

Numerical simulations of a waterfall in a downstream basin

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Context of the study



Downstream migration

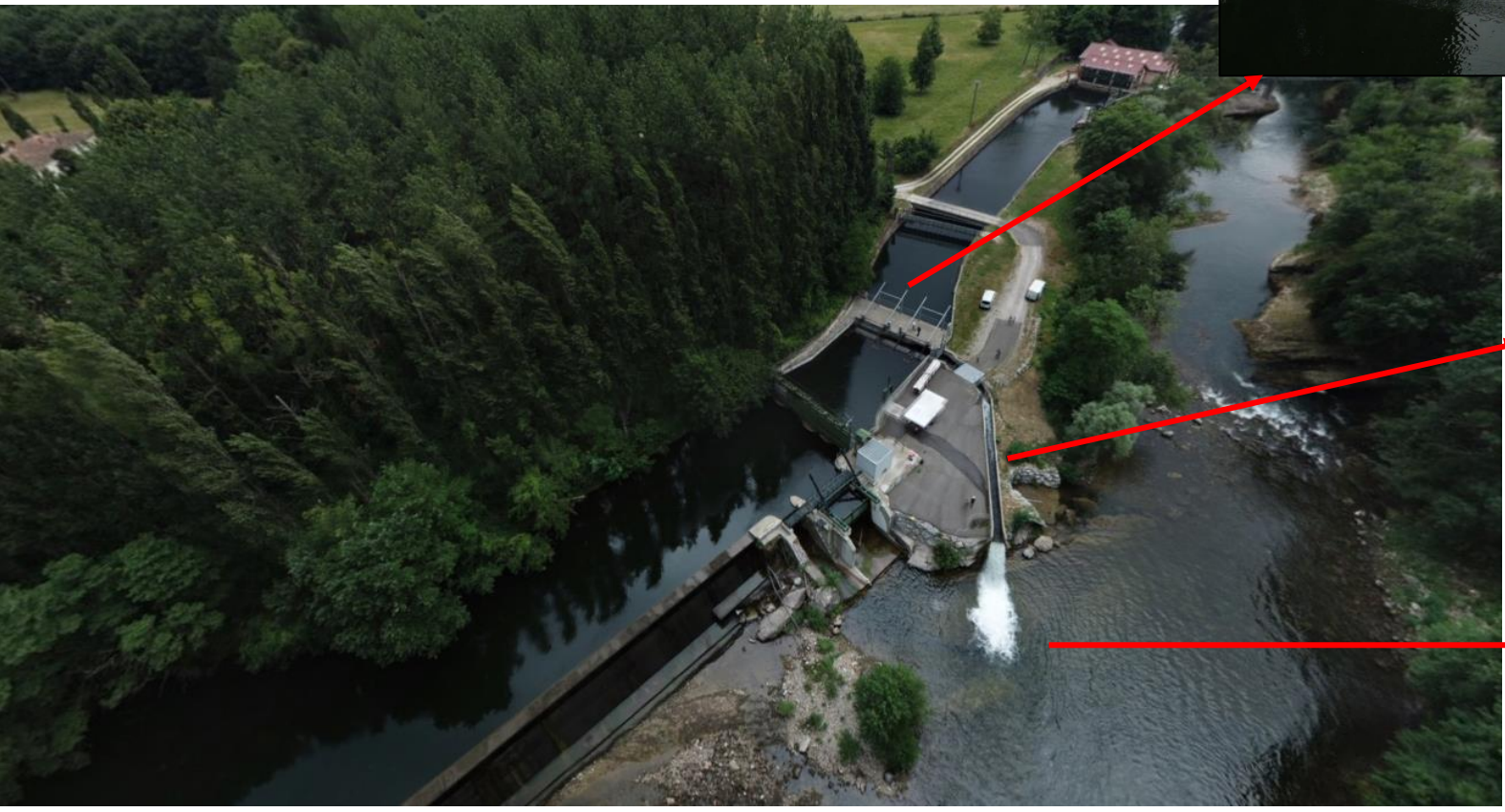
- Different solutions (Rutschmann et al. 2022)
- Bypass system should be attractive
- Reception zone should be safe

| | Concept | Type | Measure | | |
|----------------------------------|--|---|-------------------|--------------|--|
| | Fish Protection Technologies at HPP | Screening / Shielding and Guidance | Physical Barriers | Fine Screens | |
| Submerged Bar Screens | | | | | |
| Rotary Screens | | | | | |
| Eicher-Screen | | | | | |
| Wedge-Wire-Screen | | | | | |
| Barrier Nets | | | | | |
| Mechanical, Behavioural Barriers | | Skimming Walls | | | |
| | | Louvers | | | |
| | | Bar-Racks | | | |
| | | Plate Screens | | | |
| Sensory, Behavioural Barriers | Trash Racks | | | | |
| | Light (Strobe or Mercury) | | | | |
| | Low Frequency Sound | | | | |
| Collection Systems | Popper | | | | |
| | Electricity | | | | |
| | Air- / Water Curtains | | | | |
| | Surface Collection Pipes | | | | |
| Conveyance | Fish Friendly Turbines | Traveling Screens | | | |
| | | Fish Pumps | | | |
| | | Trap and Truck | | | |
| | Fish Friendly Operation | Alden Turbine | | | |
| | | Voith - Minimum Gap Runner | | | |
| | Alstom - Fish Friendly Kaplan-Turbine | | | | |
| | Early Warning Systems | | | | |
| | Weir Overflow | | | | |
| | No Partial Load Operation | | | | |



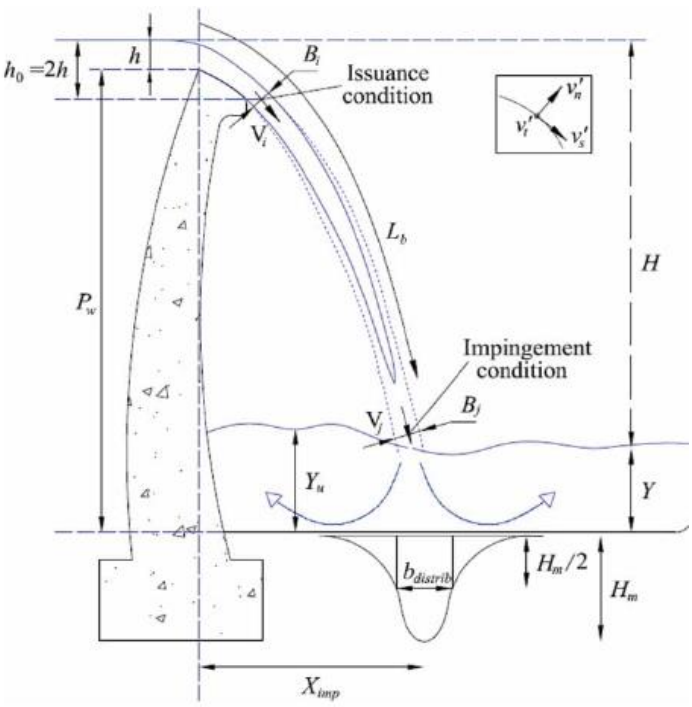
Context of the study

- Las Rives Hydro Power Plant



Context of the study

- Conditions of reception in the river



Plunge pool scheme from Castillo et al. (2014)

Criteria used in the reception zone :

- a minimum water depth of $\frac{1}{4}$ of fall height *Odeh and Orvis (1998)*
- Velocity at impact $< 5\text{m/s}$ *Turnpenny (1998), Amaral et al. (2011)*



However, these criteria integrate neither the discharge of the downstream jet, the initial velocity of the flow at the outlet of the downstream passage device, nor the shape of the jet (sheet or cylindrical) and its dimensions.

The global objective of the project is therefore to improve these reception criteria, to ensure that fish can transit without death or injury.

Context of the study

- Tests on the reception basin

$H=3.35$ m

$Y=0.68$ m $< \frac{1}{4} H$

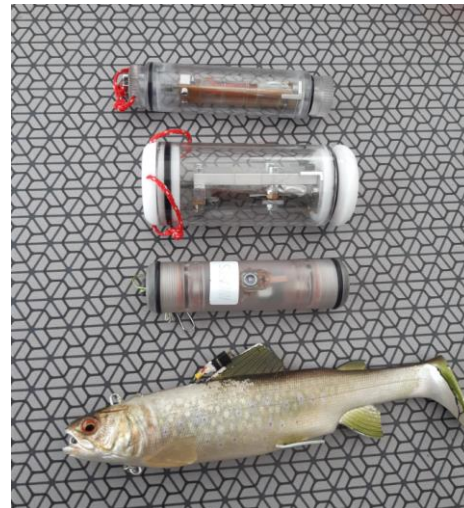
Criteria not validated



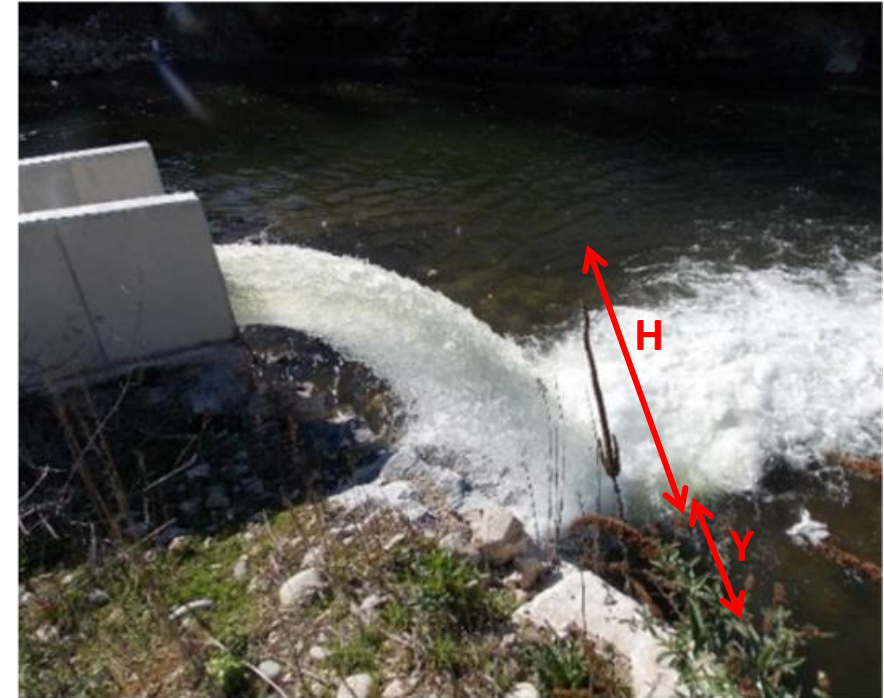
Apples



Smolts



Fish sensors



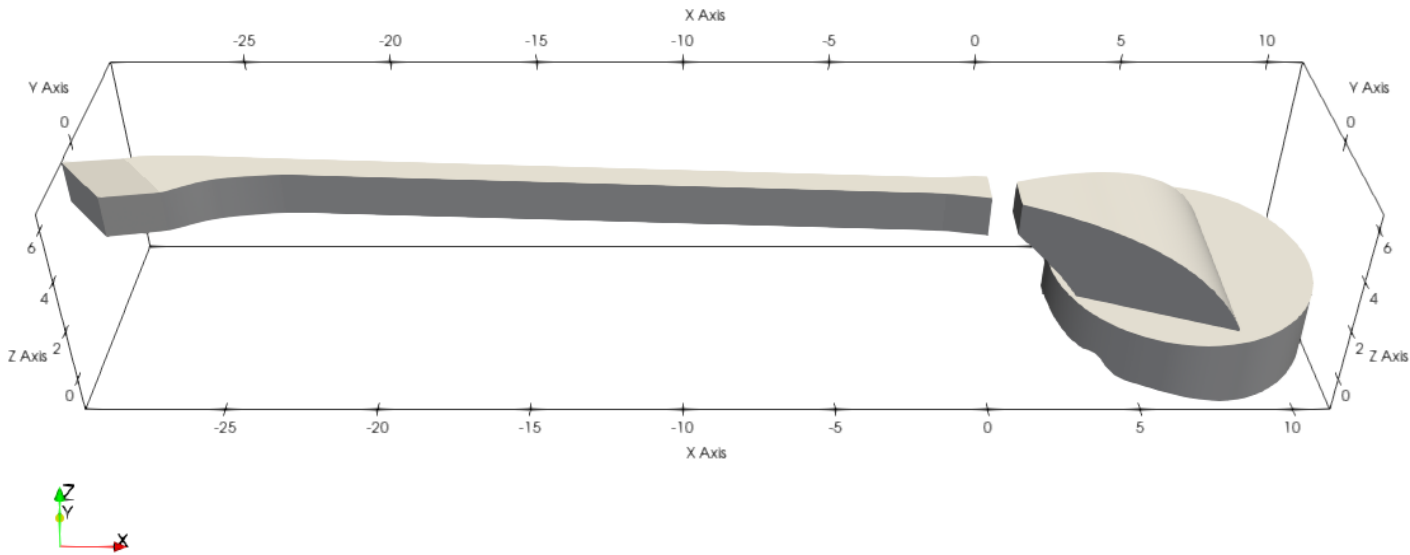
Results from *Bercovitz et al. (2022)*:

- Apples 69% without marks, 31% with marks
- Smolts 10% with minor injuries and 3 % with major injuries

The objective is now to improve this reception zone, to ensure that fish can transit without death or injury.

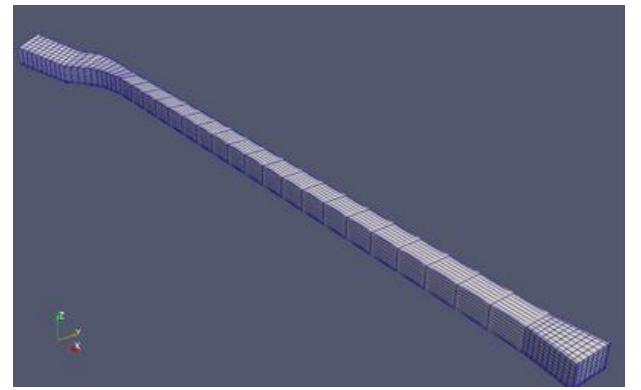
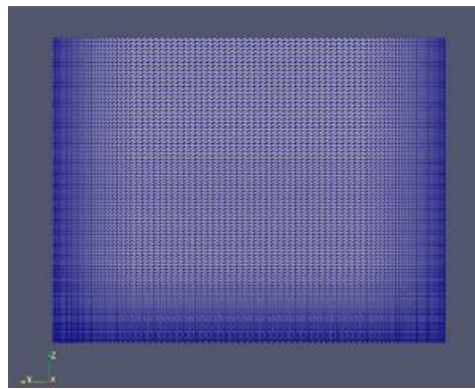
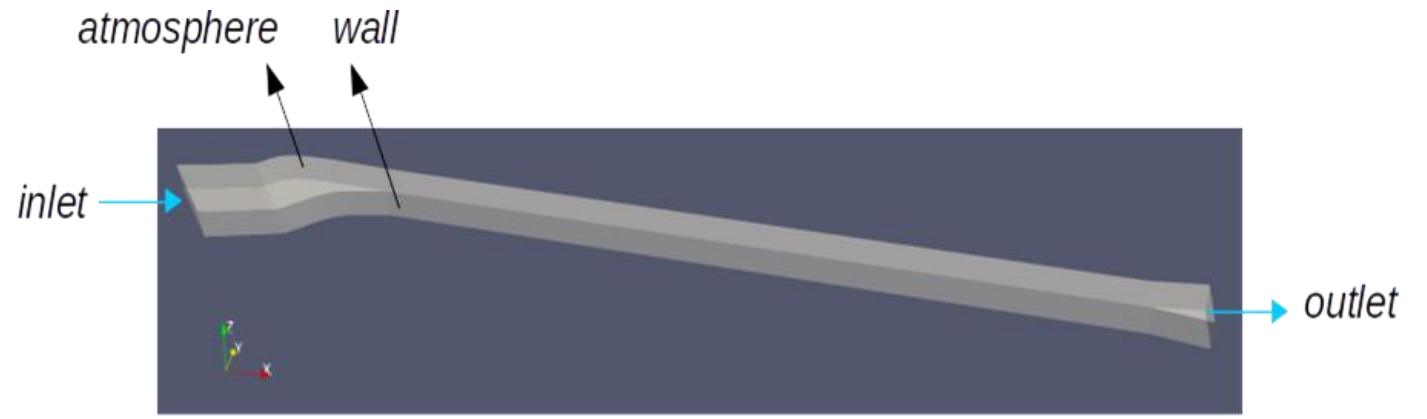
Main objectives

- Numerical simulations of the channel and of the waterfall with OpenFOAM
- Unsteady Reynolds Averaged Navier-Stokes (URANS) simulations, either with a Volume of Fluid or a Two-Phase flow approach (VOF/Two phases)
- Laminar or turbulence modelling
- Validation with experimental measurements



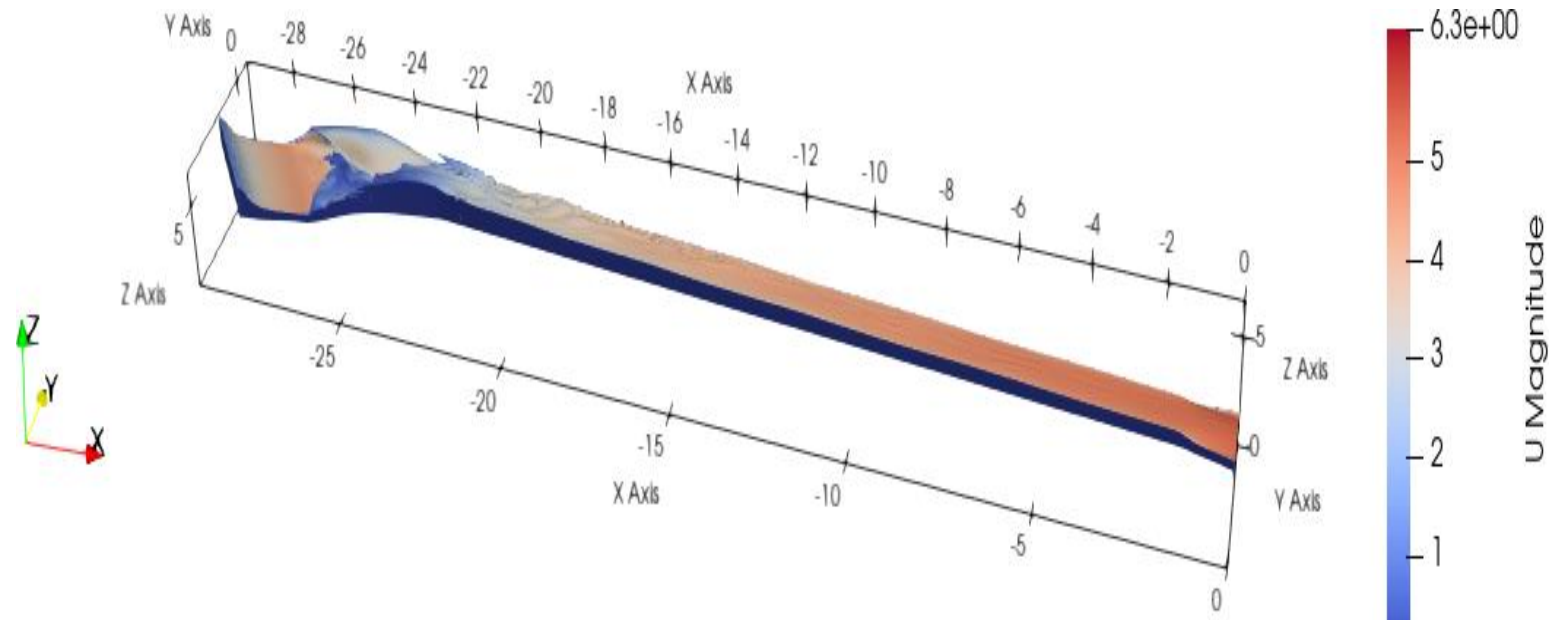
Numerical simulation of the channel

- InterFOAM Solver
- VOF
- *Model $k-\omega_{SST}$*
- Wall functions

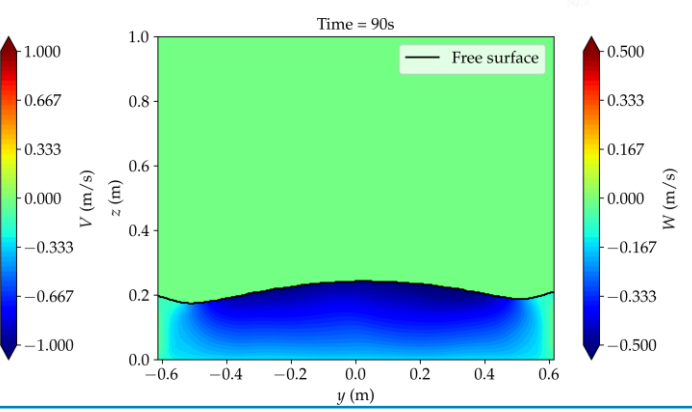
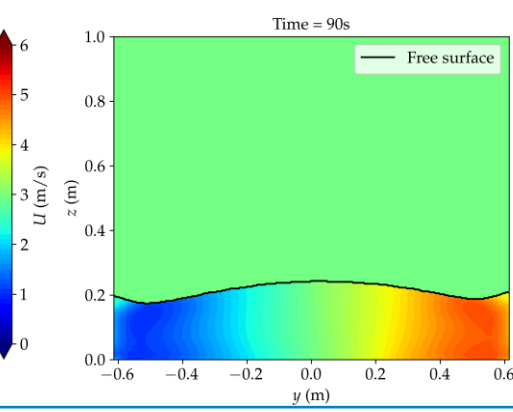
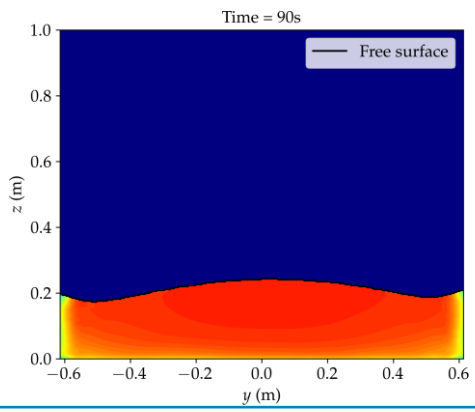


Numerical simulation of the channel

- InterFOAM Solver
- VOF
- Model $k-\omega_{SST}$
- Wall functions

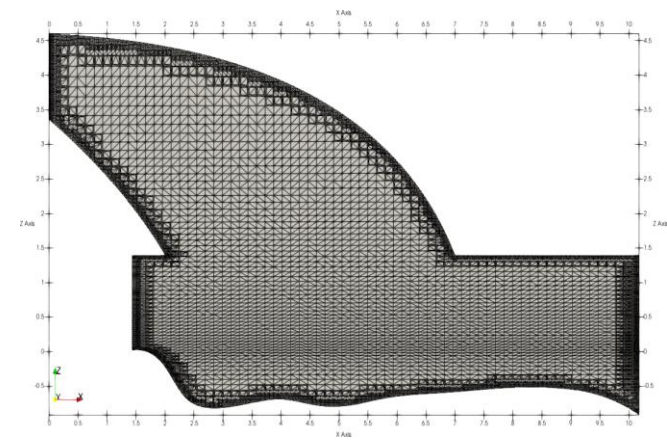


Outlet phase/velocity distribution
=
Inlet phase/velocity distribution for the waterfall

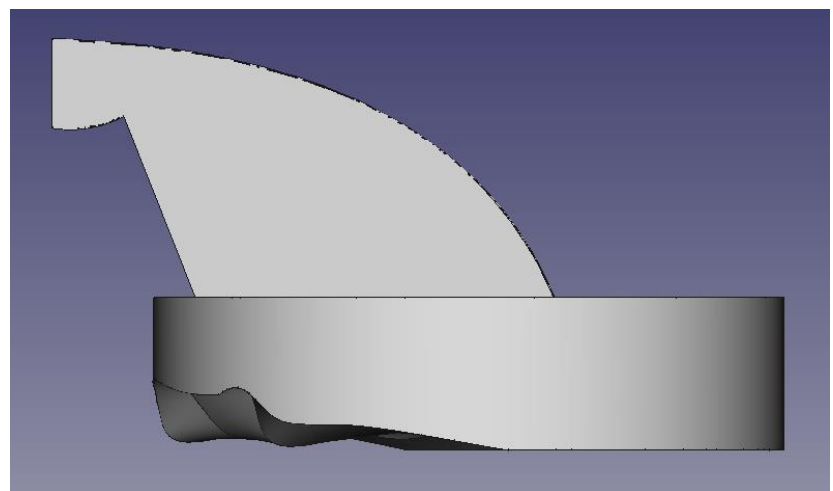


Numerical simulations of the waterfall

- InterFoam + VOF
Laminar, Turbulence model $k-\omega_{SST}$ or $k-\epsilon$
- Two-Phase Euler Foam
Laminar, turbulence model $k-\epsilon$
- Inlet waterfall = Outlet channel
- Wall functions at the bottom

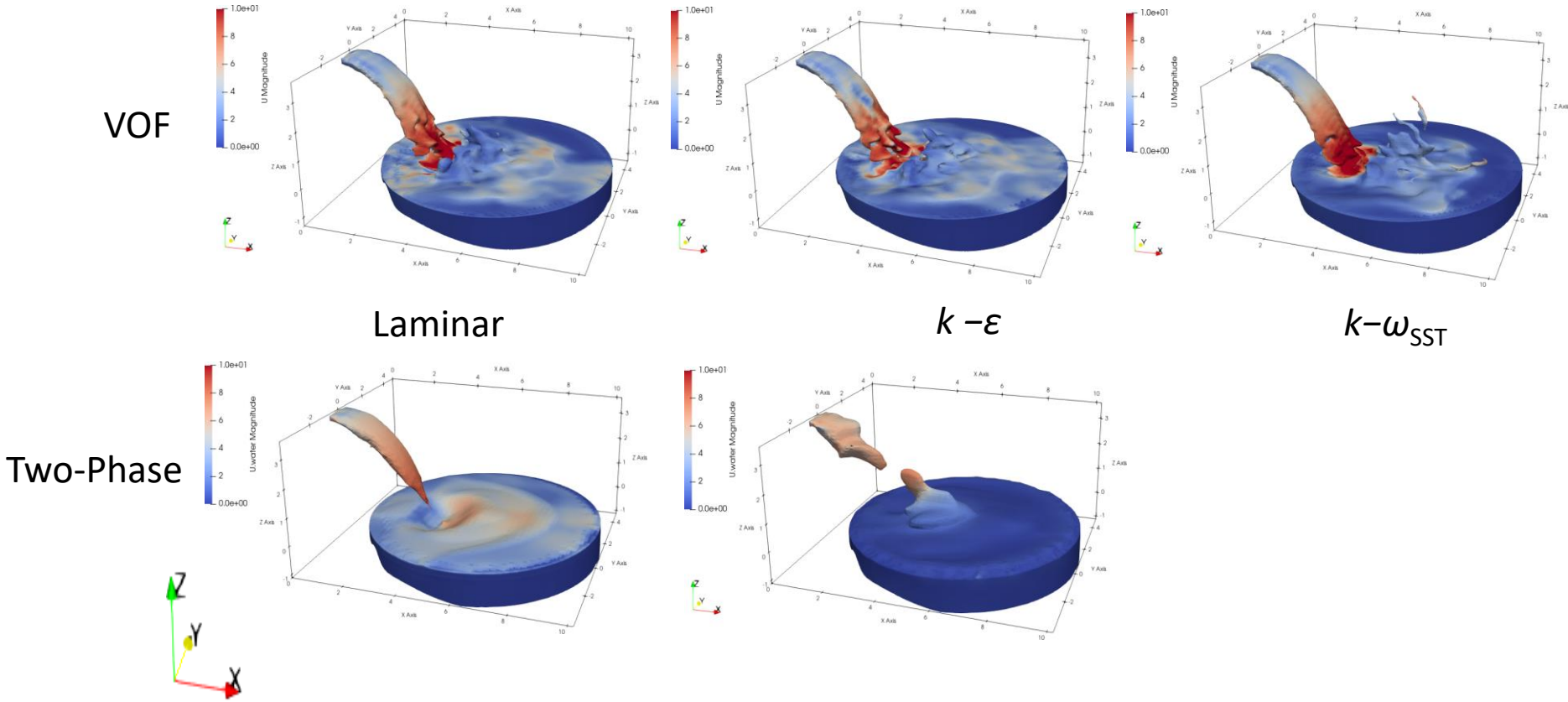


| | inlet | outlet | wall | atmosphere |
|----------------------|-----------|--------------|---------------|--------------|
| Fluid fraction | Dirichlet | Neumann | Neumann | inletOutlet* |
| Velocity | Dirichlet | inletOutlet* | No slip | inletOutlet* |
| Pressure | Neumann | Dirichlet | Neumann | Dirichlet |
| laminar (1,2) | Dirichlet | inletOutlet* | wall function | inletOutlet* |
| $k-\omega_{SST}$ (1) | Dirichlet | inletOutlet* | wall function | inletOutlet* |
| $k-\epsilon$ (1)(2) | Dirichlet | inletOutlet* | wall function | inletOutlet* |



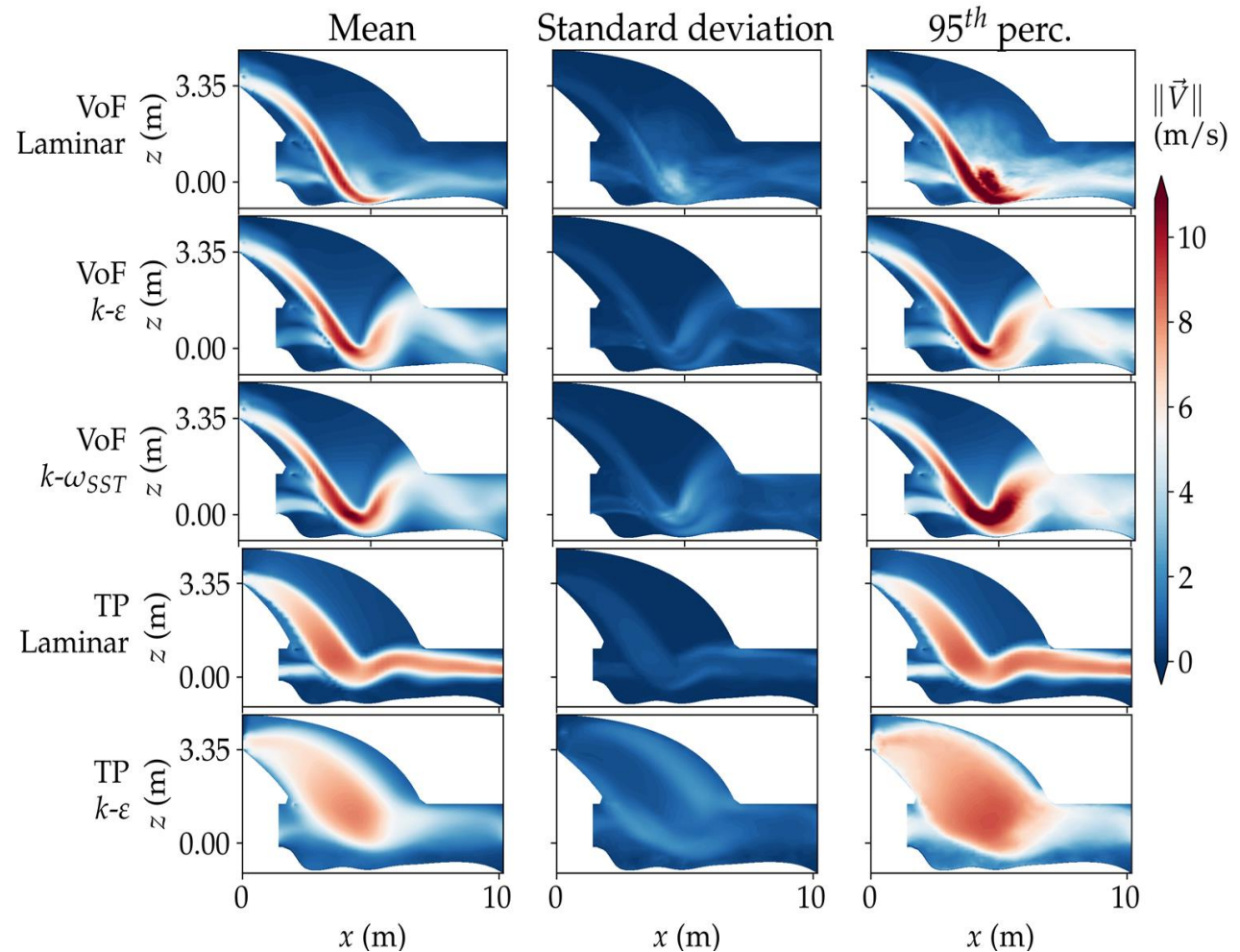
Numerical simulations of the waterfall

- Velocity fields at the iso-surface $\alpha_{\text{water}}=0.9$



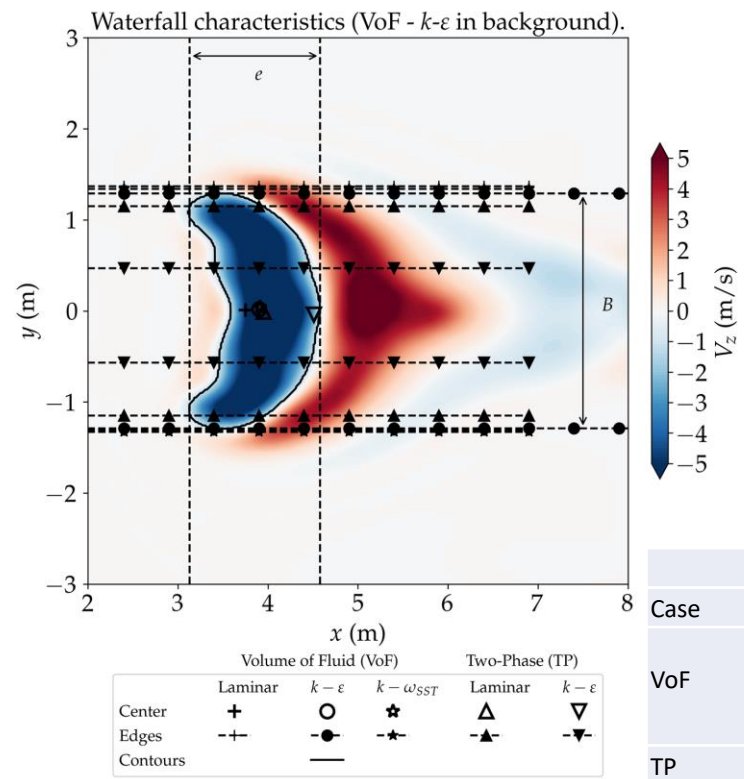
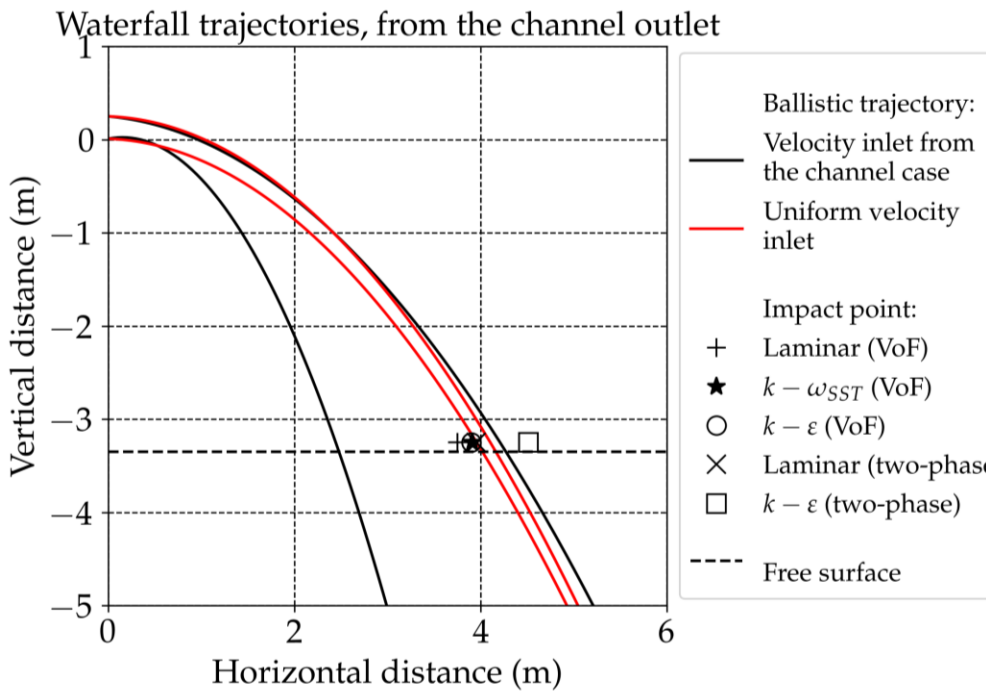
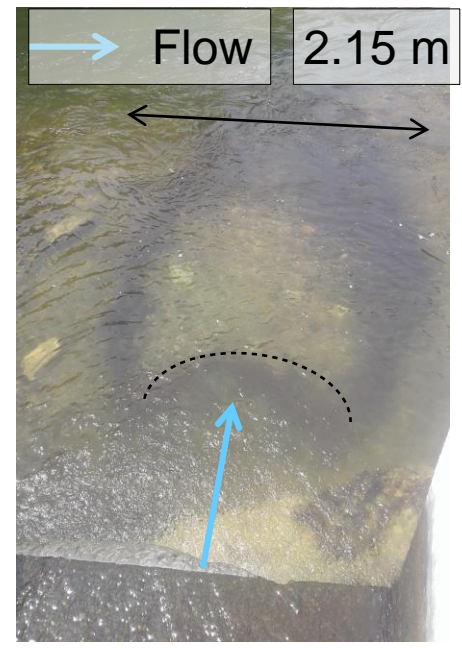
Numerical simulations of the waterfall

- Velocity fields at $y=0$



Numerical simulations of the waterfall

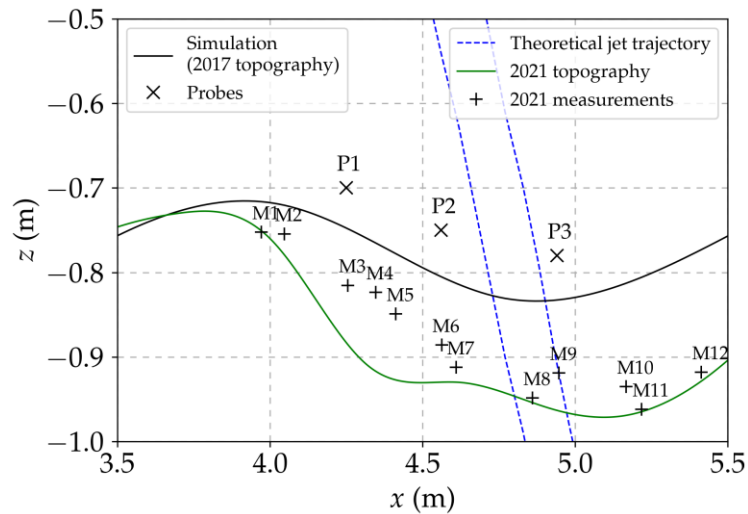
Intersection of the waterfall with the free surface



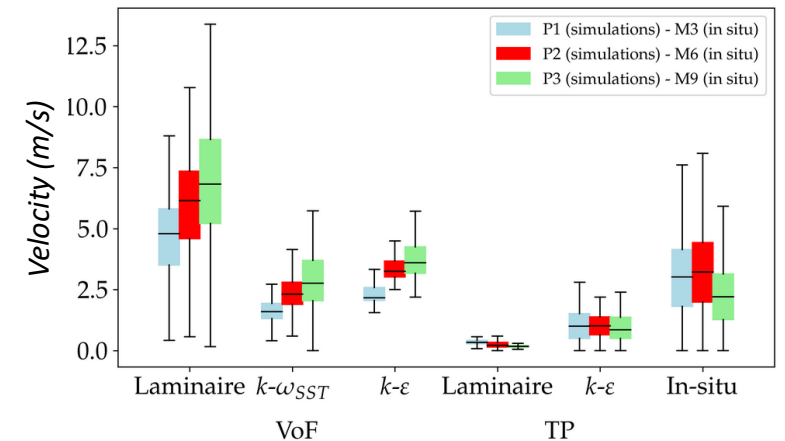
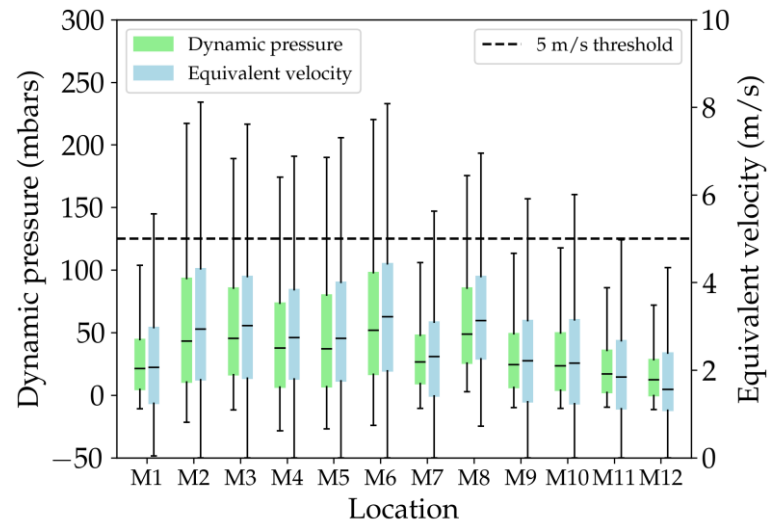
| Case | Model | Xc (m) | Yc (m) | Vmax (m/s) | e (m) | B (m) |
|--|--------------------|-------------|--------|------------|-------|-------------|
| VoF | laminar | 3.61 | 0.04 | 9.61 | 1.68 | 3.00 |
| | $k - \epsilon$ | 3.82 | 0.03 | 10.65 | 1.69 | 2.77 |
| | $k - \omega_{SST}$ | 3.82 | 0.01 | 10.25 | 1.57 | 2.65 |
| TP | laminar | 3.89 | 0.00 | 7.72 | 1.66 | 2.66 |
| | $k - \epsilon$ | 4.38 | -0.02 | 6.32 | 2.40 | 1.43 |
| Theoretical trajectories (Courret et al, 2020) | | 4.20 - 4.45 | 0.0 | 9.6 - 10 | / | 2.34 - 2.39 |

Numerical simulations of the waterfall

- Comparison with pressure measurements



Location of the pressure measurements and the numerical probes



Conclusion

- The main objective is to revisit the reception criteria, to ensure that fish can transit without death or injury.
- Numerical simulations have been carried out to reproduce the in-situ flows, in particular the reception zone
- Comparison between two approaches (VOF and Two-Phases flows) with laminar or turbulence models ($k-\varepsilon$ and $k-\omega_{SST}$)
- **VOF approach with a turbulence model ($k-\varepsilon$ or $k-\omega_{SST}$) represents well the pressure at the bottom and the intersection with the free surface.**
- This approach could be used in the future to improve the downstream basin by proposing technical solutions (increasing the water depth, moving the reception zone by adding an appendice, increasing the waterfall width, ...)



Thank you for your attention

- Novel developments towards sustainable hydropower. 2022. Editors P. Rutschmann, E. Kampa, C. Wolter, I. Albayrak, L. David, U. Stoltz and M. Schletterer. 223 pages, Springer Nature.