Fah

Tourtemagne

Sediment management options for Alpine reservoirs : current practices and innovative solutions

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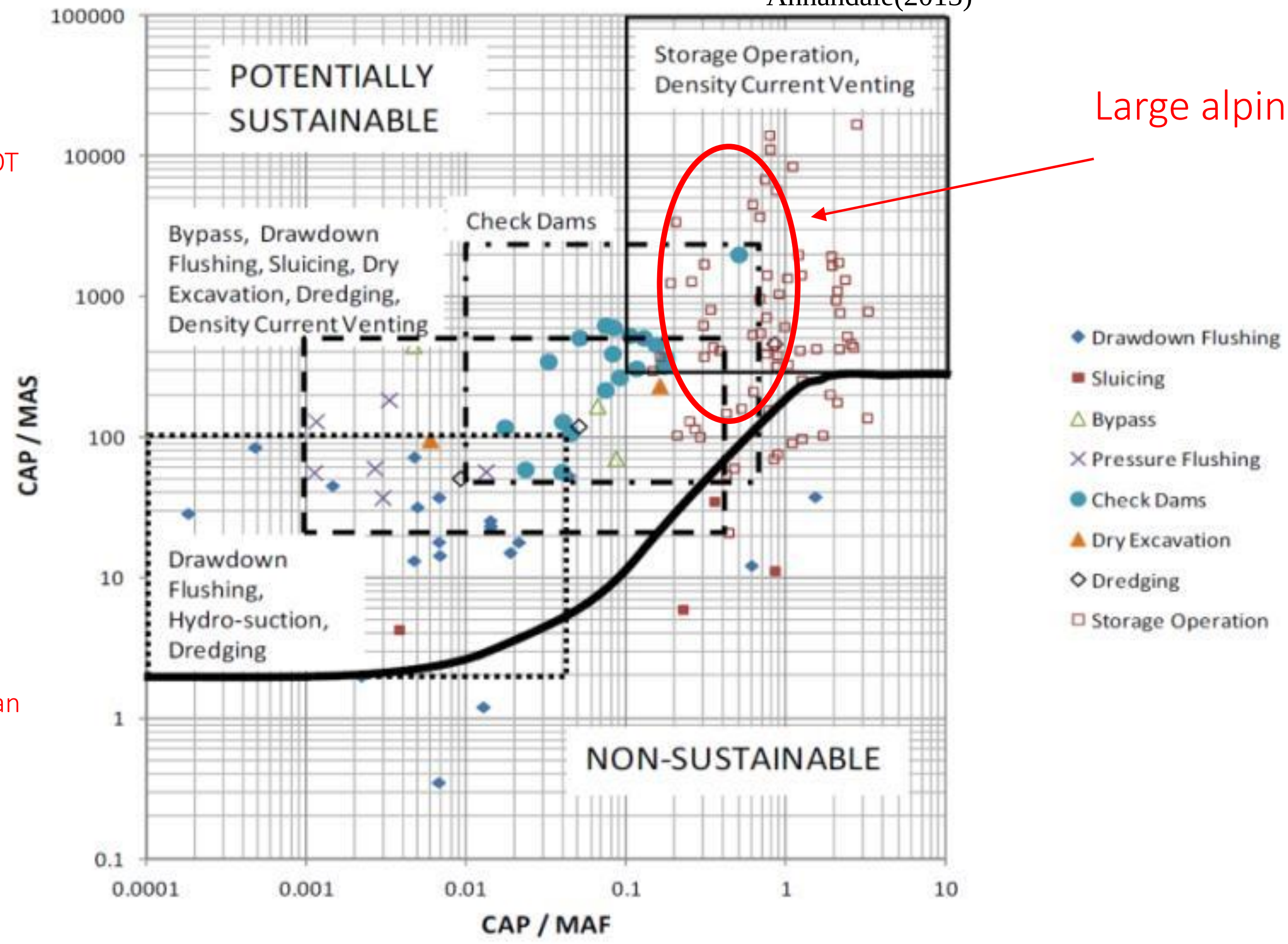
State-of-the-art

Annandale(2013)

Sedimentation is NOT a major issue

Sedimentation IS a an operational issue



Large alpine reservoirs

Intra-monthly reservoirs → Pluriannual reservoirs

Example: flushing efficiency

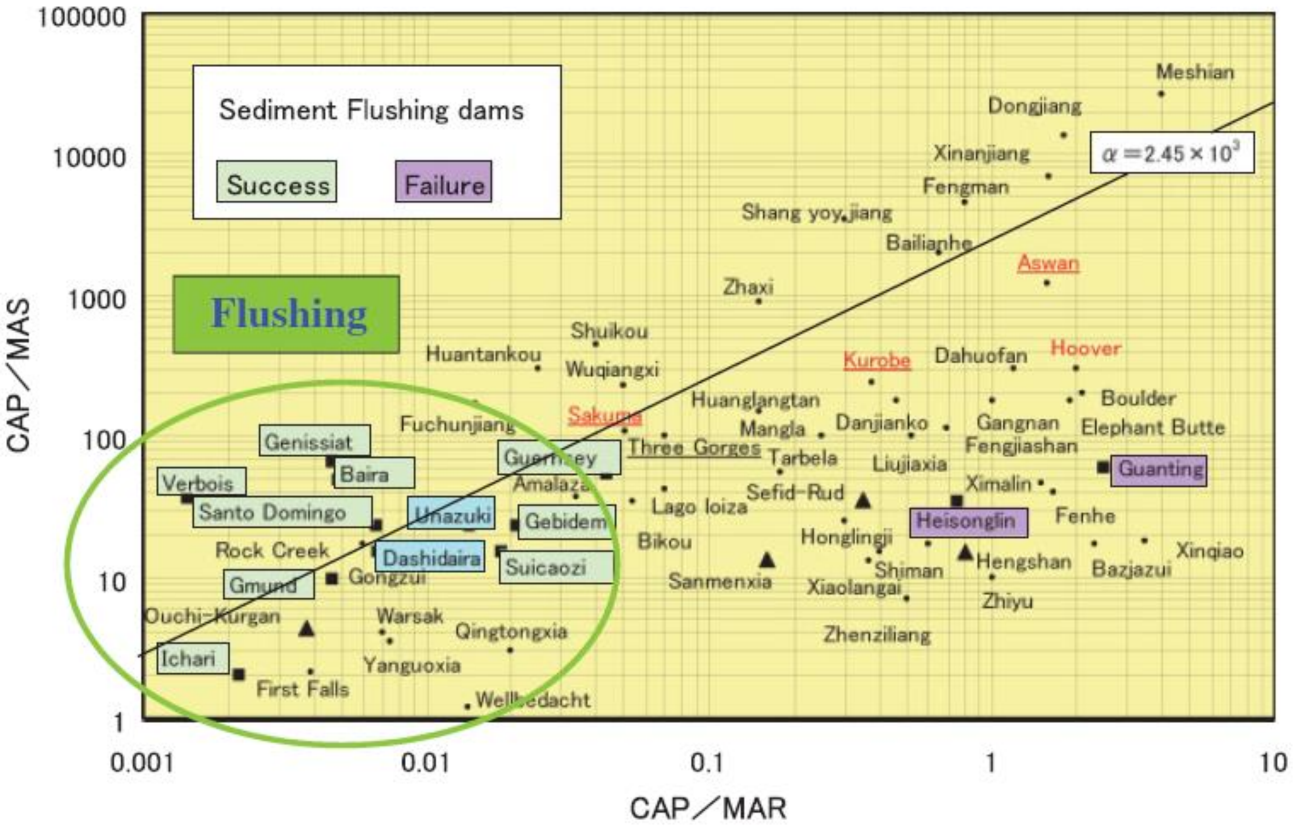


Figure 2 - Plot of flushing projects from diverse environments showing that successful cases are characterized by impoundment ratios of 0.4 or less. That is, reservoir storage capacity divided by mean annual runoff (inflow to the reservoir) should be less than 0.4. (Kondolf et al. 2014)

Questionnaire SCOD 2018

Context of the survey

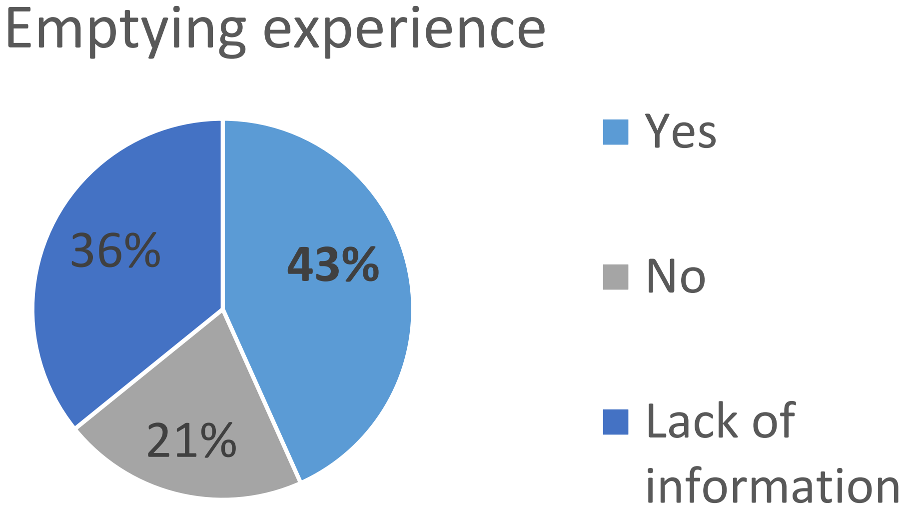
- Survey regarding sediment management
- 105 operators contacted
- Universe of 120 large dams
- 69 answers (1st round)
- 67 exploitable results (1st round)

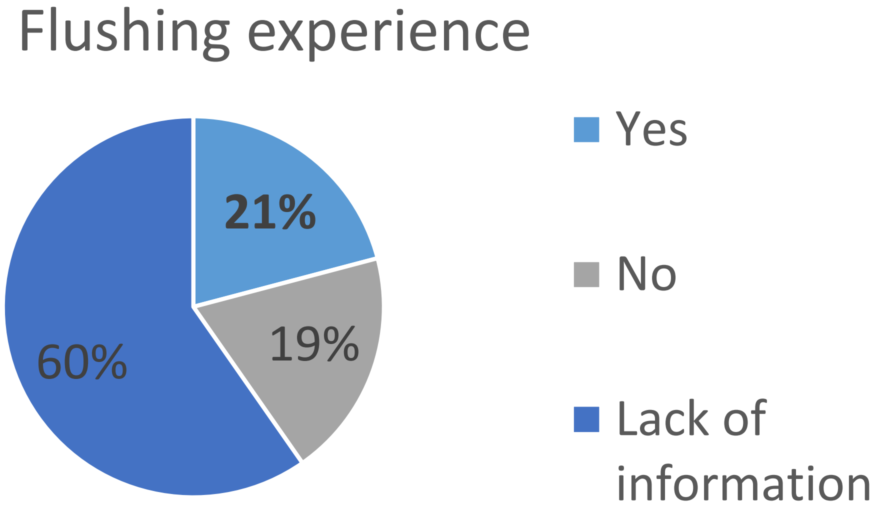
Questionnaire problèmatique des sédiments — Groupe de travail "Purges et Vidanges"

Nom du barrage	**Rossinière**		
Année de construction	1972	yyyy	
Côte du couronnement	862.5	msm	
Hauteur du barrage	30	m	
Type d'exploitation	H	J/H/S	intrajournalière/intrahebdomadaire/saisonnière
Niveau d'exploitation max	860	msm	
Niveau d'exploitation min	855	msm	
Volume total (à l'origine)	3E+06	m^3	
Volume utile (à l'origine)	2E+06	m^3	[volume original entre Nmax et Nmin]
Volume non-utile (y compris volume mort, à l'origine)	1E+06	m^3	[entre le lac vide et le Niveau min]
Côte de la prise d'eau (seuil inférieur et bord supérieur)	847/850	msm	xx/zz
Côte de la vidange de fond (seuil inférieur)	845	msm	
Côte d'une éventuelle deuxième vidange de fond (seuil inférieur)	845	msm	
Localisation de la vidange de fond (p.ex. directement sous la prise d'eau)?	prise d'eau en RD, VDF dans le corps du barrage		
estitution des eaux de vidange ou turbinées directement à l'aval du barrage?	N	Y/N	
Possibilité de restituer à l'aval de l'eau claire (pour dilution)?	Y	Y/N	
Valeur énergétique de l'eau dans les aménagements en aval	0.19	kWh/m^3	
Capacité de la vidange de fond (à lac plein)	193	m^3/s	[sinon, donner f(N)]
Capacité de la vidange secondaire (à lac plein)	193	m^3/s	[sinon, donner f(N)]
Prise d'eau: débit d'équipement de la centrale à l'aval	40	m^3/s	
Côte du fond de la vallée à l'origine	839	msm	[talweg auprès du barrage]
Bassin versant direct	398	km^2	[naturel]
Bassin versant indirect		km^2	[...des captages]
Présence de glaciers dans le bassin versant?	6	km^2	[direct + indirect]
Erosion de moraines en cours ou à risque?	N	Y/N	
Présence de fronts actifs (éboulements, glissements)?	N	Y/N	
Régime des apports solides au barrage: en continu et/ou pendant les crues?	crues		[p.ex. pendant fonte glaciaire]
Jours estimées/mesurés de transport solide	50	jours/an	
Niveau des sédiments actuels auprès du barrage (point le plus haut)	854.9	msm	
Niveau des sédiments actuels auprès de la prise d'eau	848	msm	
Niveau des sédiments actuels auprès de la vidange de fond	850	msm	
Volume des sédiments actuels	2E+06	m^3	
Opérations d'évacuation des sédiments déjà réalisées	2009/2017		[années xx/zz/ww/..]
Mesures constructives liées aux sédiments déjà réalisées			[p.ex. seuils fixes, tunnel de bypass, mur guide, etc.]
Type de sédiments à la racine de la retenue	sable graveleux		
Volume de ces sédiments à la racine		m^3	
Type de sédiments près du barrage	limon argileux		
Volume de ces sédiments près du barrage		m^3	
Les sédiments ont posé des problèmes dans le passé?	Y	Y/N	
Les sédiments posent un problème actuellement?	Y	Y/N	
On gère la sédimentation qu'avec des mesures actives dans le temps?	N	Y/N	[actives = mesures d'exploitation]
Lesquelles?	purges partielles / pompages		
Les sédiments poseront vraisemblablement des problèmes dans le futur?	Y	Y/N	
Pourquoi?	Alluvionnement de 44000 m3/an		
Volume évacué estimé dans la purge historique la plus efficace	5000	m^3	
Il y a eu de grave dégâts à l'aval?	N	Y/N	
Lesquels?			(décrire)
Jurée d'accumulation de sédiments avant la purge historique la plus efficace		années	
Avez-vous déjà réalisé une vidange complète?	N	Y/N	
Raison(s) de la (des) vidange(s) complète(s)			(décrire)

Emptying / Entleerung
Purges / Spülung

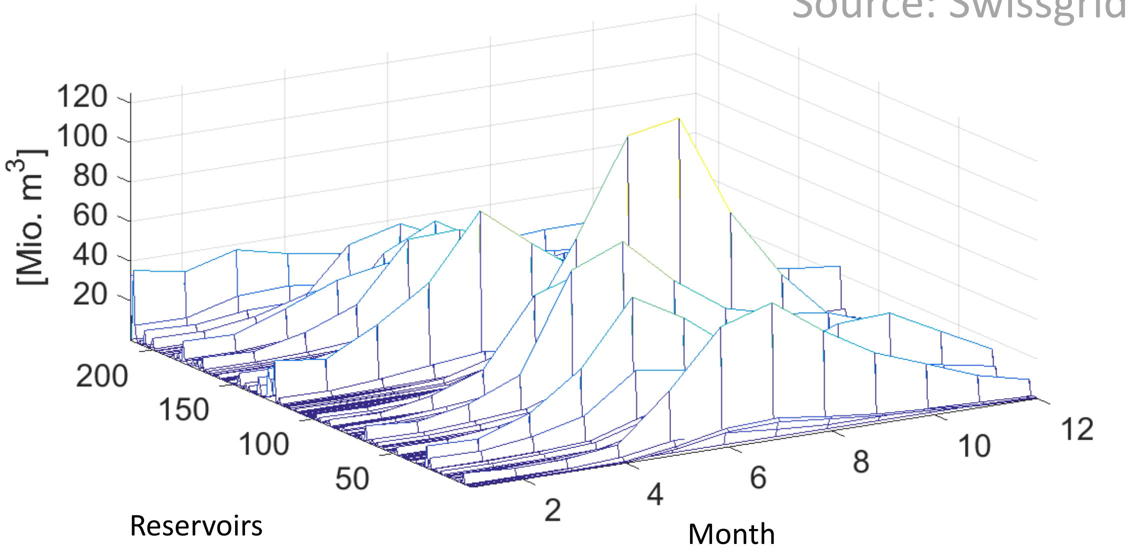
Photo J. Stamm/KWO (2015)

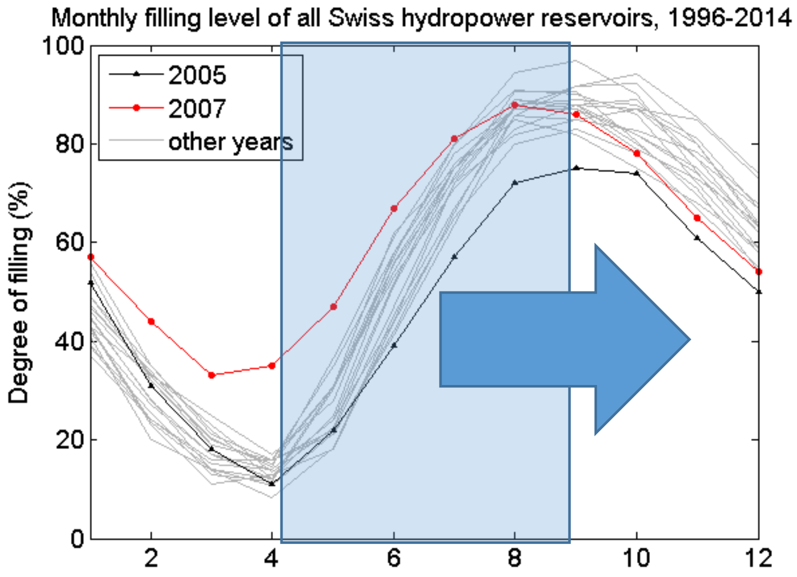




Seasonal reservoirs

Source: Swissgrid





- **Yearly cycle / seasonal transfer / Typical of Alpine reservoirs**
- **Lower filling ration in winter time / Higher filling ration in late summer / autumn**
- **Bed load in springtime mainly**
- **Fine sediments also from glacier melt flows and from short floods**

EPFL Innovative methods

Goal: routing the maximum amount of sediments without reducing turbine lifetime

In the reservoir

Routing through the power waterways

Operational stirring (inlet/outlet interplay)

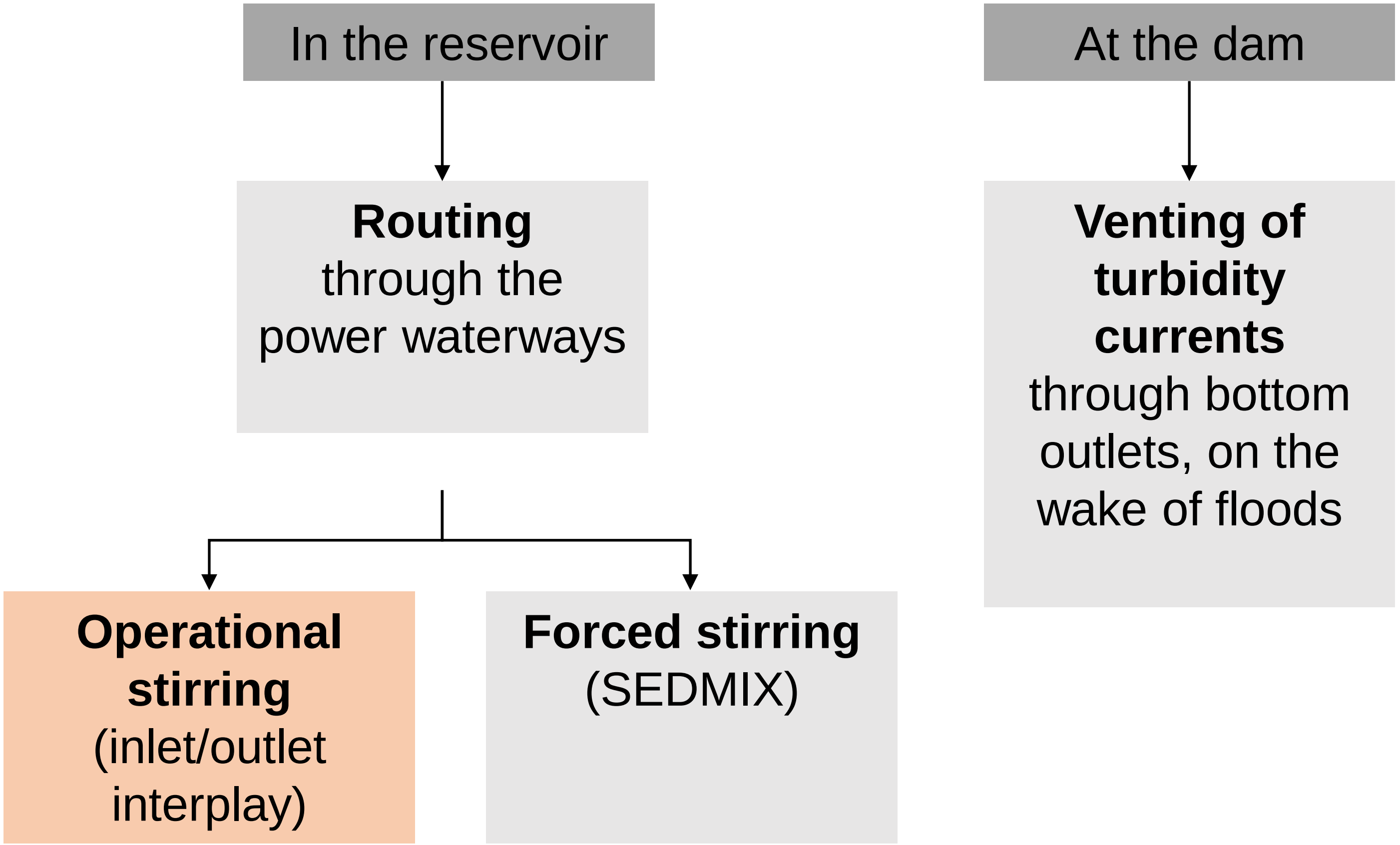
Forced stirring (SEDMIX)

At the dam

Venting of turbidity currents through bottom outlets, on the wake of floods

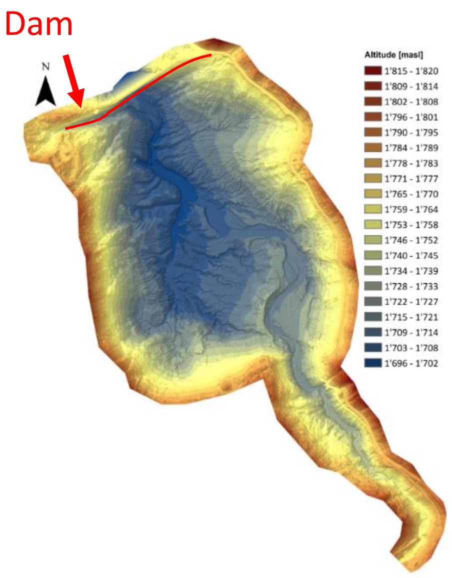
Goal: routing the maximum amount of sediment with minimum water losses

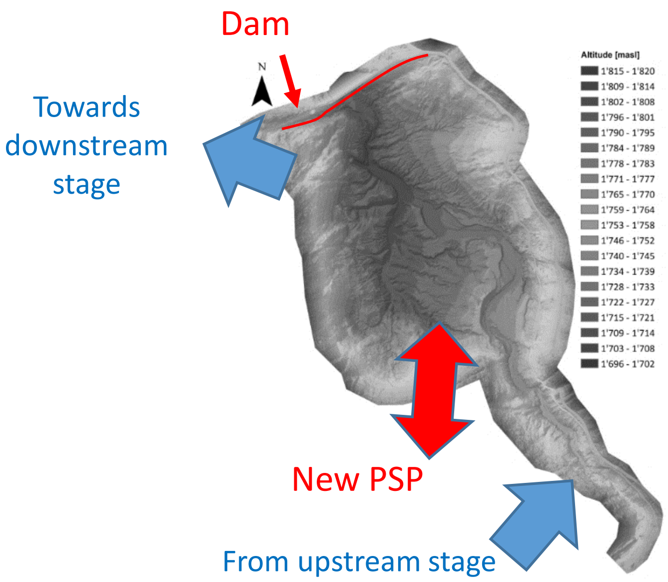
EPFL Innovative methods

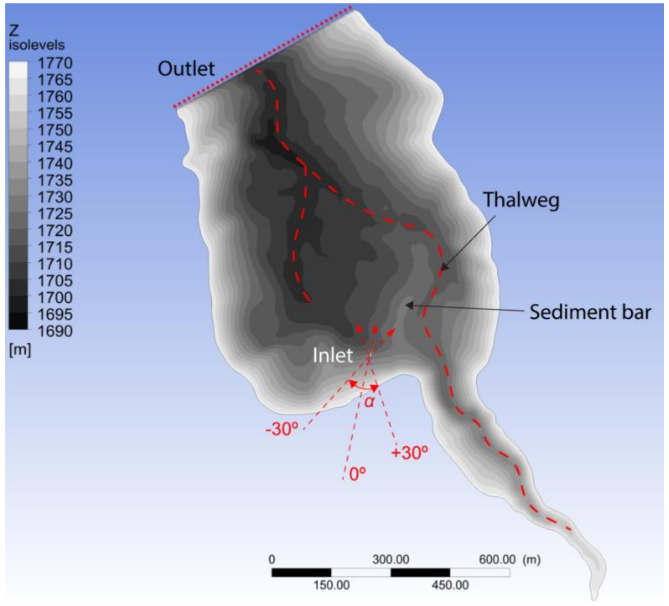


Operational stirring

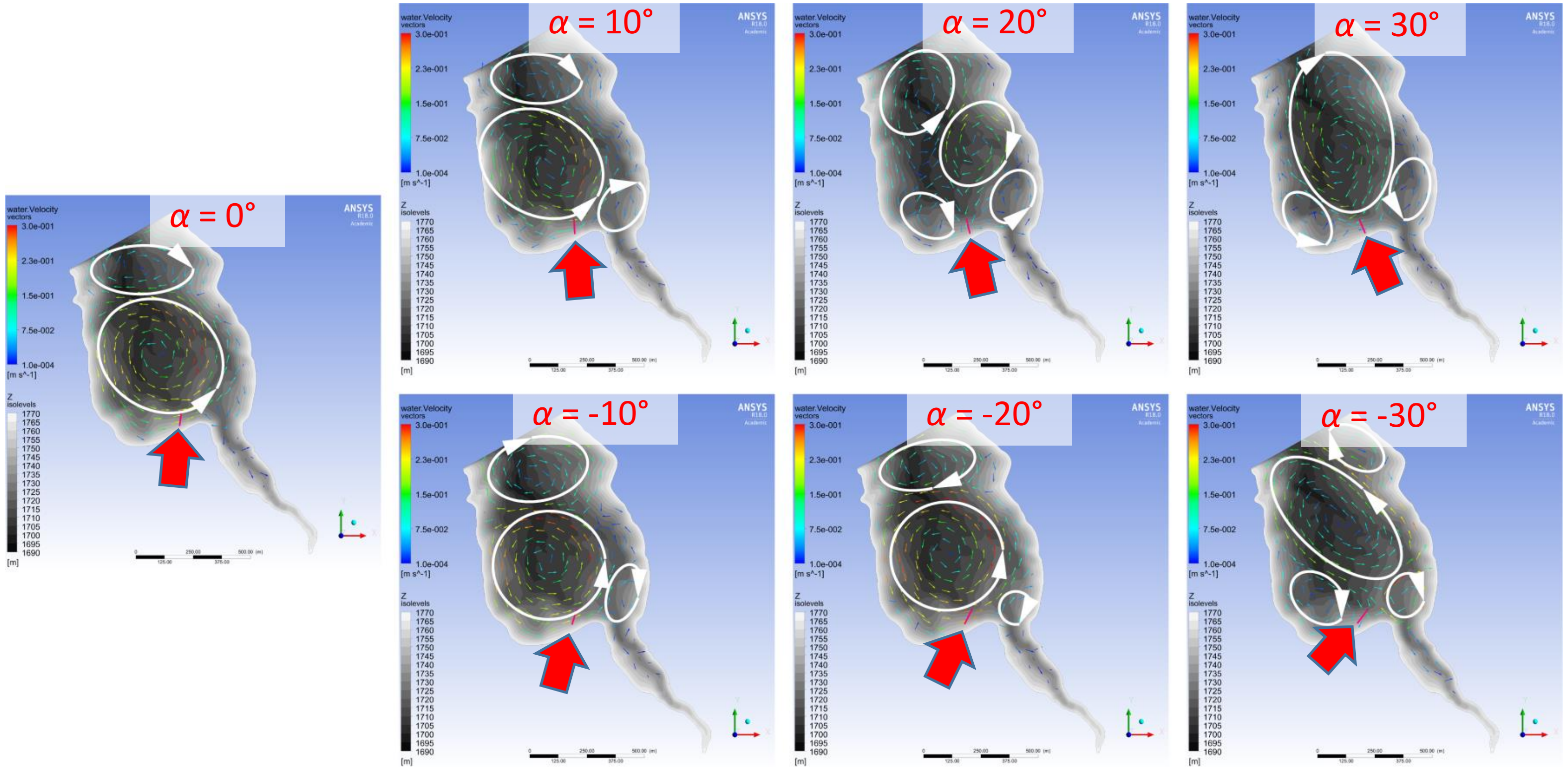
- **Make use of the interaction between in-flows and reservoir hydrodynamics**
- **Hamper settling of fine sediment particles**
- **Apply in the design of new HPP/PSP outlets**

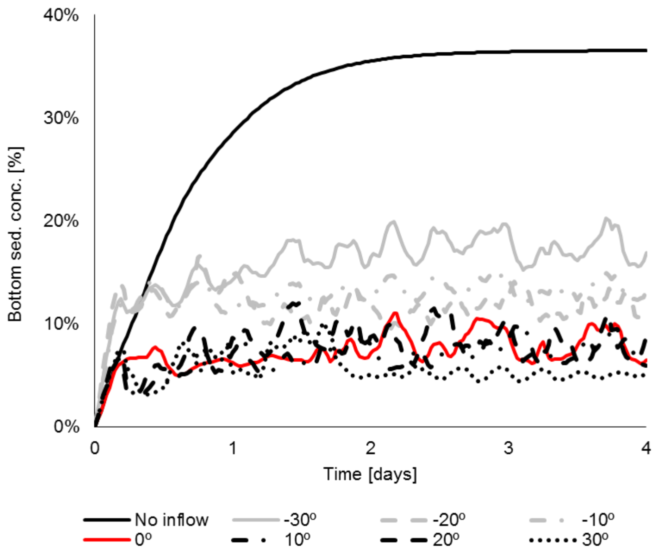






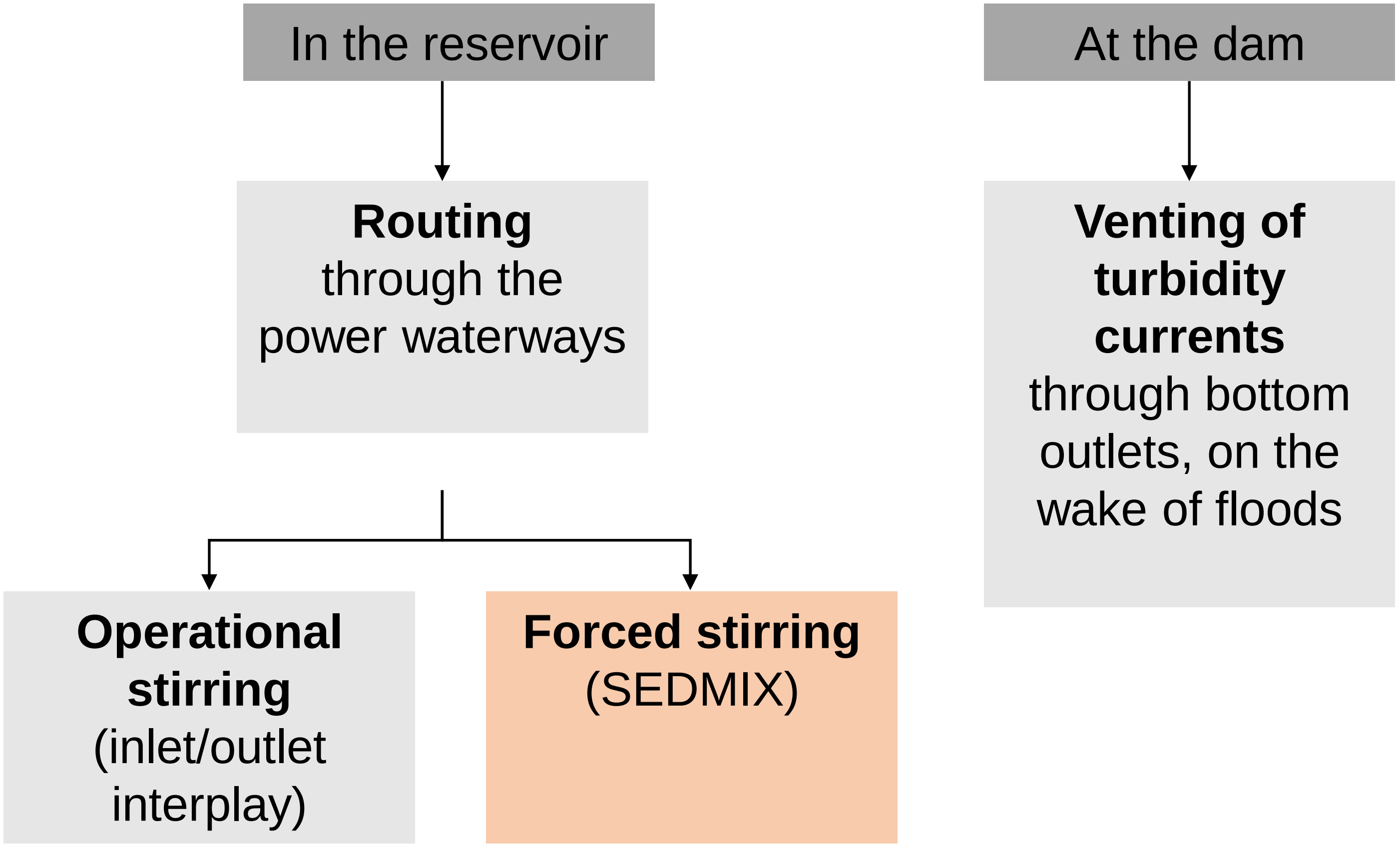
Operational stirring



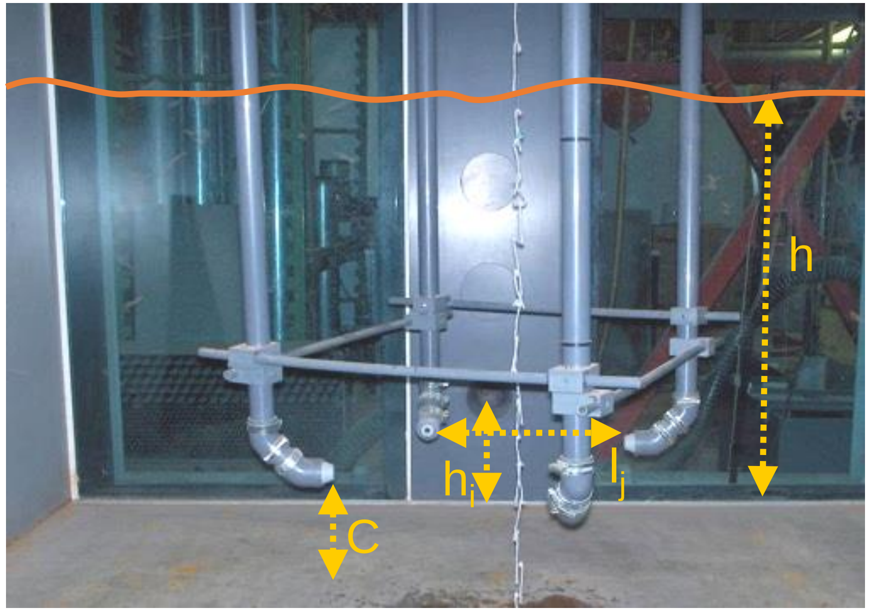


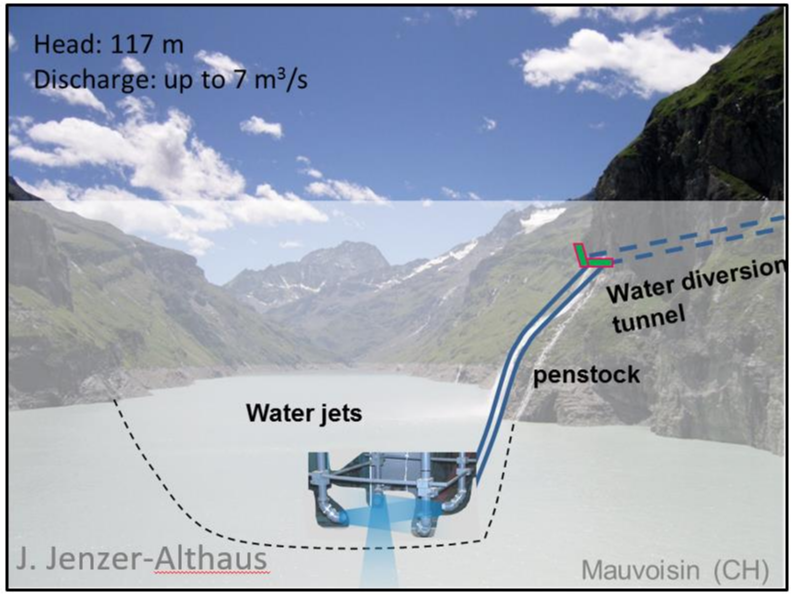
Outflow-jets have major influence in deep reservoir hydrodynamics and turbulence levels.
Adequate jet orientation can significantly reduce sediment deposition

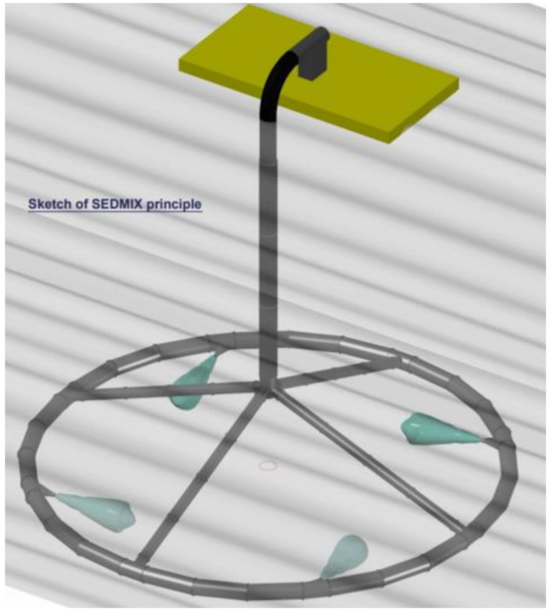
EPFL Innovative methods



Forced stirring



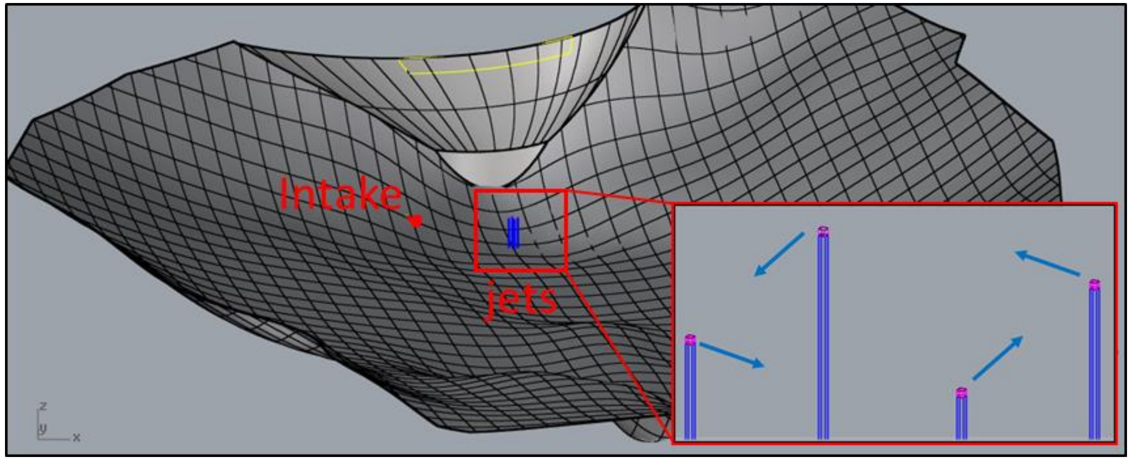




Outflow-jets in swirling flow, ascending effect
On-demand operation

Customized operation (space, time, flow rate)
Potential energy or pumped supply
Modular

Case study: new Trift reservoir, periglacial context



Evacuated sediment ratio (ESR), ratio between evacuated and supplied sediment, is increased by five.

Next steps : 1. build large scale demonstrator facility, 2. operate and monitor, 3. replicate

20.11. 2018, Olten => azin.amini@epfl.ch

EPFL Innovative methods

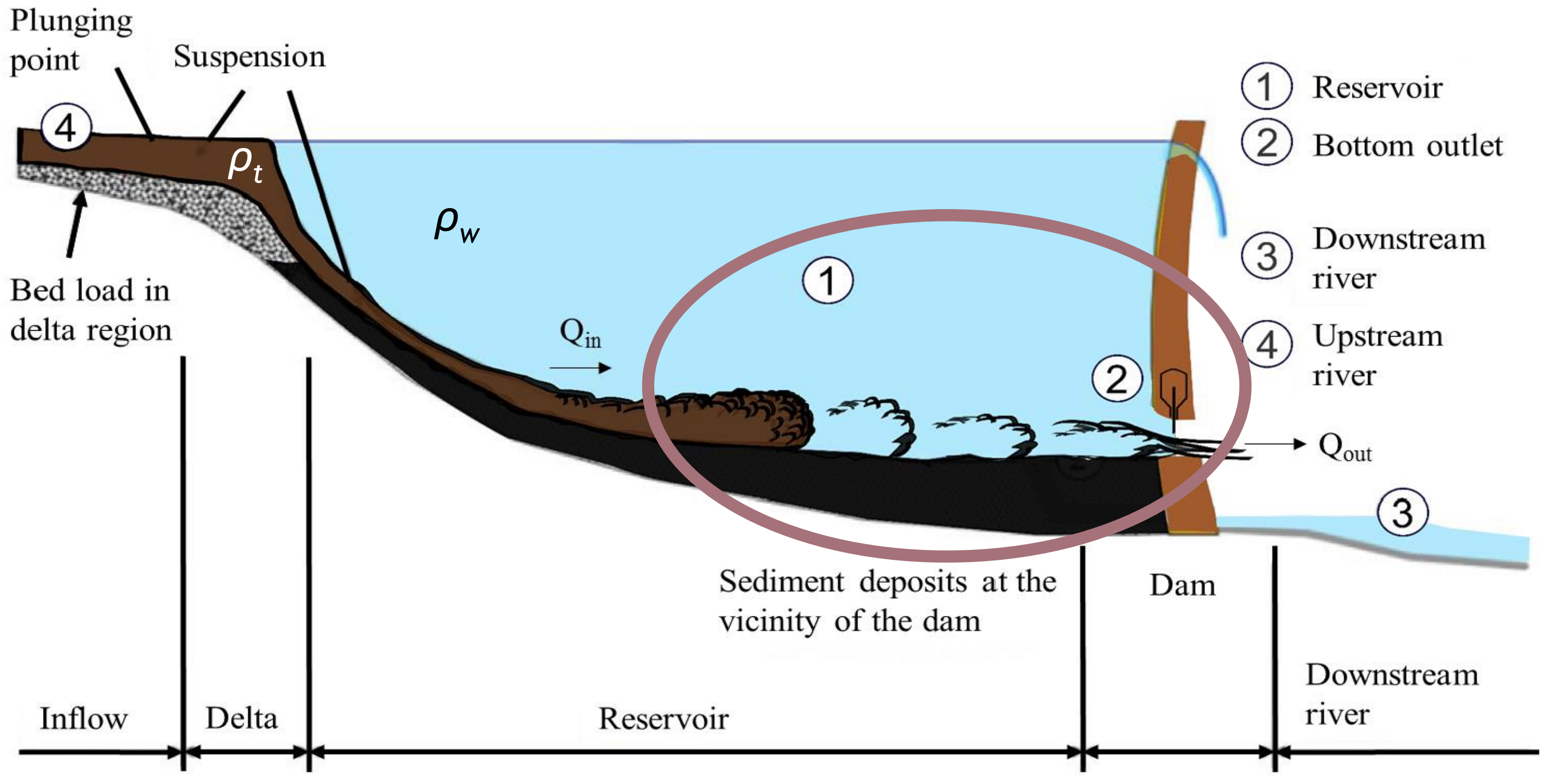
In the reservoir

- **Routing** through the power waterways
  - **Operational stirring** (inlet/outlet interplay)
  - **Forced stirring** (SEDMIX)

At the dam

- **Venting of turbidity currents** through bottom outlets, on the wake of floods

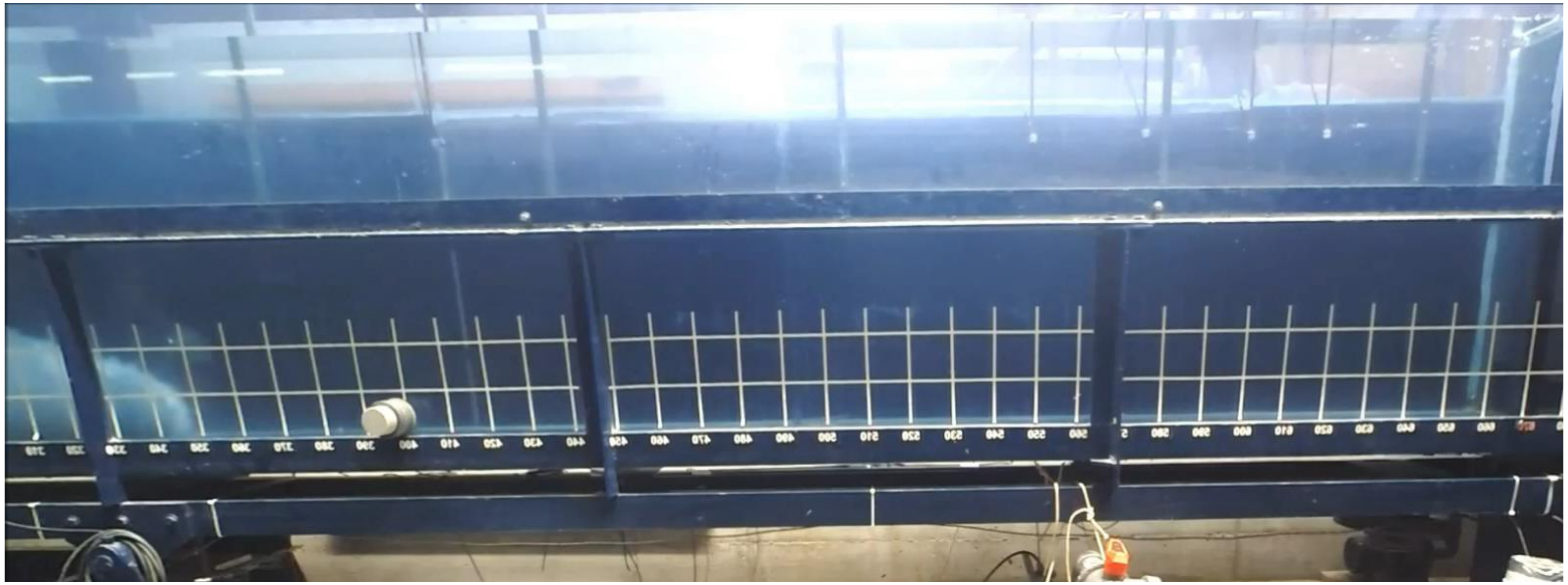
Venting of turbidity currents



Rhone river plunging into Lake Geneva (De Cesare et al., 2001)

Venting of turbidity currents (PhD Thesis S. Chamoun 2017)

Numerical model: validation

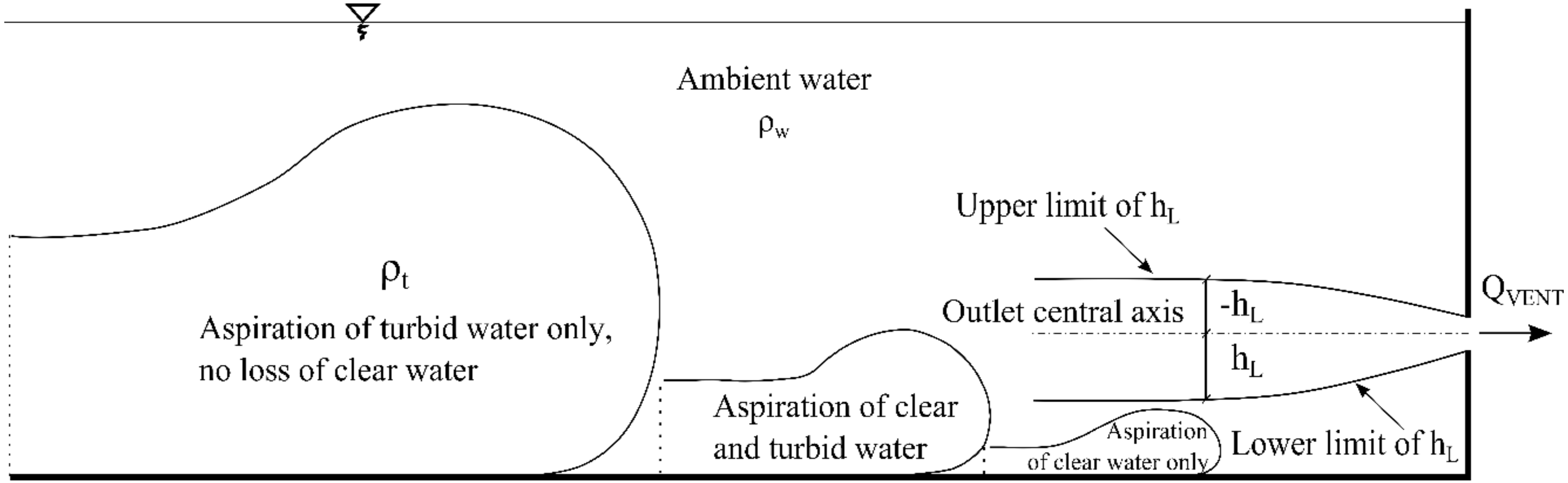


11 times faster

Venting of turbidity currents: outlet position and height

- Venting efficiency in linked with the **height of aspiration *h_L***
- Developed by Gariel (1949) and Craya (1949) based on saline currents.
- Fan (1960) adapted it for turbidity currents

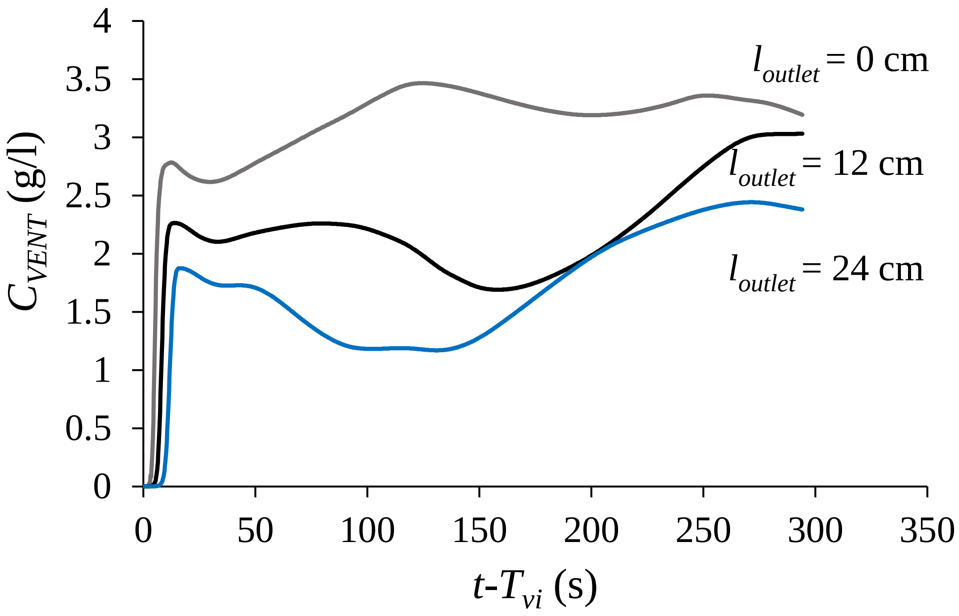
$$\left[\frac{\Delta\rho}{\rho_w}\frac{g(h_L)^5}{Q^2_{out_{av}}}\right]^{1/5} = K$$

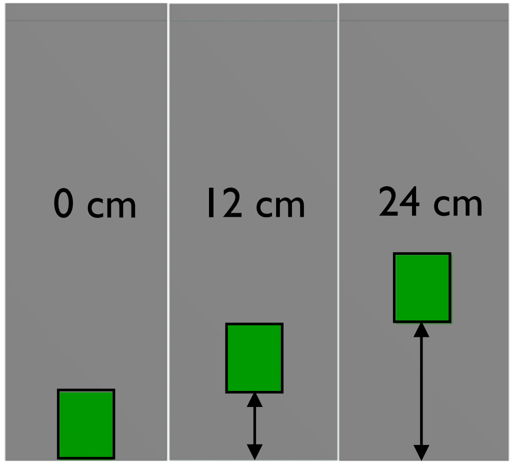


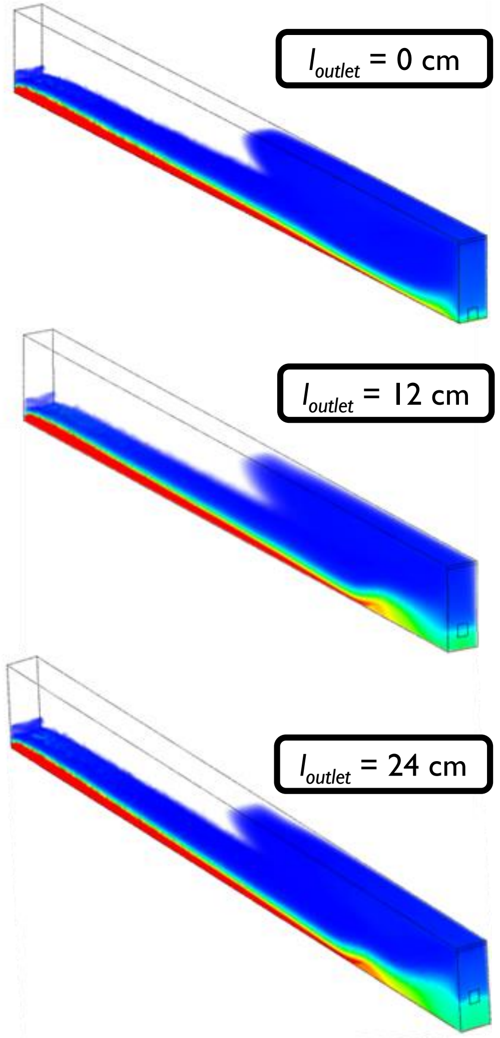
Where to place the outlet to increase the efficiency of venting?

Venting of turbidity currents

- **Influence of Outlet level from bed**







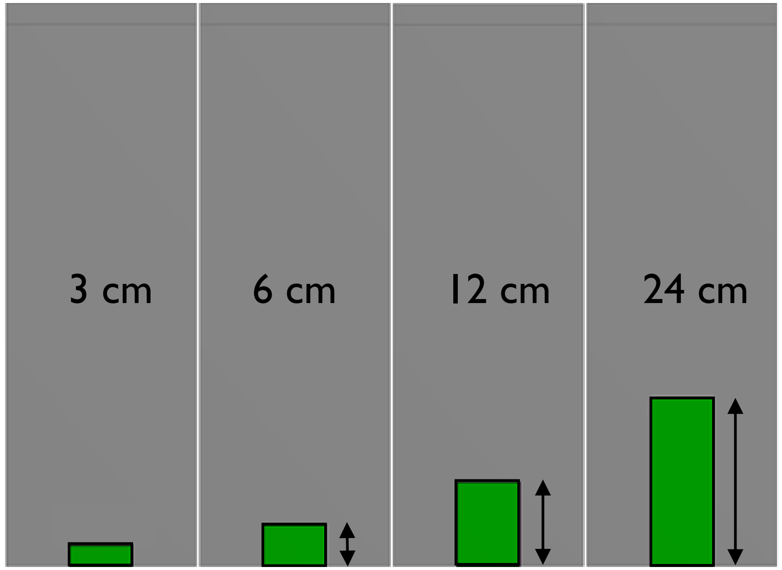
Lower height of aspiration only reaches 8.5 cm above the bed

The outlet should be placed at the lowest level possible, minimizing the dead storage, for which the venting concentration remains the highest, the longest.

Venting of turbidity currents

Venting of turbidity currents

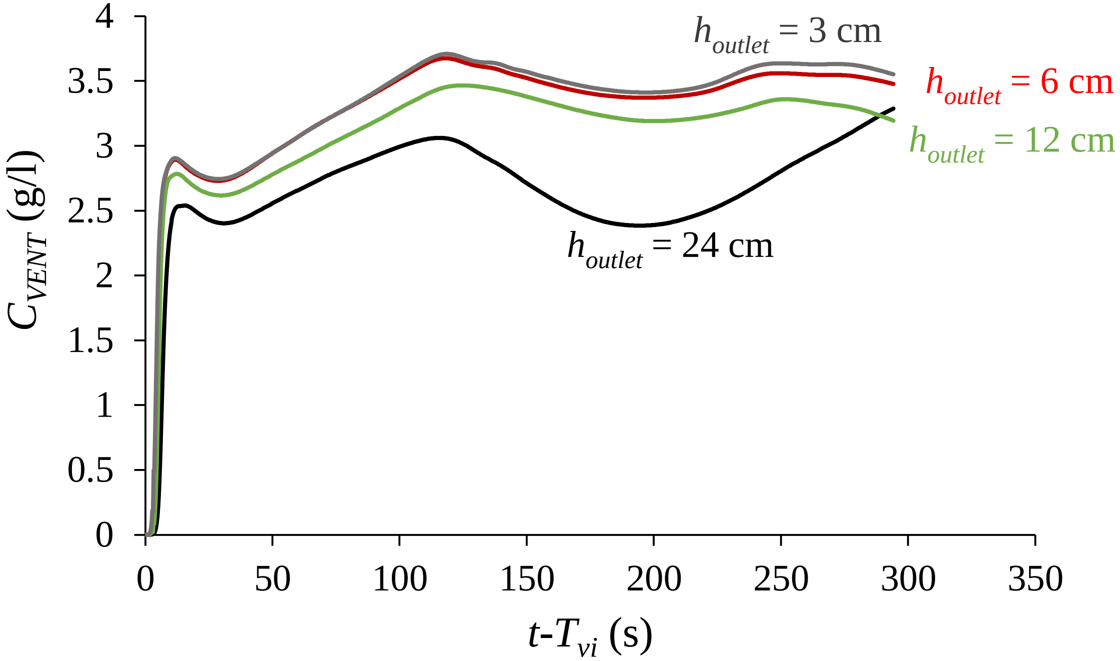
- **Influence of Outlet height**



➢ $[h_L + (h_{outlet}/2)]/H$ =

1.0 / 1.1 / 1.2 and 1.5

for increasing heights



The height of the entrance of the outlet should be chosen in a way that the height of aspiration encloses the turbidity current body.

Outlook

In the reservoir

No water losses

Routing through the power waterways

- **Operational stirring** (inlet/outlet interplay)
- **Forced stirring** (SEDMIX)

At the dam

Venting through bottom outlets, on the wake of floods

With water losses

From conception (HPP expansion)

Customization (life cycle)

From conception (greenfield / brownfield)

Acknowledgements & Selected references

- Swisselectric Research
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- MANSO P., VORLET S. L., GUILLÉN LUDEÑA S., DE CESARE G., STAMM J., SCHWEGER B., FANKHAUSER A. "Evolution of reservoir flushing and emptying practices in a cascade of large reservoirs across several decades", Hydro 2018 – progress through partnerships, Gdansk.
- DE CESARE G., MANSO P., CHAMOUN S., GUILLÉN-LUDEÑA S., AMINI A., SCHLEISS A. J. "Innovative methods to release fine sediments from seasonal reservoirs ». ICOLD Congress Vienna 2018 July 2-8., Question 100.
- AMINI, A., MANSO, P., VENULEO, S., LINDSAY, C., LEUPI, C., SCHLEISS, A.J. Computational hydraulic modelling of fine sediment stirring and evacuation through the power waterways at the Trift reservoir. In Proc. Hydro 2017, Seville, Spain
- CHAMOUN, S., DE CESARE, G. and SCHLEISS, A.J. Managing reservoir sedimentation by venting turbidity currents: a review. International Journal of Sediment Research, 31(3), pp. 195-204, 2016
- CHAMOUN, S., DE CESARE, G. and SCHLEISS, A.J. Venting turbidity currents for the sustainable use of reservoirs. International Journal on Hydropower and Dams, 23(5), pp.64–69, 2016
- GUILLÉN-LUDEÑA, S., MANSO, P.A., & SCHLEISS, A. J. Fine sediment routing in a cascade of alpine reservoirs: Influence of the inlet angle on settling of fine sediments. In Proc. Hydro 2017, Seville, Spain.
- JENZER-ALTHAUS J., DE CESARE G., and SCHLEISS A. J. Sediment Evacuation from Reservoirs through Intakes by Jet-Induced Flow. Journal of Hydraulic Engineering, Vol. 141/2, 2015
- MÜLLER, M., DE CESARE, G. and SCHLEISS, A.J. Experiments on the effect of inflow and outflow sequences on suspended sediment exchange rates. International Journal of Sediment Research, 32(2), pp.155–170, 2017
- OEHY, Ch. and SCHLEISS, A.J. Control of turbidity currents in reservoirs by solid and permeable obstacles. J. Hydr. Engrg. 133, 637-648, 2010
- SCHLEISS, A. J., FRANCA, M. J., JUEZ, C., and DE CESARE, G. Reservoir sedimentation. Journal of Hydraulic Research, 54(6), 595–614, 2016