Venting of turbidity currents against reservoir sedimentation

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HYDRO OPERATION INTERNATIONAL


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12.09.2018

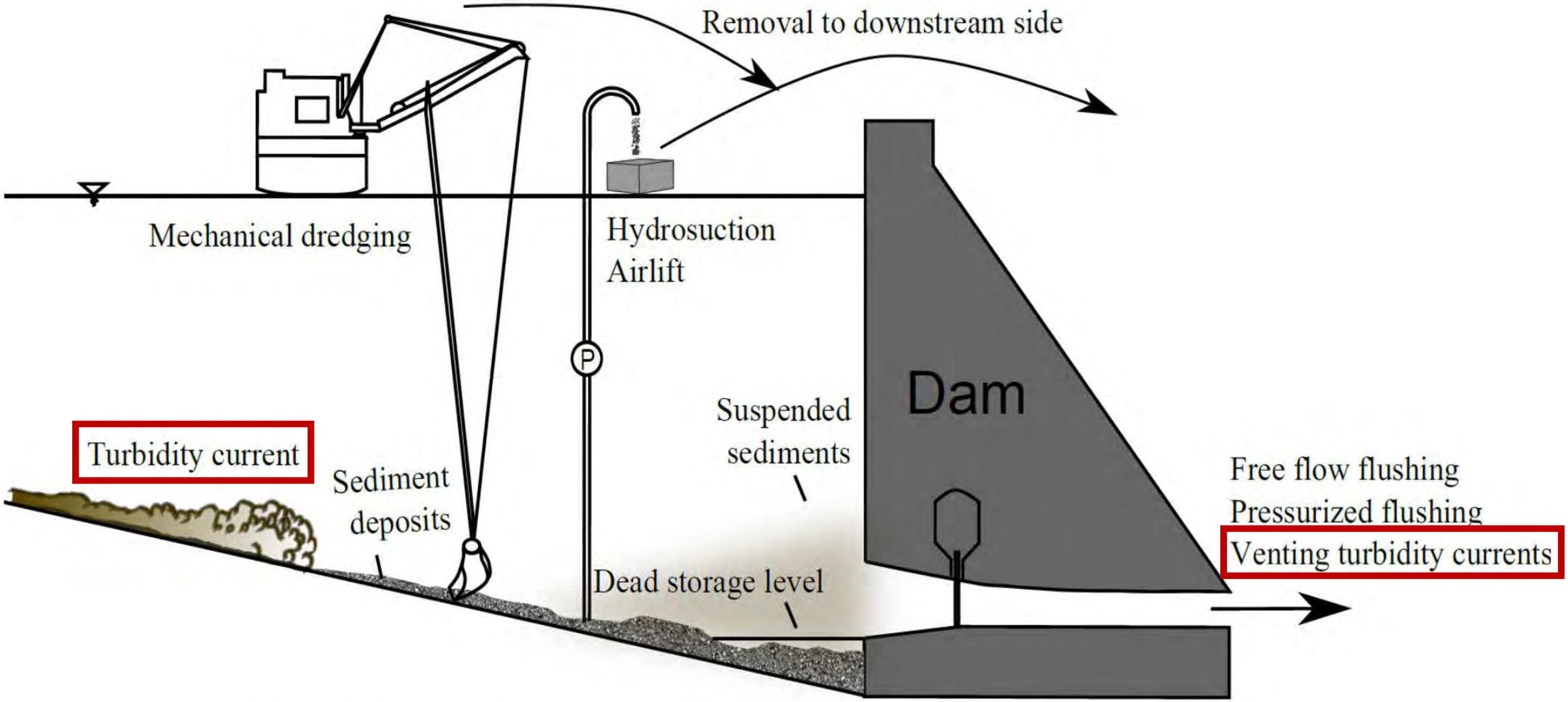
Reservoir sedimentation

- Main consequences
  - Generation
  - Equipment
  - Security
  - Environment

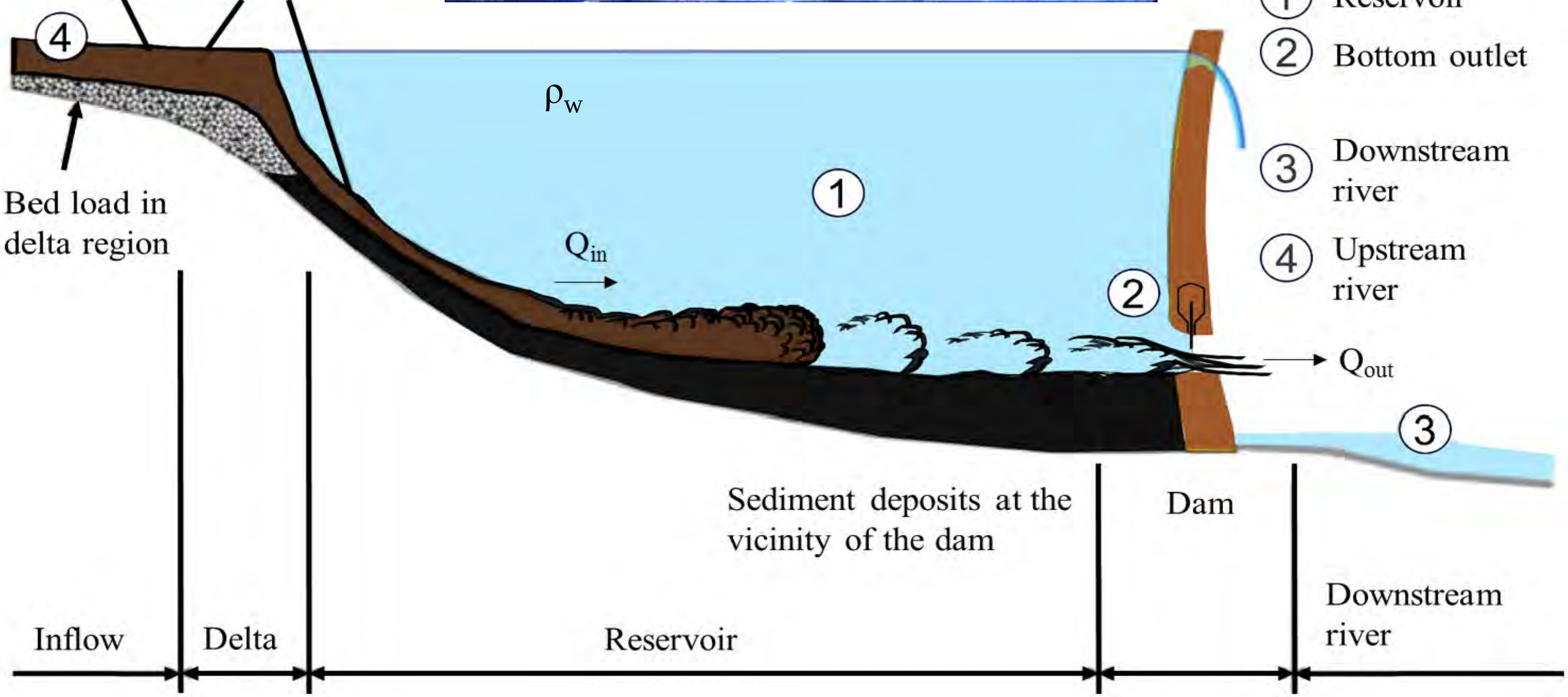
Bottom outlet partially blocked by sediments at the Jiroft Dam, Iran (Photo by S. Emami)

Sedimentation of Sufers reservoir, Switzerland (photo courtesy of Kraftwerke Hinterrhein AG)

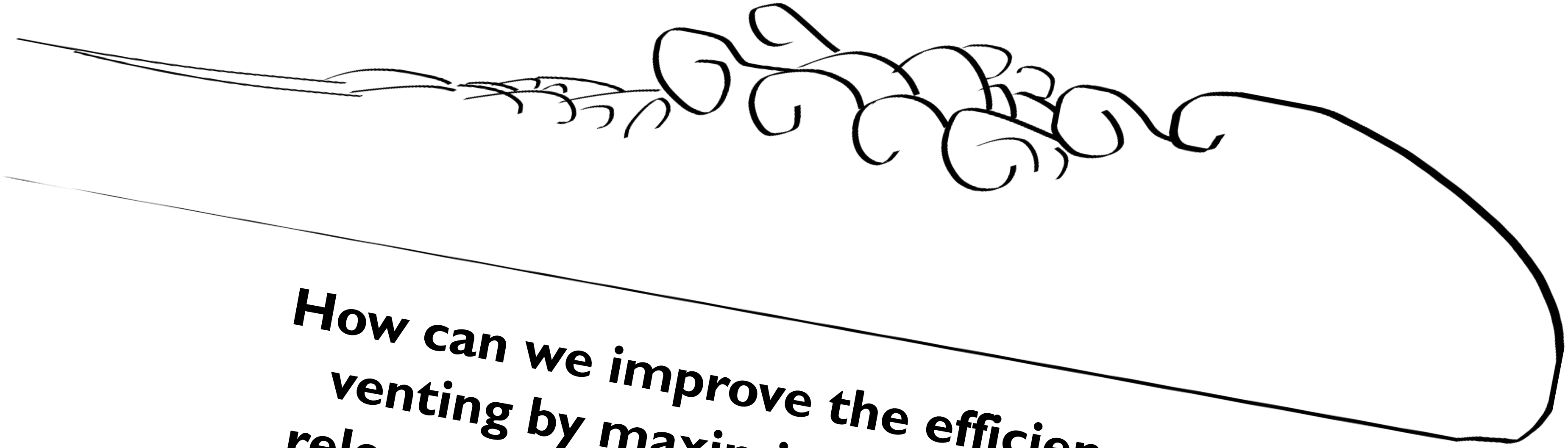
Reservoir sediment management



Venting of turbidity currents



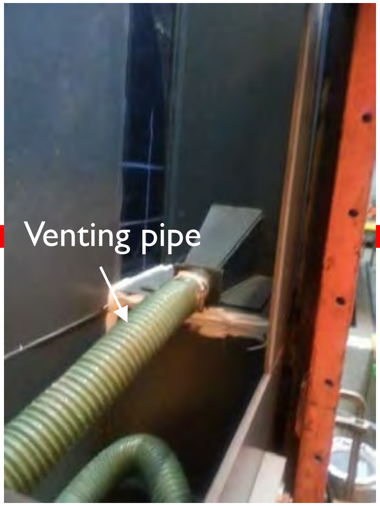
Objective of the study

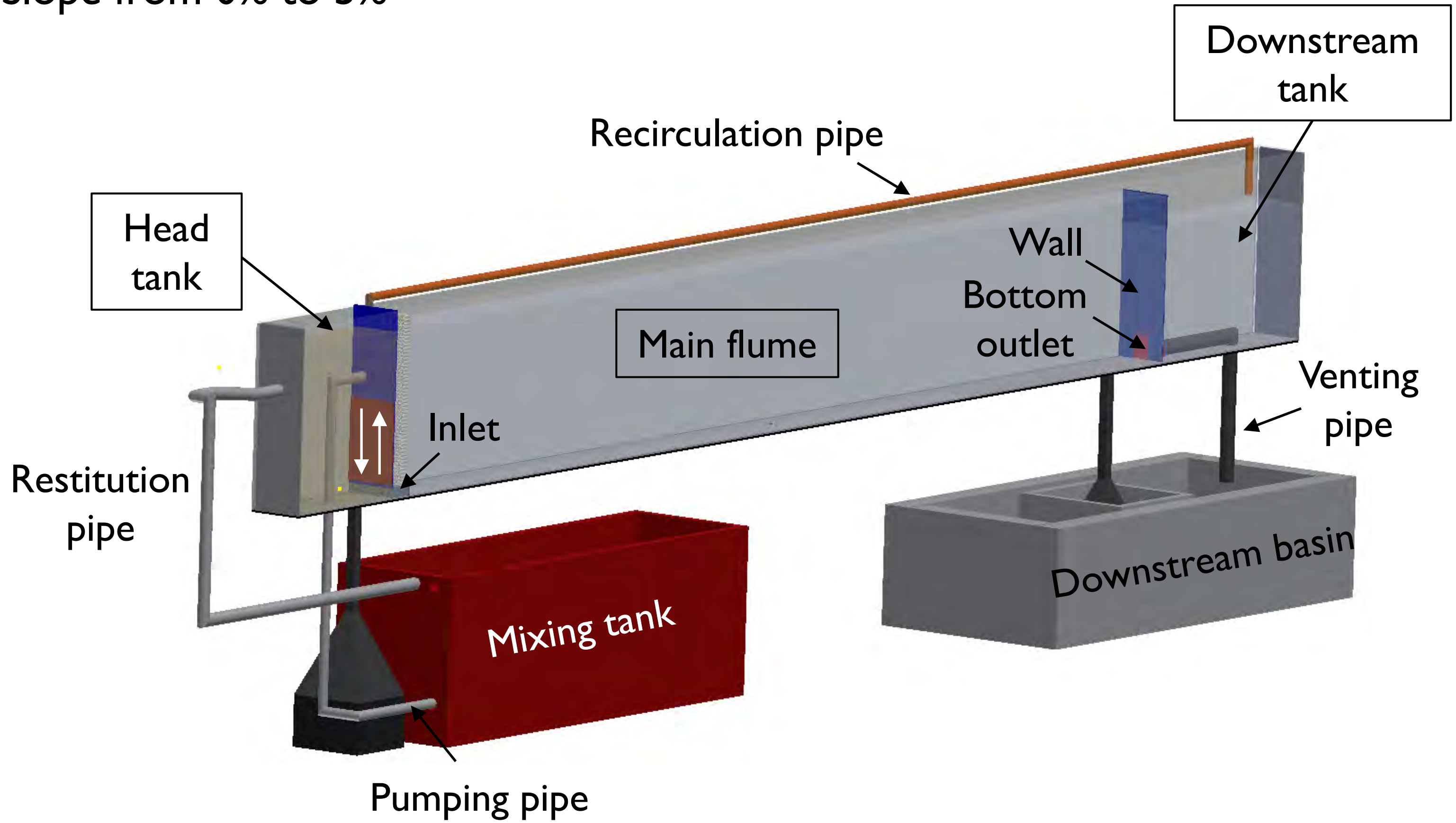


How can we improve the efficiency of venting by maximizing sediments released and minimizing water loss?

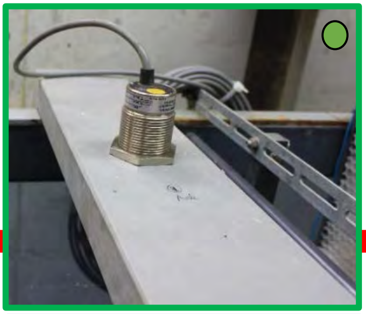
Experimental set-up

- Flume: Total length = 8.55 m; width = 0.272 m; height = 0.9 m
- Bottom outlet: width = 9 cm; height = 12 cm
- Slope from 0% to 5%

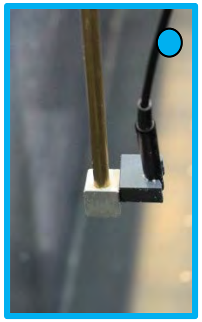




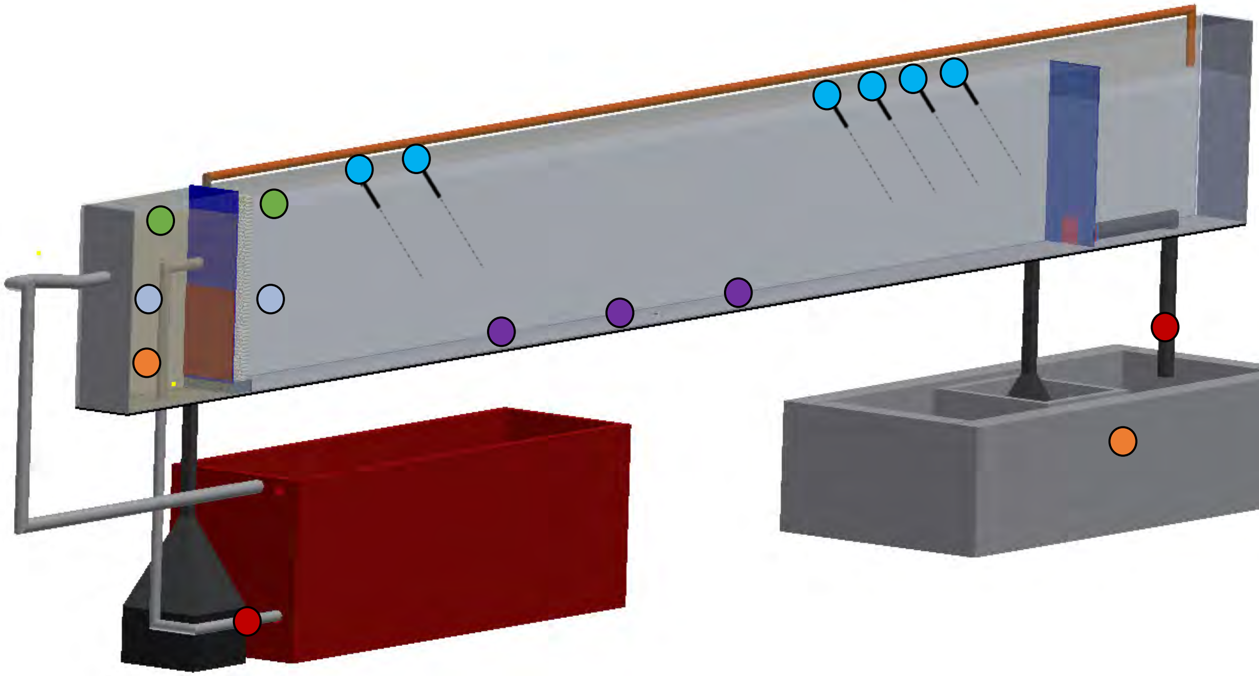
Measurements



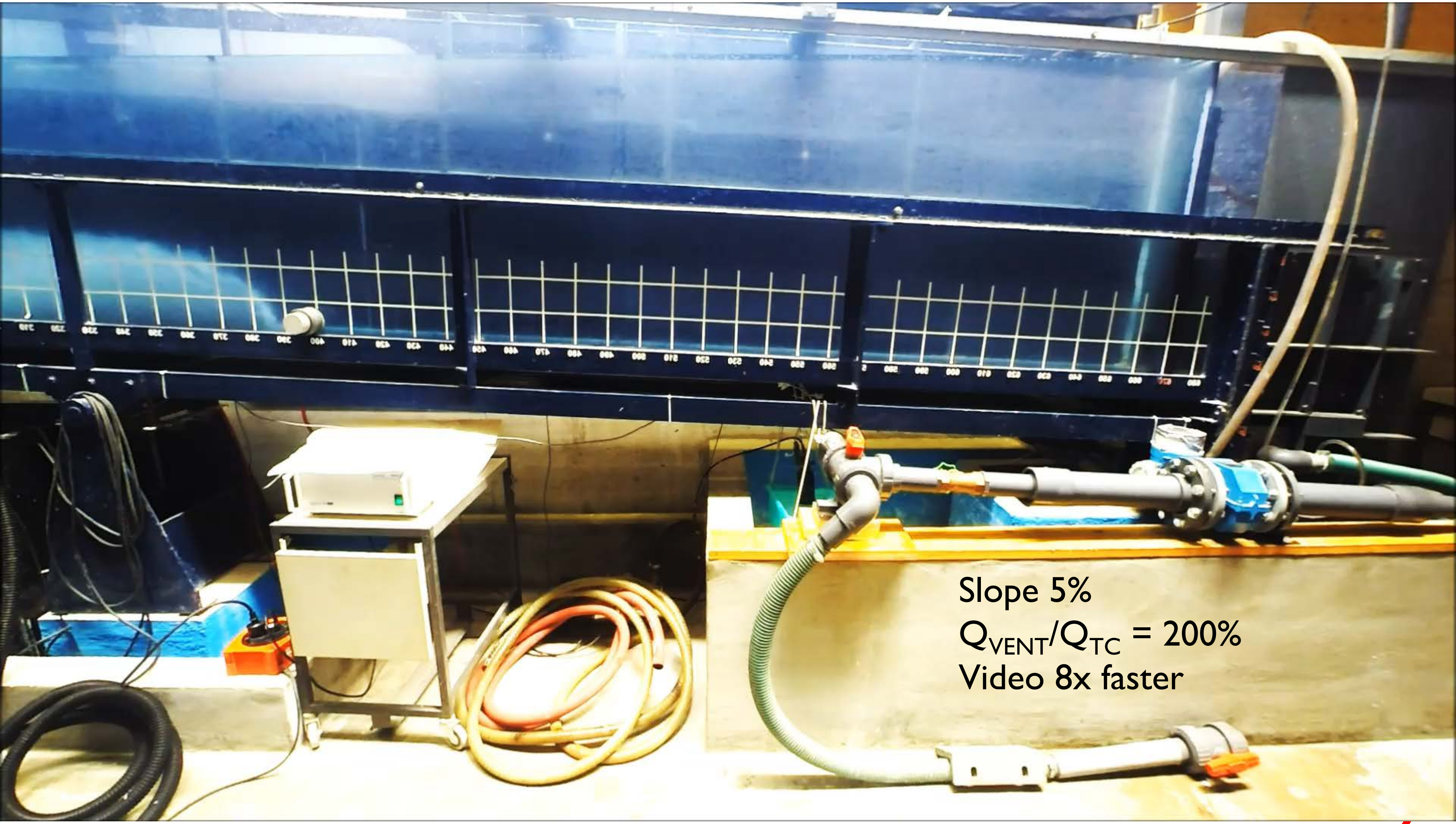
- A LabVIEW interface was created to run and stop the measurements simultaneously.
- Acquisition frequency (data recorded every 360 ms)



- 🔴 Flowmeter
- 🟢 Level probe
- 🟠 Turbidity probe
- 🟣 Depositometer
- 🔵 UVP transducer
- ⚪ Thermometer
- ⚫ Camera



A glimpse of experiments



Slope 5%

Q_{VENT}/Q_{TC} = 200%

Video 8x faster

Local venting efficiency

$$LVE = \frac{M_{VENT}}{M_{TC}} = \frac{\int_{t=T_{vi}}^{T_{vf}} C_{VENT}\, Q_{VENT}\, dt}{\cancel{\int_{t=0}^{T_{vi}} C_{TC}\, Q_{TC}\, dt} + \int_{t=T_{vi}}^{T_{vf}} C_{TC}\, Q_{TC}\, dt - \int_{t=T_{vi}}^{T_{vf}} \dot{m}_{dep}\, dt} = \frac{\text{Total outflow sediment mass \textbf{during} venting}}{\cancel{\text{Total inflow sediment mass \textbf{before} venting}} + \text{Total inflow sediment mass \textbf{during} venting} - \text{Total deposited mass \textbf{during} venting}}$$

$\dot{m}_{dep}$: deposited sediment mass flow rate

T_{vi} : Beginning of venting

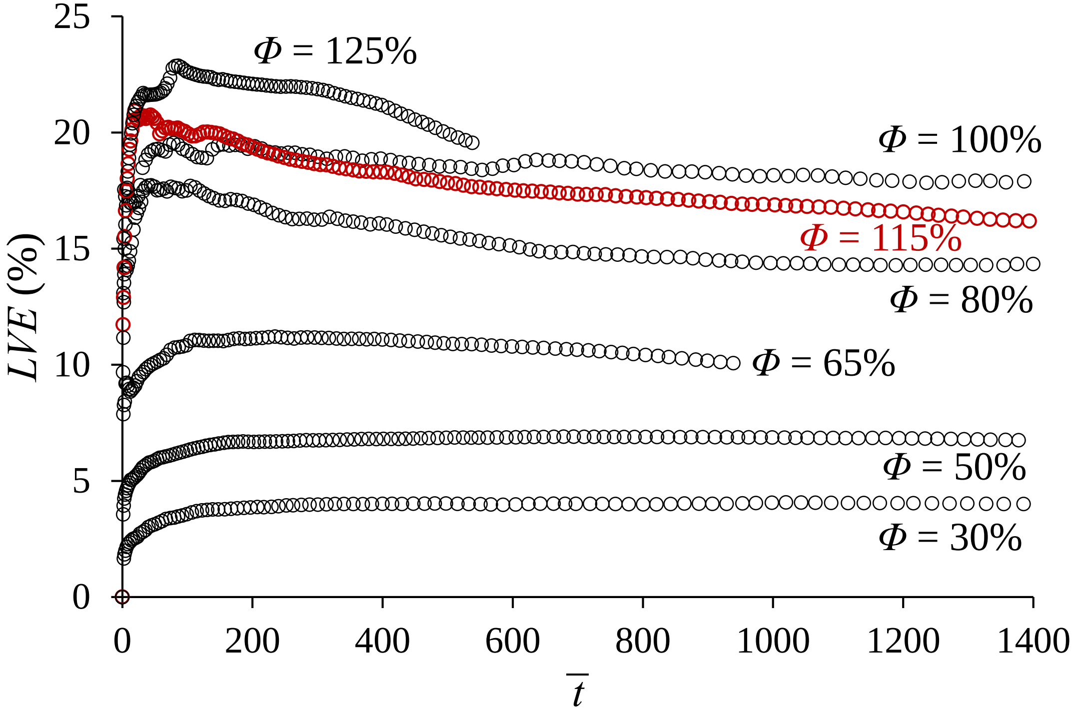
T_{vf} : End of venting

C_{VENT} and C_{TC} : outflow and turbidity current sediment concentrations at time t

Q_{VENT} and Q_{TC} : outflow and turbidity current discharges at time t

LVE on a horizontal bed

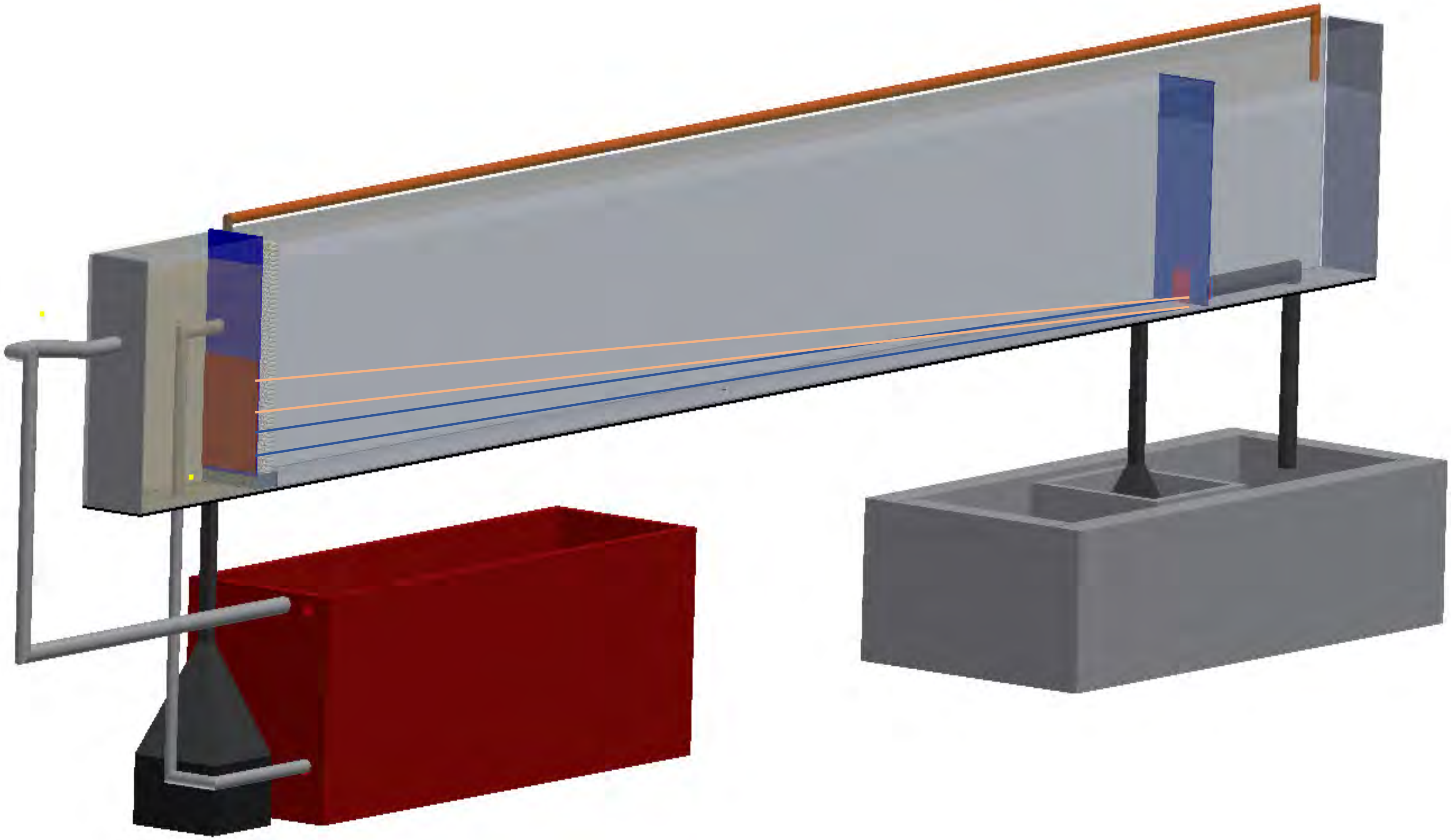
- Parameter varied: Venting degree $\Phi = Q_{vent}/Q_{TC}$
- Horizontal bed: $S = 0\%$
- In-time venting: at arrival of the current to the outlet



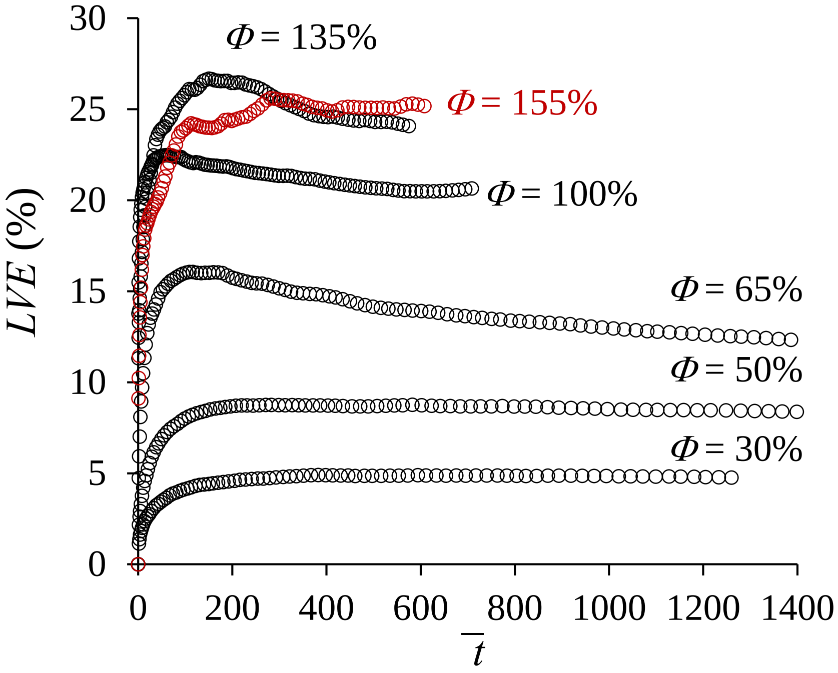
Venting on a horizontal bed leads to the highest efficiencies when using $\phi = 100\%$.

$\overline{t}$: Normalized venting duration
LVE : Local Venting Efficiency

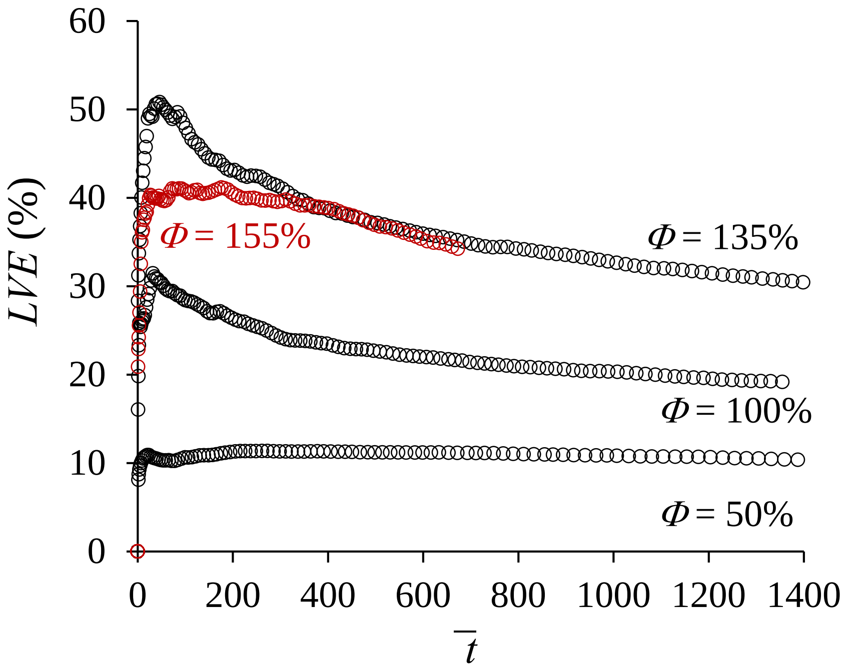
LVE on steeper bed slopes



LVE on steeper bed slopes



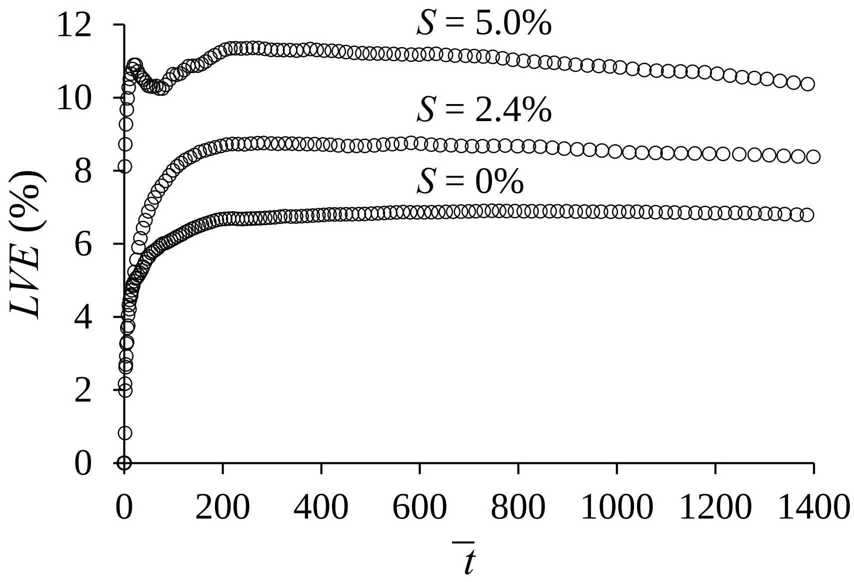
S = 2.4%



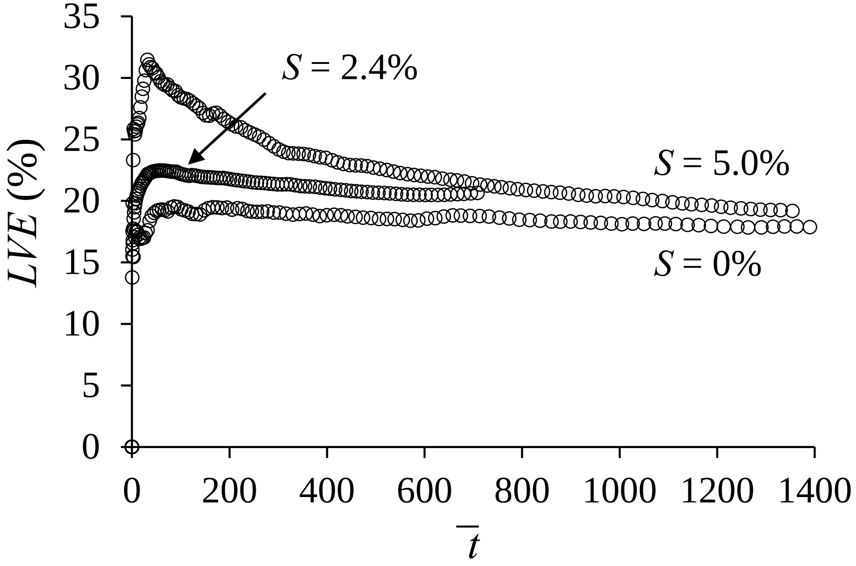
S = 5%

The optimal venting degree depends on the reservoir slope in the vicinity of the outlet. Steeper slopes yield higher optimal venting degrees.

LVE on steeper bed slopes



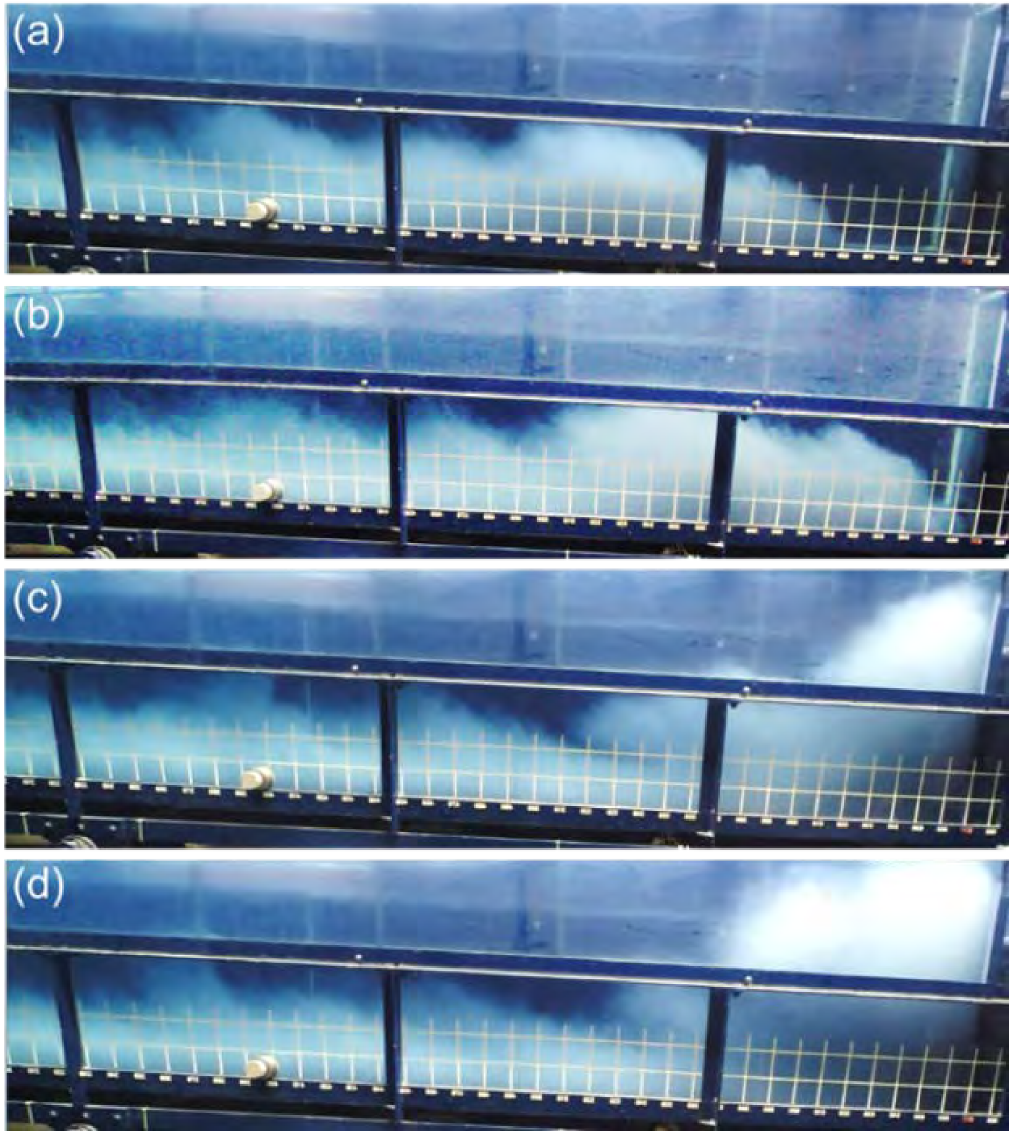
Φ = 50%



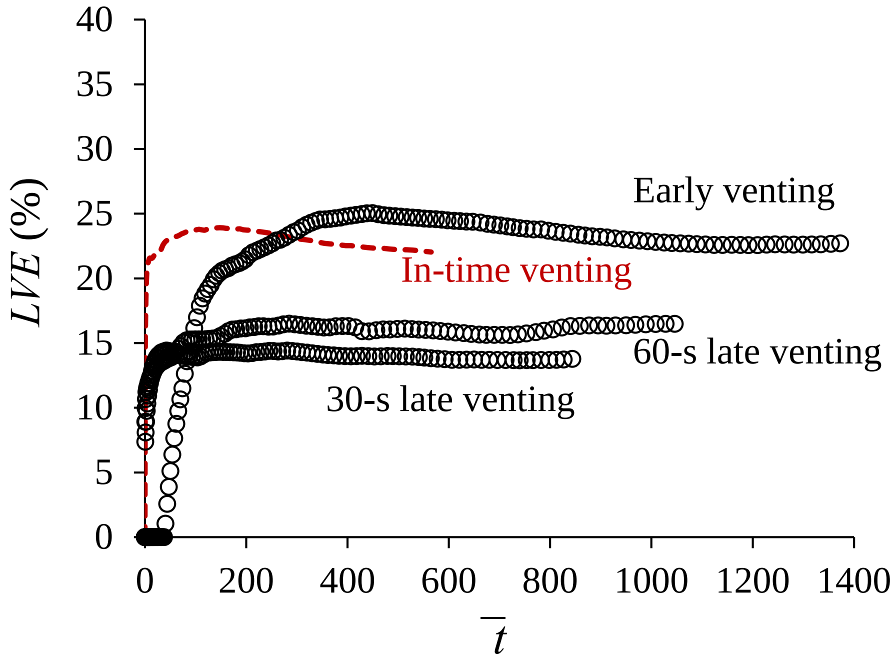
Φ = 100%

Steeper bed slopes lead to higher venting efficiencies.

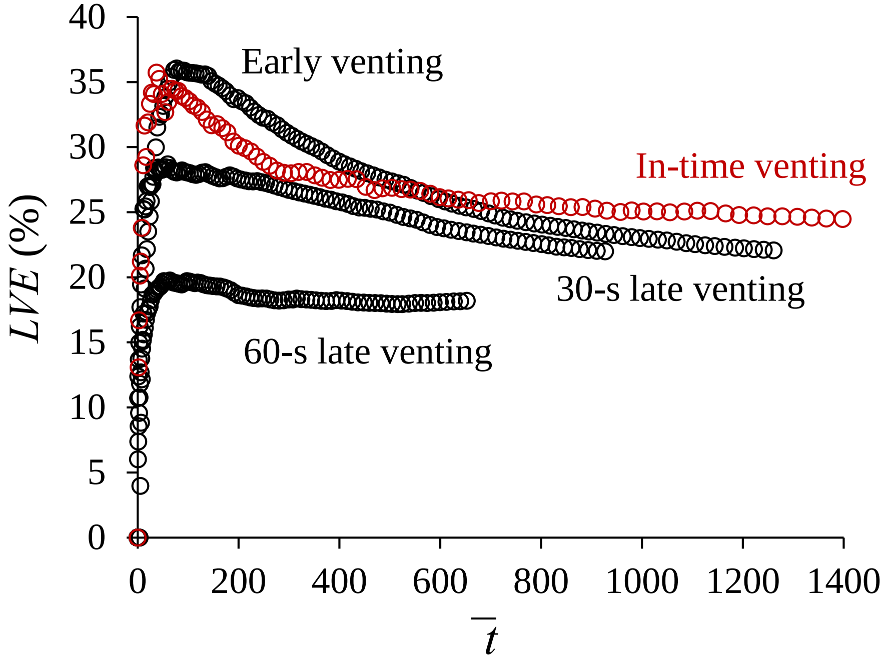
LVE with different timings



LVE with different timings



$S = 2.4\%$; $\Phi = 115\%$

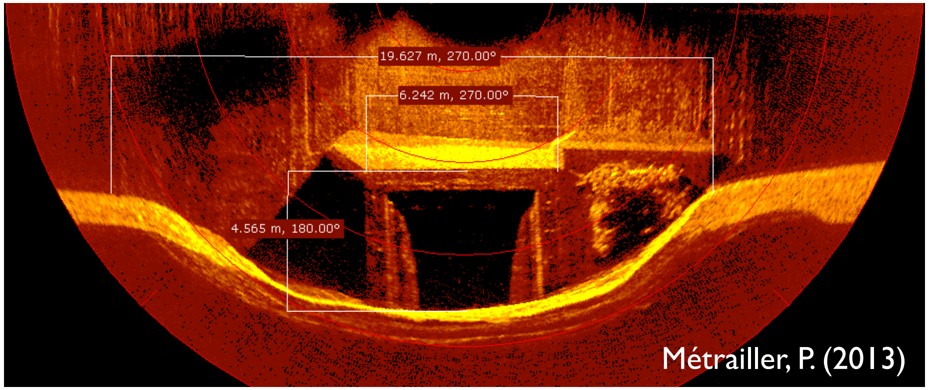


$S = 5\%$; $\Phi = 115\%$

The timing or start of venting should be synchronized with the arrival of the turbidity current at the dam.

Conclusions

- On a horizontal bed, venting is the most efficient with ϕ = 100%. With the 2.4% and 5.0%, venting is the most efficient using ϕ = 135%.
- Venting efficiency increases with increasing slopes. Hence, venting should start directly after the commissioning of the dam, in order to maintain the formation of a cone in front of the low-level outlets and avoid the filling of the dead storage.
- Venting is the most efficient when synchronized with the arrival of the turbidity current at the outlet.
- Early venting is more efficient than late venting.



Métrailler, P. (2013)

Journal publications

Chamoun, S., Zordan, J., De Cesare, G., and Franca, M.J. (2016), "Measurement of the deposition of fine sediments in a channel bed", *Flow Measurement and Instrumentation,* 50, pp. 49-56.

Chamoun, S., De Cesare, G., and Schleiss, A.J. (2016), "Managing reservoir sedimentation by venting turbidity currents: A review", *International Journal of Sediment Research*, 31, pp. 195-204.

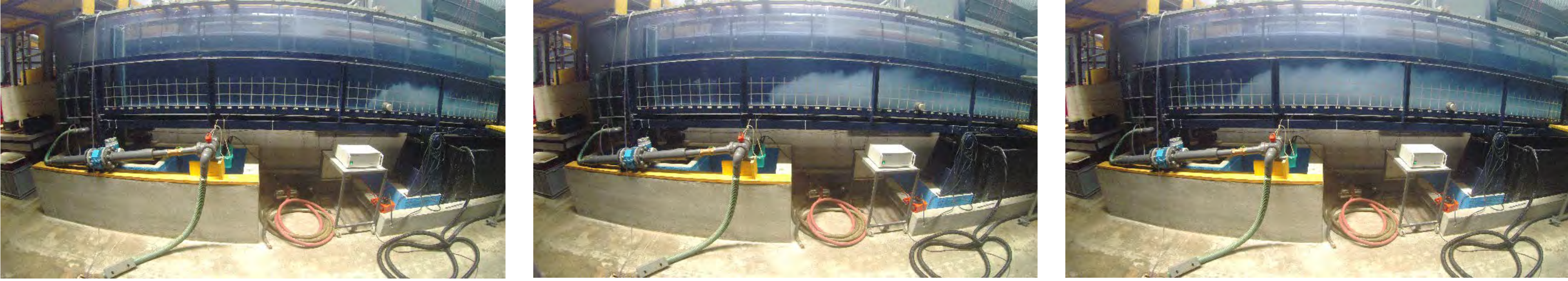
Chamoun, S., De Cesare, G., Schleiss, A.J. (2017), "Venting of turbidity currents through a rectangular opening", *Journal of Hydraulic Research* (accepted for publication, available online).

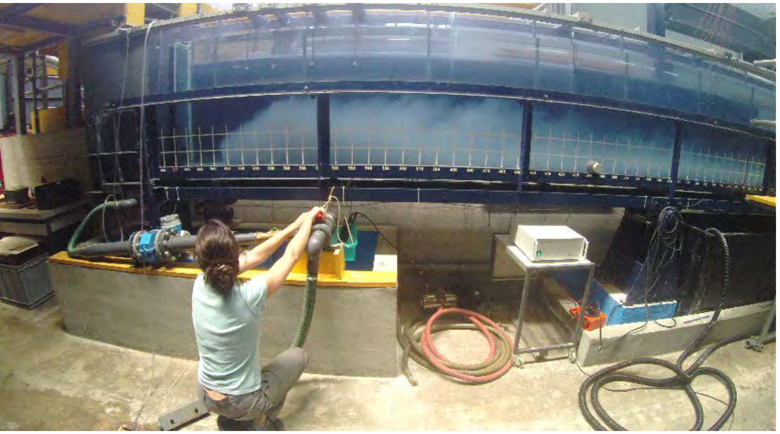
Chamoun, S., De Cesare G., and Schleiss A.J. (2016) "Venting turbidity currents for the sustainable use of reservoirs" *The International Journal on Hydropower & Dams*, 64-69.

Chamoun, S., De Cesare, G., Schleiss, A.J. (2017), "Management of turbidity current venting in reservoirs under different thalweg slopes", *Journal of Environmental Management,* 204, pp. 519-530 .

Chamoun, S., De Cesare, G., Schleiss, A.J. (2017), "Influence of operational timing on the efficiency of venting turbidity currents", *Journal of Hydraulic Engineering, 144(9)* .

Chamoun, S., De Cesare G., and Schleiss A.J. "L'évacuation des courant de turbidité en vue de réduire la sedimentation des reservoirs de barrages" *Wasser Energie Luft,* 110, pp. 7-12.





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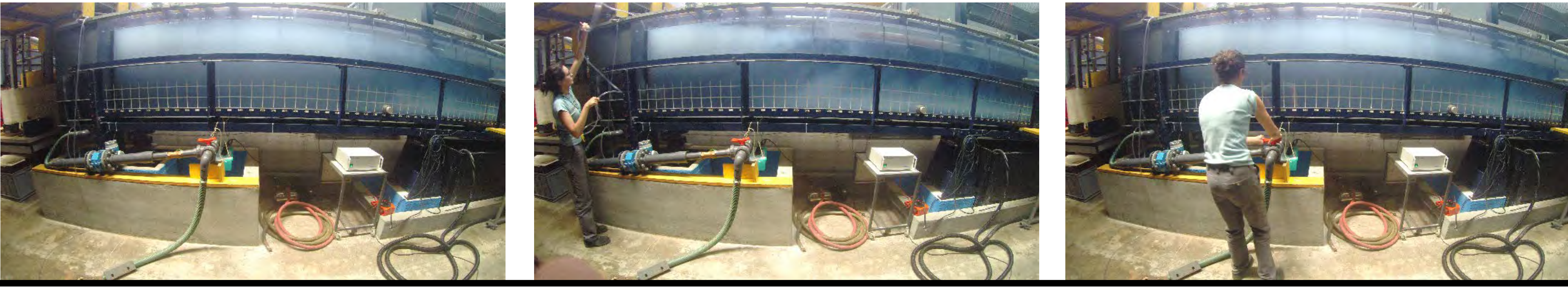

Research funding:

swisselectric research

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Appendix slides

Many factors determine rates of mechanical abrasion. Of particular importance is sediment type and physical characteristics. Angular sediments composed of minerals with a Mohs hardness greater than 5 - such as quartz, feldspar and tourmaline - are problematic. In addition, hydraulic and facility operation parameters such as flow velocity, hydraulic head, turbulence, turbine rotation speed and turbine material affect abrasion susceptibility. Impulse turbines, such as Pelton or Turgo, are more susceptible to abrasion than are reaction turbines.[8] However, runner changes and needle tip/seat ring replacement are much easier with Pelton turbines. Therefore, they may be preferable on the basis of the overall life cycle cost.

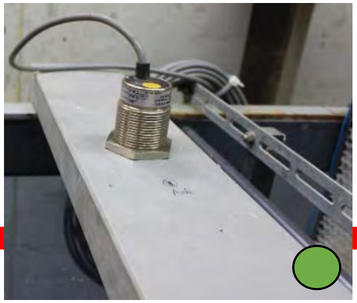
Turbine designs need to minimize peak velocities to reduce impacts. For a Pelton turbine, fewer jets and larger runner buckets with larger radii reduce centrifugal forces between the sediment and runner surfaces. Regardless of the turbine selected, designs must consider issues such as the ease of runner removal for future maintenance.

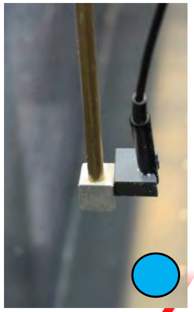
Abrasion can be reduced by selecting metals to increase erosive resistance and/or by reducing the volume of fine sediment that reaches mechanical equipment. Plants often are designed to remove most of the coarse sediment particles. However, even silt can cause significant abrasion if the quartz content and pressure head is high enough.[9] The 1,500 MW Nathpa Jhakri hydroelectric plant in India used four desilting chambers that were successful in removing coarser sediments. However, damage from the finer particles was so severe that parts of the turbines had to be replaced within one year.

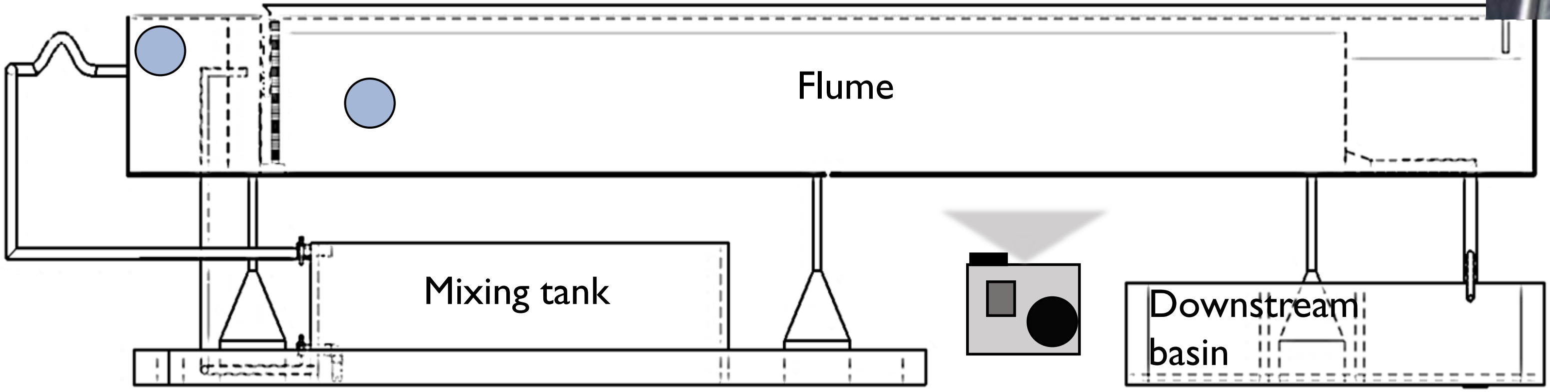
Materials used commonly in sediment-prone hydropower plants are stainless steels that are heat treated for hardening and increased protection from abrasion.[8] Protecting mechanical equipment from sediment abrasion can also be achieved with hard surface coatings of ceramic paints or pastes or with hard facing alloys.[8] Research has shown improved resistance to sediment abrasion when tungsten carbide-based composites are used as a surface coating.[8] In undertaking such assessments, it is important to consider the fact that abrasion will increase as the reservoir fills. The Nozaki method can be used to assess turbine repair frequency. The method accounts for the effective sediment concentration, particle size and shape, the turbine material and any coatings.

Measuring instruments

	Instrument	Parameter
🔴	Electromagnetic flowmeter	Discharge
🟢	Ultrasonic level probe	Water level
🟠	Turbidity probe	Concentration
🟣	Depositometer	Deposition thickness
🔵	UVP transducer	Velocity profiles
⚪	Thermometer	Temperature
⚫	Camera	Photos and video recording



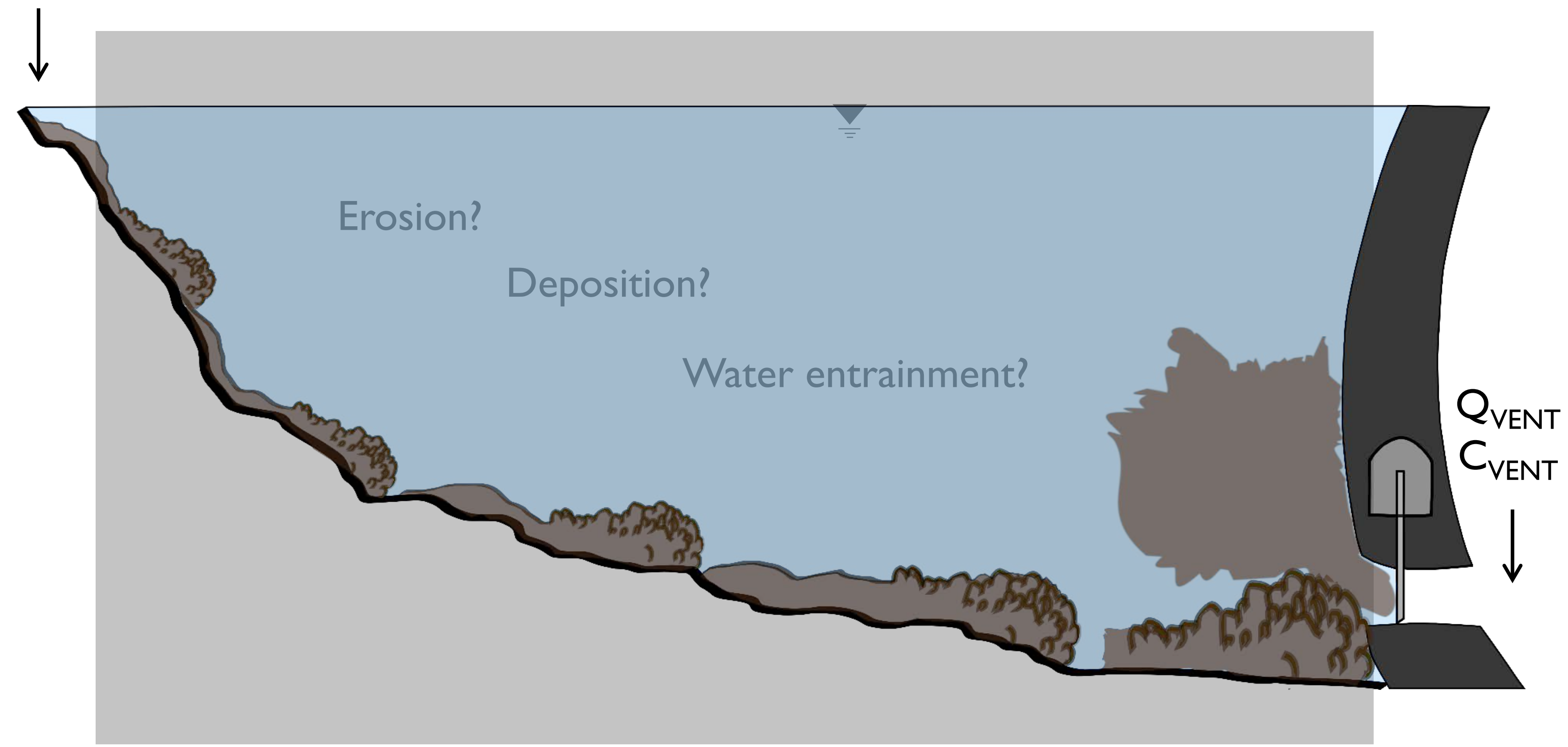




Global view

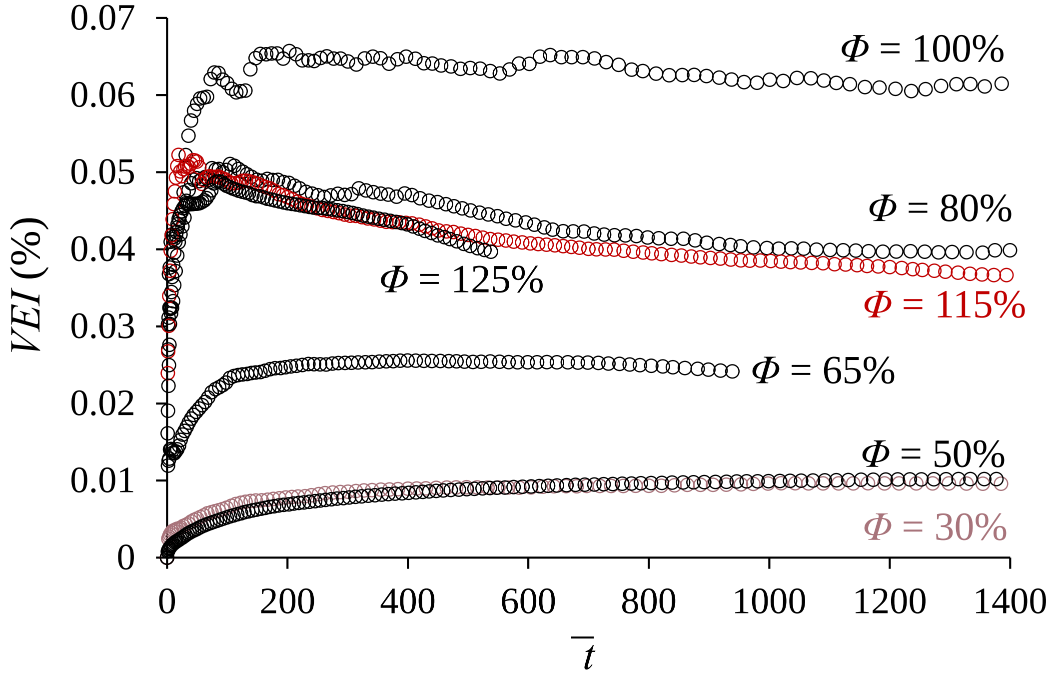
$$VE = \frac{M_{VENT}}{M_{TC}} = \frac{\int_{t=0}^{t=T} C_{VENT}\, Q_{VENT}\, dt}{\int_{t=0}^{t=T} C_{TC}\, Q_{TC}\, dt}$$

Q_{TC}
C_{TC}



Q_{VENT}
C_{VENT}

Venting efficiency indicator



$\bar{t}$: Normalized venting duration

VEI : Venting efficiency indicator

When considering water losses:

- For $\phi = 115\%$ and 125%, curves shifted below $\phi = 100\%$ and very similar to $\phi = 80\%$
- *VEI* is closely similar for $\phi = 30\%$ and 50%

Venting on a horizontal bed leads to the highest efficiencies when using $\phi = 100\%$.

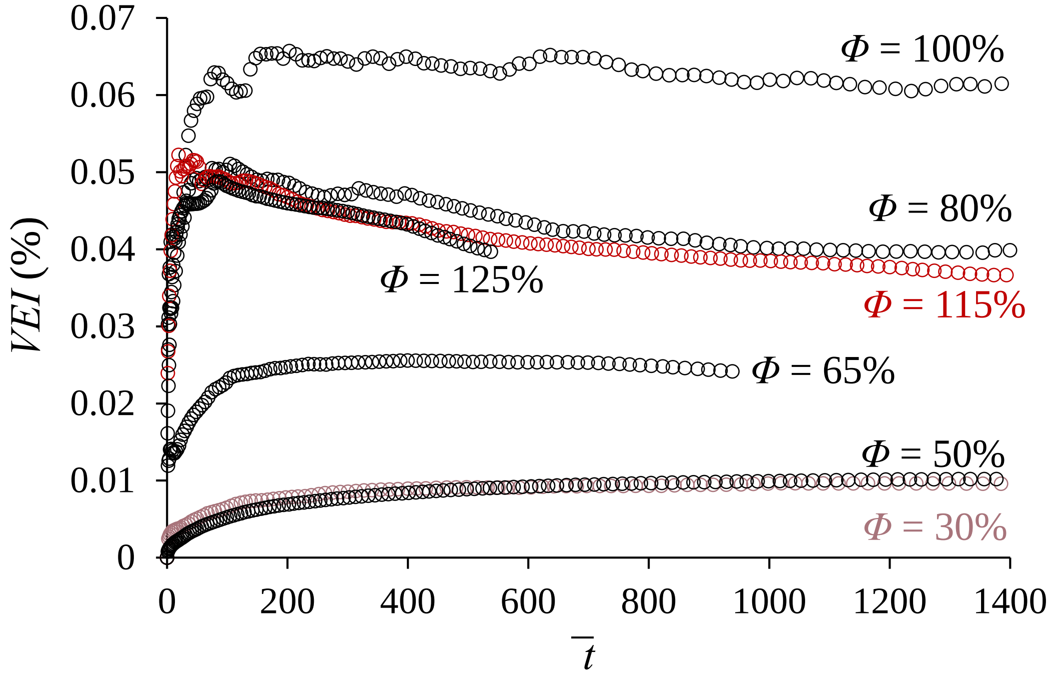
Venting efficiency indicator

$$VEI = \frac{\int_{t=T_{vi}}^{T_{vf}} C_{VENT}\, Q_{VENT}\, dt}{\int_{t=T_{vi}}^{T_{vf}} C_{TC}\, Q_{TC}\, dt - \int_{t=T_{vi}}^{T_{vf}} \dot{m}_{dep}\, dt} \; \frac{\overbrace{\int_{t=T_{vi}}^{T_{vf}} V_{VENTsed}\, dt}^{\text{Total outflow sediment volume } \textbf{during} \text{ venting}}}{\underbrace{\int_{t=T_{vi}}^{T_{vf}} V_{VENTwat}\, dt}_{\text{Total outflow water volume } \textbf{during} \text{ venting}}}$$

$V_{VENTsed}$ = Volume of sediments evacuated during venting

$V_{VENTwater}$ = Volume of clear water evacuated during venting

Venting efficiency indicator



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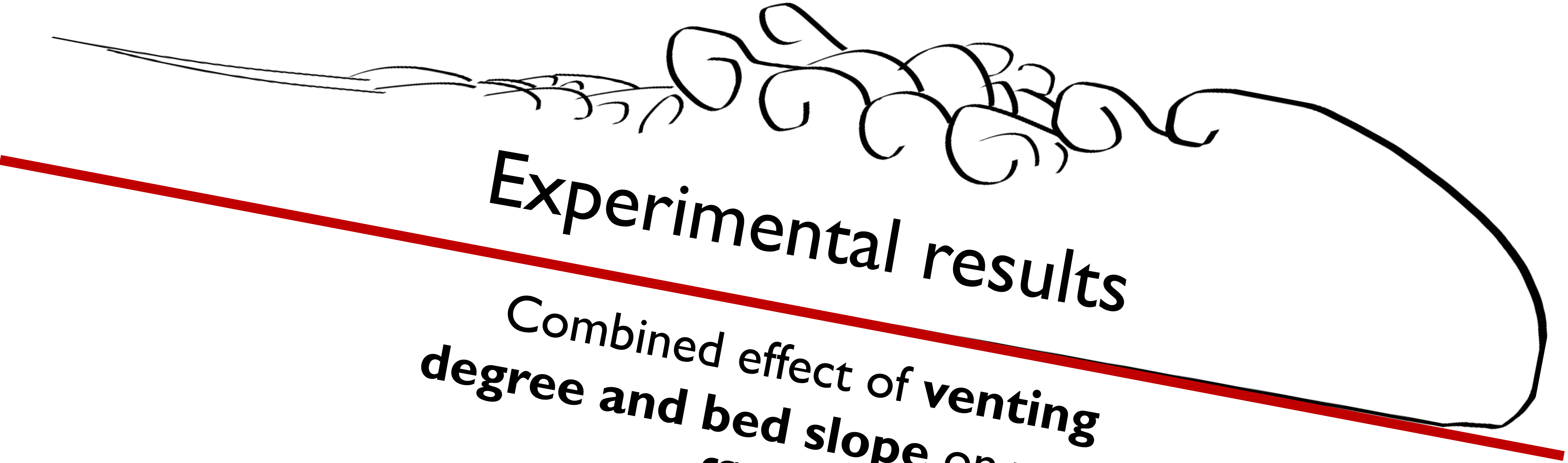

Experimental results

Combined effect of **venting degree and bed slope** on venting **efficiency**

Chamoun, S., De Cesare G., and Schleiss A.J. (201X) "Venting of turbidity currents on different bed slopes.", *Journal of Environmental Management* (under revision)