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VERTICAL SLOT FISHWAY SIMULATED WITH PCFLOW2D AND DUALSPHYSICS V4.2 MODELS

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ABSTRACT

Correct predictions of flow through fishways are important for both designing and determining their suitability for diverse fish species. We present simulations with Dual SPHysics v4.2 code in a vertical slot fishway (VSF) previously investigated with extensive field measurements, a physical model and a validated two-dimensional depth-averaged numerical model PCFLOW2D. Field measurements of water surface elevation and flow velocity components were performed during steady flow with Q = 1.0 m^3/s discharge, average depth h = 1.3 m and head difference Δh = 0.05 m between adjacent pools. An inlet section, 9 pools, and an outlet section were simulated, amounting to dimensions of 39.5 x 2.2 x 1.5 m. A periodic boundary condition was used to simulate a subcritical free-surface flow. The following execution parameters of DualSPHysics were employed: initial inter-particle distance of 0.02 m (amounting to about 15 million particles), simple precision, Verlet algorithm, artificial viscosity alpha value of 0.01, zero viscosity factor with boundary, no delta-SPH, no shifting. Time of simulation was set to 30 s to allow flow conditions to become steady. Simulations were performed on a PC with a single Nvidia GTX 1080 graphics card. Discharge and water depth were calculated correctly in the observed pool in the middle of the fishway and in both adjacent pools. The longitudinal water surface drops Δh between the pools were slightly underestimated, and the tailwater elevation was slightly overestimated. Despite certain discrepancies, the measured and the calculated velocity profiles were in relatively good agreement. DualSPHysics proved to be a fast and satisfactory accurate tool for 3D modeling of flow conditions in VSF.

Keywords: DualSPHysics, vertical slot fishway, 3D simulation, CFD

1 INTRODUCTION

Fishways have a great ecological importance as they bridge the interruption of fish migration routes, caused by dams of hydropower plants. One of the various types of fishways is a vertical slot fishway (VSF), which is characterized by the linear relation between flow and depth. One such VSF is located at the Arto – Blanca hydropower plant in Slovenia. Prior to this paper, this VSF was subject to field measurements (Bombač et al., 2015), a scaled physical model, and a depth-averaged two-dimensional (2D) numerical model PCFLOW2D (Bombač et al., 2014, 2017). With release of the new version of DualSPHysics code in 2018 (version 4.2) we run simulations on a graphical processing unit (GPU) and test the results against both the experimental data and the results from 2D simulations of the VSF.

Generally, flow conditions in a VSF are mostly two-dimensional (i.e. velocity components in vertical direction are practically negligible, as shown in Bombač et al., 2015), and significantly different from the 3D cases of violent flows or breaking waves, which are typically simulated with smoothed particle hydrodynamics (SPH) models, such as DualSPHysics. However, the abundance of the experimental data made it reasonable to test the freshly released DualSPHysics 4.2 even against such mild case of turbulent free-surface flow, as an increasing number of fishways are being simulated with more established 3D mesh models (one recent example being Duguay et al., 2017).

This paper gives a brief overview of the field measurements, depth-averaged 2D model, and DualSPHysics v4.2 model. It then discusses the DualSPHysics results into more detail. At the time of writing (spring 2019), additional simulations of the mentioned VSF are being performed using the beta release of DualSPHysics v4.3, which includes an improved set of open boundary conditions (e.g. inlet / outlet).

2 FIELD MEASUREMENTS

The presented VSF is located at the Arto – Blanca hydropower plant (HPP) in Slovenia. It consist of two reaches: a concrete upstream reach with vertical slots (i.e. VSF reach) is followed by a significantly more naturallike meandering downstream reach, as shown in Figure 1. This paper focuses on the straight section within the VSF reach.


Figure 1. Fishway at HPP Arto – Blanca, Slovenia: the VSF reach (left), and the meandering reach.

During field measurements the VSF flow conditions were kept constant, namely: discharge Q = 1.0 m^3/s, water depth h = 1.3 m, head difference between pools Δh = 0.05 m, and water slope S_0 = 0.0167. In the selected pool, located in the middle of the straight concrete reach, the following parameters were measured: water surface elevation, bed elevation, and all velocity components. Elevations were determined with leveling, while flow velocities were measured with SonTek 3D Micro – Acoustic Doppler Velocimeter (i.e. ADV probe). Velocities were measured in more than 250 points covering the whole area of the selected pool. The preliminary measurements along various verticals confirmed the two-dimensional nature of the VSF flow, i.e.: vertical distributions of components u, v, and w were all uniform, and values w were practically zero. With velocities u and v having uniform vertical distribution, only the velocities in the horizontal plane z / h = 0.4 were recorded.

3 SIMULATIONS

3.1 PCFLOW2D

Firstly, numerical simulations were performed with the PCFLOW2D model, which solves depth-averaged shallow water equations coupled with a k – ε turbulence model. Numerical model of the VSF consisted of 9 pools (each 3 m long), an inlet reach (1.5 m), and an outlet reach (9.5 m) (Figure 2). A dense numerical mesh of Δx = 0.02 m by Δy = 0.01 m was used to avoid effects of numerical diffusion. To ensure numerical stability and convergence, the time step was set to Δt = 0.1 s.

At the upstream boundary, we set a constant discharge with uniform velocity distribution normal to the inlet. At the downstream boundary, the depth was determined iteratively, so that the water depth in the middle section of central pools was 1.3 m, thus obtaining uniform flow conditions. As shown in Bombač et al. (2014), bed friction does not play an important role for such type of flow in the VSF, thus no special calibration (i.e. adjustment of roughness coefficient) was needed.

The main results of the PCFLOW2D model, which are significant for the present paper, are the longitudinal profile of the water surface, longitudinal velocities u, and transverse velocities v, as discussed in section 4.

3.2 DualSPHysics v4.2

The second set of numerical simulations was performed using an open-source DualSPHysics v4.2 model (available at DualSPHysics web site https://dual.sphysics.org/index.php/downloads/). The geometry of the simulated fishway is shown in Figure 2; it was set up with a user interface Design SPHysics, running as a special macro within the open-source software FreeCAD.

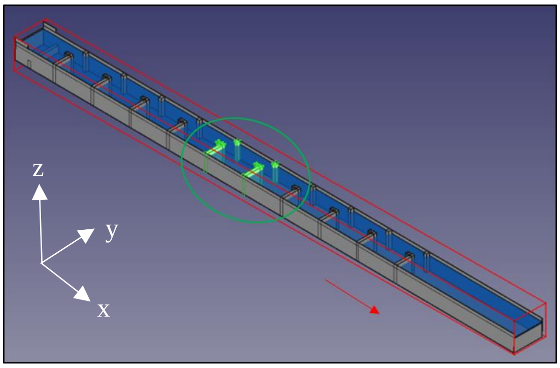

Figure 2. The geometry of the VSF, with observed middle pool (in green) and flow direction (red arrow).

DualSPHysics v4.2 did not contain an inlet-outlet boundary condition yet, therefore a periodic boundary condition was used to simulate a constant, gravity driven flow. The particles leaving the domain by flowing over the downstream wall were returned to the upstream boundary, thus maintaining constant flow. Adequate discharge regulation was achieved by iteratively adjusting the height of the wall at the downstream end of the fishway, thus adjusting the height of the water freely spilling over the weir. The initial elevation of the water surface was set in accordance with the average value from the field measurements. Neither the initial velocity fields nor the discharges were imposed.

The best results were achieved with the following execution parameters of the DualSPHysics: initial inter-particle distance 0.02 m (amounting to about 15 million particles), simple precision, Verlet algorithm, artificial viscosity alpha 0.01, zero viscosity factor with boundary, no delta SPH, no shifting. Time of simulation was set to 30 s, with the output recorded at every 0.2 s, to allow flow conditions to settle into steady state. The computational time was about 23 hours on a PC with a single Nvidia GTX 1080 graphics card.

4 DISCUSSION OF THE DUAL SPHYSICS V4.2 RESULTS

4.1 Discharge

While the flow of 1 m^3/s was imposed in PCFLOW2D through specified initial inlet velocities, it had to be calculated in Dual SPHysics v4.2. The discharge was calculated with the FlowTool, a Dual SPHysics post-processing tool. It determines the inflow and the outflow by calculating the volume of all the particles entering or leaving the user specified box, and dividing this volume by the interval time. As shown in Figure 3, the desired discharge was achieved accurately: over the last 10 s of the simulation the discharge in the observed pool was 0.99 m^3/s, 0.97 m^3/s in the adjacent upstream pool, and 0.99 m^3/s in the adjacent downstream pool.

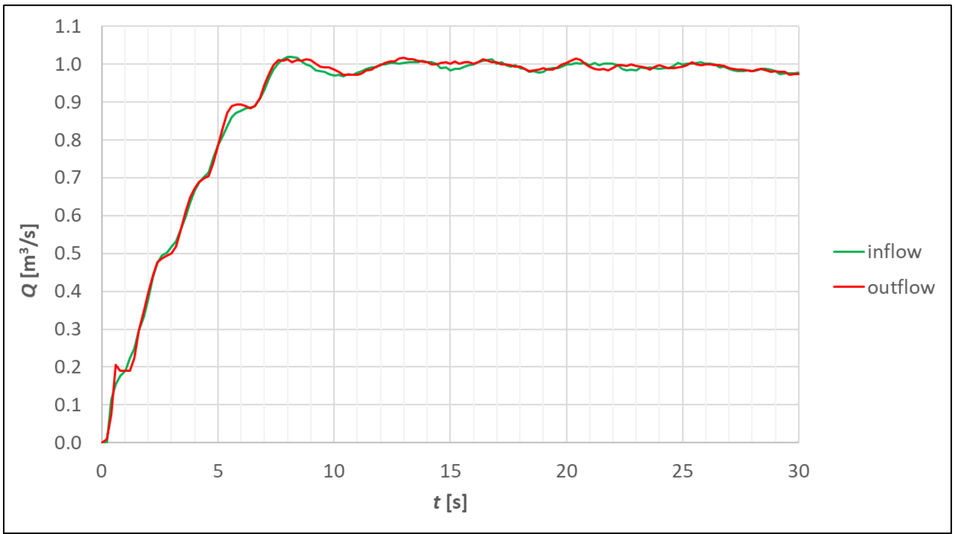

Figure 3. Inflow to and outflow out of the observed pool in Dual SPHysics v4.2.

4.2 Longitudinal water surface profiles

Another Dual SPHysics post-processing tool, the MeasureTool, was used to determine the longitudinal water surface profiles. The average depth of 1.3 m was achieved accurately in the observed pool and in both adjacent pools. When compared to the results of the 2D model, the longitudinal water surface drops Δh between the pools were slightly underestimated, and the tailwater elevation was slightly overestimated, as shown in Figure 4. The peaks in the graph denoted by “y = 1.1 m” represent the locations of individual slots.

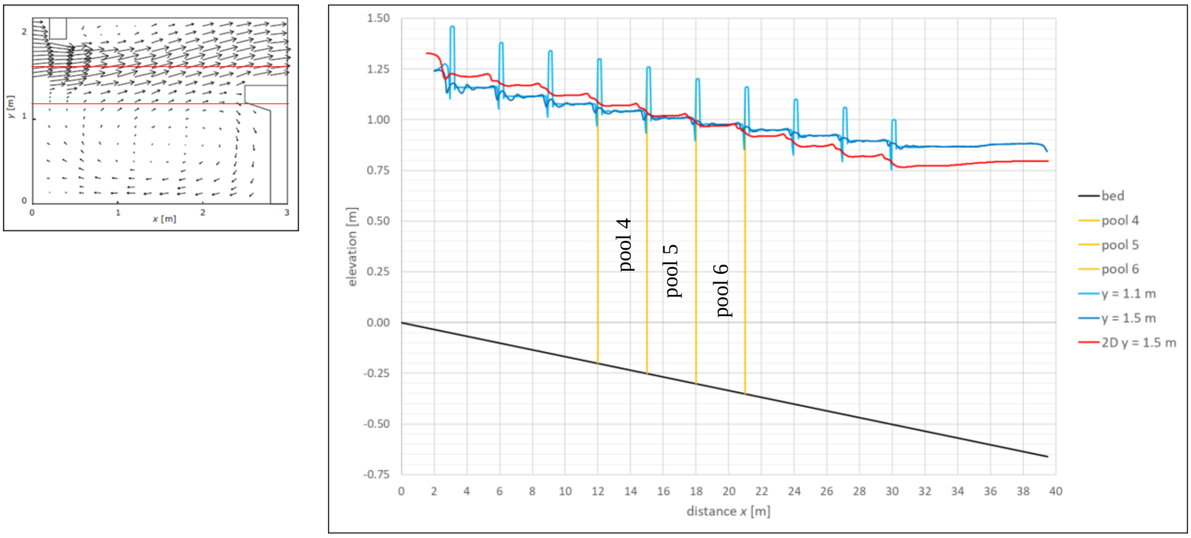

Figure 4. Longitudinal water surface elevation profiles along the y = 1.1 m line and along the y = 1.5 m line (see the top left frame). Results of the 2D model are in red, Dual SPHysics v4.2 results are in blue.

4.3 Velocity profiles

The post-processing MeasureTool was employed again to determine velocity profiles. First, the vertical velocity components *w* were compared against the results of ADV measurements. Figure 5 shows the vertical distribution of the velocity components at two separate locations, i.e. vertical V1 at x/y = 0.6/1.6, and vertical V4 at x/y = 2.05/1.6 (both are in the main flow region).

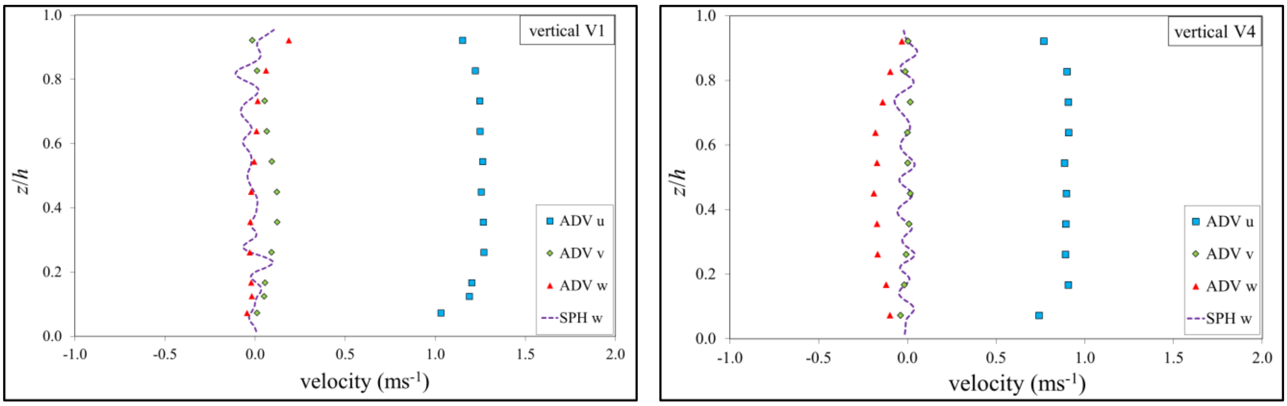

Figure 5. Vertical distribution of the velocity components in the main flow region.

With vertical velocity components *w* evidently close to zero, the study focused on longitudinal and transverse velocity components *u* and *v* in 4 transverse profiles, located 0.6, 1.2, 1.8, and 2.4 m from the upstream wall of the observed pool. To make a comparison with results from depth-averaged 2D model, MeasureTool was employed to determine *u* and *v* profiles at depths z = 0.05, 0.25, 0.5, 0.75, 1.0, and 1.2 m, and these 6 profiles were then averaged, as shown in Figure 6.

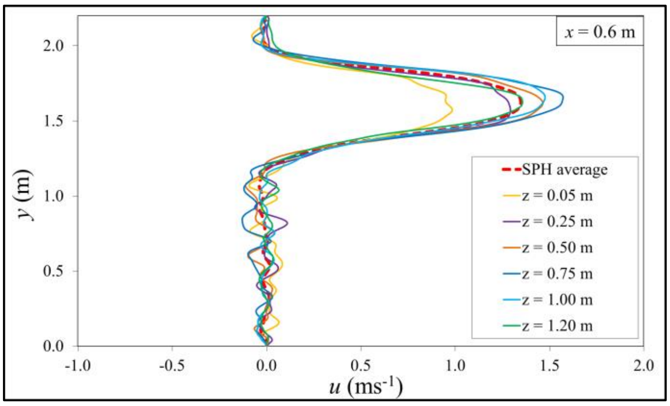

Figure 6. Calculation of average profile of velocity *u* at location x = 0.6 m.

The averaged profiles calculated for the individual locations are depicted in Figures 7 to 10.

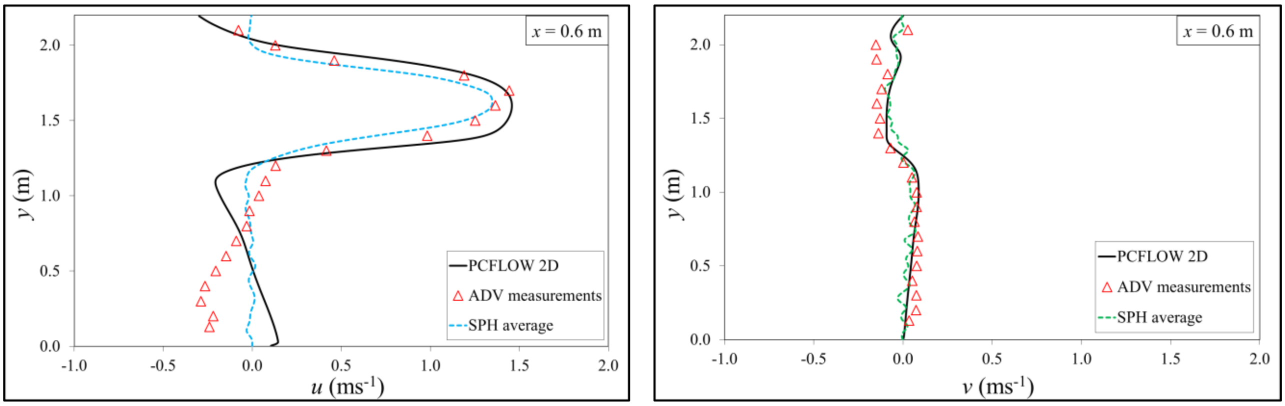

Figure 7. Average velocity profiles at location x = 0.6 m.

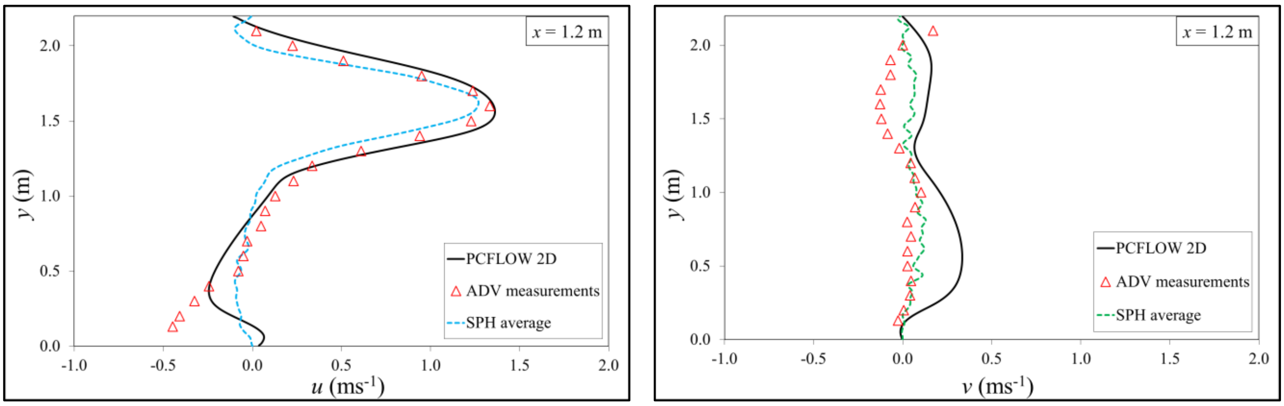

Figure 8. Average velocity profiles at location x = 1.2 m.

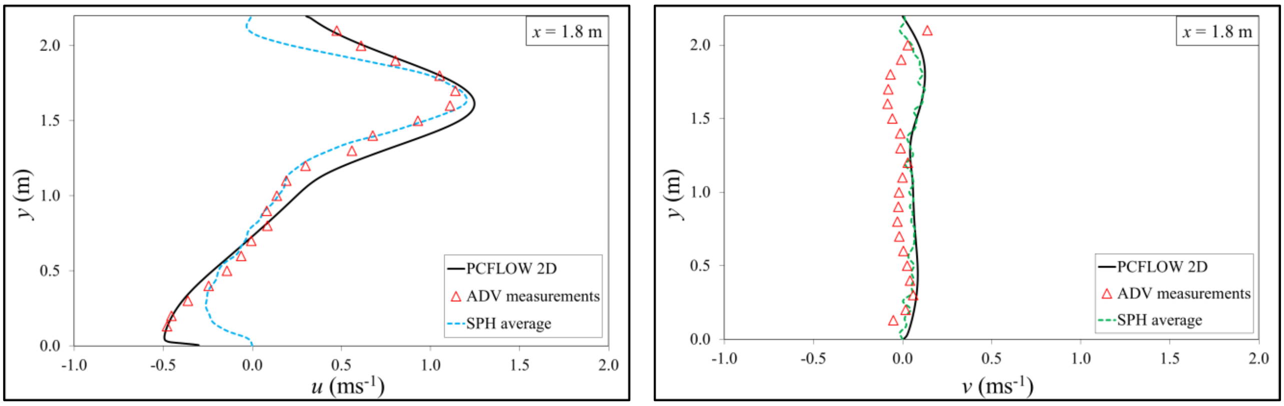

Figure 9. Average velocity profiles at location x = 1.8 m.

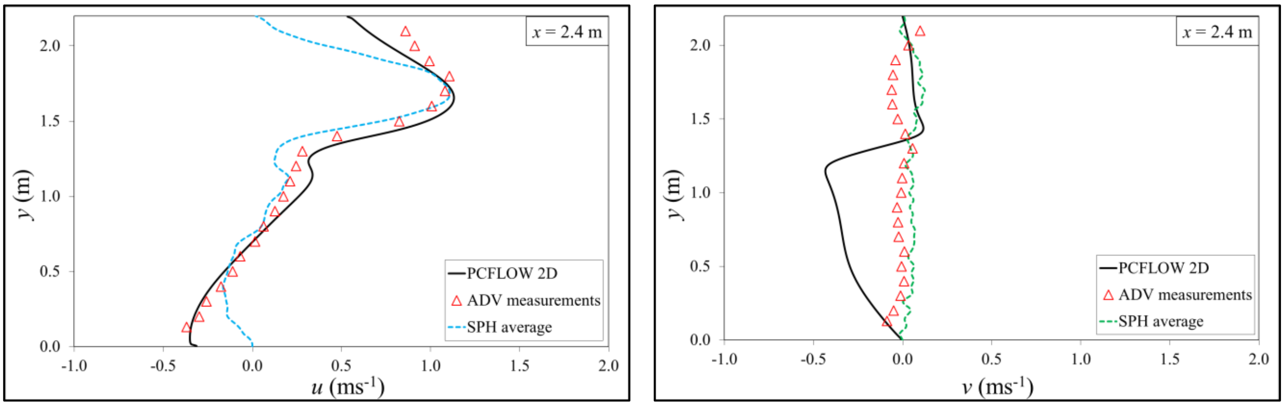

Figure 10. Average velocity profiles at location x = 2.4 m.

Despite certain discrepancies, the measured and the calculated velocity profiles were in good agreement.

5 CONCLUSIONS

We obtained satisfactory results by employing the Dual SPHysics v4.2. Using the initial fluid object, comprised of about 15 million particles, and periodic boundary condition, it was possible to simulate a constant subcritical open-channel flow in the VSF. The resulting discharge, water surface elevation and velocity fields were in good agreement with both the field measurements and the 2D model, proving the Dual SPHysics to be a fast and satisfactory accurate tool for 3D modeling of VSF flow.

At the time of writing, the work on the presented fishway simulations continues with an application of the latest Dual SPHysics code, namely version 4.3 beta (released just recently and only in limited edition), which includes improved open boundary conditions, as described in Tafuni et al., 2018.

REFERENCES

Bombač, M., Novak, G., Rodič, P., and Četina, M. (2014). Numerical and physical model study of a vertical slot fishway. *Journal of Hydrology and Hydromechanics,* 62 (2), 1-10.

Bombač, M., Novak, G., Mlačnik, J., and Četina, M. (2015). Extensive field measurements of flow in vertical slot fishway as data for validation of numerical simulations. *Ecological Engineering,* 84 (2015), 476-484.

Bombač, M., Četina, M., and Novak, G. (2017). Study on flow characteristics in vertical slot fishways regarding slot layout optimization. *Ecological Engineering,* 107 (2017), 126-136.

Duguay, J.M., Lacey R.W.J., and Gaucher, J. (2017). A case study of pool and weir fishway modeled with OpenFOAM and FLOW-3D. *Ecological Engineering*, 103(2017), 31-42.

Tafuni, A., Dominguez, J.M., Vacondio, R., and Crespo, A.J.C. (2018). A versatile algorithm for the treatment of open boundary conditions in Smoothed particle hydrodynamics GPU models. *Computer methods in applied mechanics and engineering*, 342 (2018), 604-624.