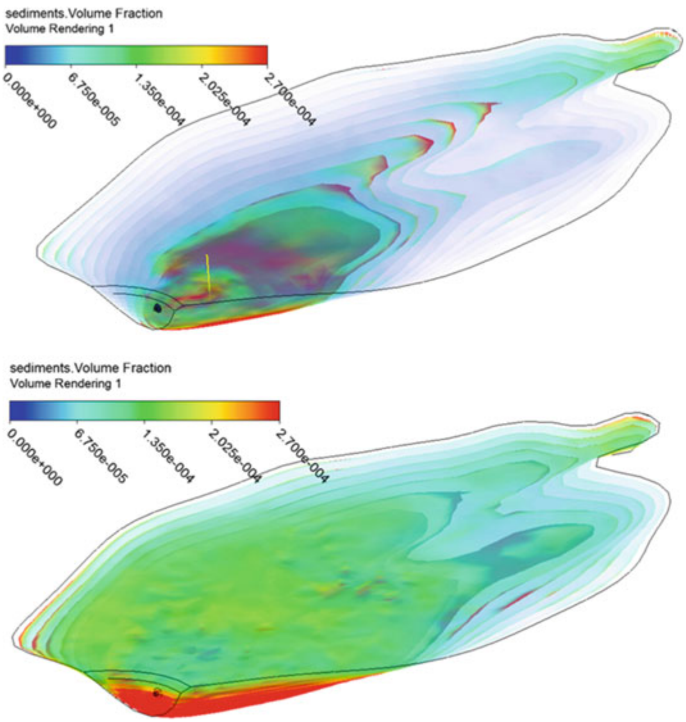

Fig. 73.10 Sediment volume fraction; top: before SEDMIX functions; Bottom: 30 h after launching SEDMIX

reservoir, namely near the water intake and the dam, that may keep fine sediments in suspension. It is shown that the presence of SEDMIX does create a vortex flow pattern and sediment movement upward. It can also be seen that the sediment volume fraction in the higher layouts of the reservoir increases with time (Fig. 73.10).

The evacuated sediment ratio (defined in Eq. 1) is equal to 14% for the reference case without SEDMIX jets. However, the presence of SEDMIX device increase the evacuation rate up to about 70%. This result brings out the efficiency of SEDMIX device in increasing the sediment release to the downstream.

The transient simulation with SEDMIX does reach a Steady State S_i (at a $t \simeq 3\tau_j$ with $\tau_j = V/\Sigma Q_j$) (Figs. 73.11). The reached steady state S_i as presented in Fig. 73.11 has been used as initial conditions for all the performed steady state models.

The optimal configuration is corresponding to the jets discharge of 5 m^3/s. In addition, the maximum performance is obtained when SIDMIX is placed in front of the water intake as shown in Fig. 73.12.

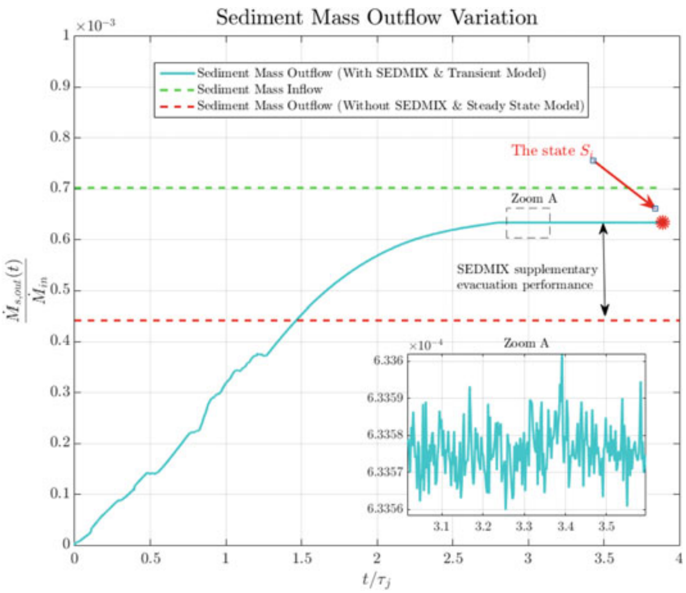

Fig. 73.11 Sediment Mass Outflow: Steady and transient models, with and without SEDMIX

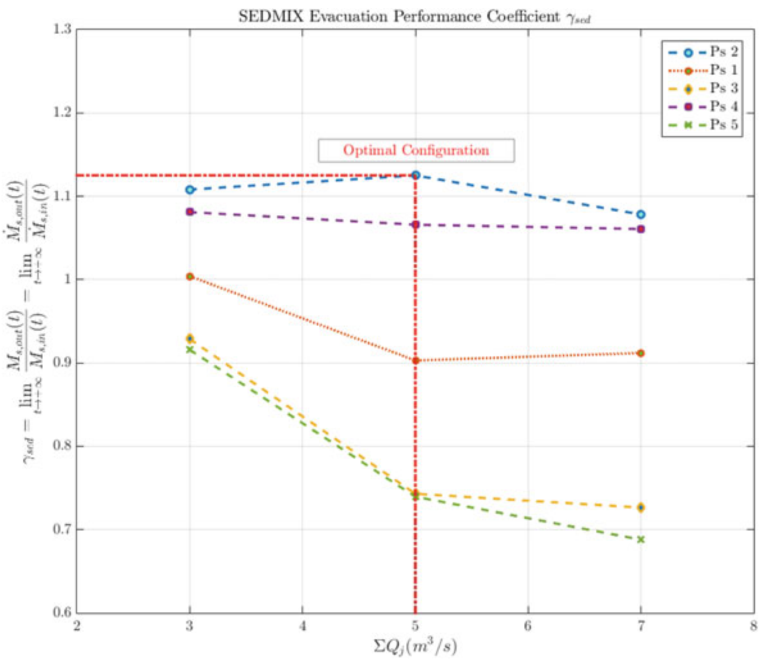

Fig. 73.12 SEDMIX performance in each position

73.6 Conclusions

This study shows high contribution of SEDMIX jets in keeping fine sediments in suspension and evacuation through the water intakes during normal operation of the hydropower plant. Numerical simulations have been successfully launched. However, due to the complex morphology of the reservoir, the hydrodynamic behavior needs further investigation.

The optimal discharge corresponds, as expected, to the SEDMIX geometric upscaling discharge (5 m^3/s) which was proposed by Jenzer-Althaus [8]. When SEDMIX device is located in front of the water intake, the fine sediment evacuation rate is higher than other places.

References

1. Schleiss AJ, Oehy C (2002) Verlandung von Stauseen und Nachhaltigkeit. Wasser, Energie, Luft - Eau, Energie, Air 94:227–334
2. De Cesare G (1998) Alluvionnement des retenues par courants de turbidité. Ph.D. thesis, Ecole Polytechnique Fédérale de Lausanne, Switzerland
3. Schleiss AJ, Franca MJ, Juez C, De Cesare G (2016) Reservoir sedimentation. J Hydraul Res 54:595–614
4. Gabl R, Gems B, Birkner F, Hofer B, Aufleger M (2018) Adaptation of an existing intake structure caused by increased sediment level. Water 10:1066
5. Carrillo JM, García JT, Castillo LG (2018) Experimental and numerical modelling of bottom intake racks with circular bars. Water 10:605
6. Castillo LG, García JT, Carrillo JM (2017) Influence of rack slope and approaching conditions in bottom intake systems. Water 9:65
7. De Cesare G, Manso P, Chamoun S, Guillén Ludeña S, Amini A, Schleiss A (2018) Innovative methods to release fine sediments from seasonal reservoirs. In: Proceedings of the 26th international congress on large dams, ICOLD 2018, pp 612–624
8. Jenzer Althaus J (2011) Sediment evacuation from reservoirs through intakes by jet induced flow. Ph.D. thesis, Ecole Polytechnique Fédérale de Lausanne, Switzerland
9. Jenzer Althaus JMI, De Cesare G, Schleiss AJ (2015) Sediment evacuation from reservoirs through intakes by jet-induced flow. J Hydraul Eng 141:04014078
10. Jenzer Althaus J, De Cesare G, Schleiss AJ (2016) Release of suspension particles from a prismatic tank by multiple jet arrangements. Chem Eng Sci 144:153–164
11. Amini A, Manso P, Venuleo S, Lindsay N, Leuipi C, Schleiss A (2017) Computational hydraulic modelling of fine sediment stirring and evacuation through the power waterways at the Trift reservoir. In: Hydro 2017 proceedings, Seville, Spain, 9–11 October 2017