Fish behavior during hydropeaking in a channel equipped with a lateral shelter

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Abstract: In the framework of a research project focusing on mitigation measures for hydropeaking, a lateral embayment at the channel bank is studied as a fish refuge. Systematic experiments with different refuge configurations were carried out. The basic configuration is rectangular with a length of 2 m and a width of 1.2 m installed at the right bank of a 12 m long and 1.2 m wide flume supplied with freshwater from a natural river. In order to trigger water exchange between the flume and the rectangular refuge a wall acting like a groyne was installed inside the refuge protruding slightly in the main channel. Position, inclination and protrusion rate of this groyne were varied systematically in order to obtain an optimal water exchange and the best attractiveness of the shelter for fishes during hydropeaking.

Each configuration was tested three times with juvenile wild brown trout (Salmo trutta fario) (0+ and 1+), with 2 different groups of 10 and the combined group of 20 brown trout. They where exposed during 3 hours each time to a hydropeaking flow of 220 l/s in the main channel. During every test, the movements of the fish were recorded continuously by video camera and their positions were observed every 20 minutes. 6 series of 20 fishes were used for 36 sequences corresponding to the 12 configurations tested. For each configuration the analysis of the fish positions gave a global frequentation rate as well as the favorite staying places in the shelter. Some in- and outgoing fish trajectories were obtained by the treatment of video pictures. A particular focus was given to the interface section between the refuge and the main channel in order to relate the spatial distribution and the frequency of fish passage from up- and downstream into the shelter.

In order to link the swimming trajectories of the trout with the flow conditions, systematic measurement of the velocity field was performed using UVP technique. The flow velocities were analysed in several horizontal and vertical transects across the refuge and flume. Comparing the velocity patterns with the fish trajectories, the attractiveness of different configurations of fish refuges could be analyzed.

The tests reveal that a very basic refuge configuration, with low water exchange between shelter and channel, is not interesting for fish. When forcing a water exchange by introducing a deviation groyne into the shelter, its frequentation can be increased significantly. The fish can easily detect the refuge by the exchange flux when searching its way upstream. The refuge attractiveness can be optimized by testing different groyne orientations, creating an expanded velocity field close to the exit and the entrance. Important is a high velocity field leaving the refuge at its lower end but also a backwater zone near the groyne. The high velocity field attracts the fish and the close backwater zone allows the fish to enter the shelter. For the best configuration, more than 80% of the fish found the refuge by swimming mainly from downstream, 20 minutes after the beginning of hydropeaking.

Keywords: hydropeaking, fish shelter, embayment, lateral refuge, groyne, juvenile brown trout, swimming trajectories, UVP, velocity.

Introduction

The electricity production of storage hydropower plants during peak hours of high demand, are responsible for the hydropeaking phenomena. Ecological value of river reaches affected by hydropeaking is often significantly reduced, by a highly altered river hydrological regime downstream of restitution of the turbinated water. The Fischnetz study (2004) reveals that the brown trout caught in Swiss rivers has diminished by approx. 60% since 1980. Hydropeaking is mentioned to be partly responsible for this decrease.

When hydropeaking occurs fish are weakened by the sudden increase of flow velocities, which can go up to causing mortality amongst population along with invertebrates (Jungwirth et al. 2003). When turbines are closed, the rapid lowering of the water surface level brings the fish to be trapped on the substrate of the high water channel (Baumann et Klaus 2003). Also, degradation of natural habitats has been made evident (Valentin et al. 1996, Ovidio et al. 2006, Gouraud et al. 2008), considering a bedload regime being likewise highly altered (Baumann et Klaus 2003, Eberstaller et Pinka 2001).

Technical measures have been studied in order to reduce the effects of hydropeaking by introducing macro roughness riverbanks (Meile 2008), or damping its routing in multipurpose reservoirs (Heller et al. 2007). Fish shelters are commonly proposed when it comes to preventing the effect of high velocities. In this sense Valentin et al. (1996) demonstrated the relevance of the lateral bank refuge. These can protect fish and other organisms from rapid hydraulic parameters variations.

Materials and Methods

In order to find optimal shelter configurations, fish have been exposed to hydropeaking episodes in a channel outfitted with a lateral refuge. This ecohydraulic channel was built in the former powerhouse of Maigrauge dam in Fribourg (Switzerland), thus having direct access to an intake supplying the system with a permanent fresh river water (Fig. 1) and enabling to control light intensity. Effective length of the channel is 12 m with a width of 1.2 m. The refuge of 2 m length and 1.2 m width is located on the right bank.

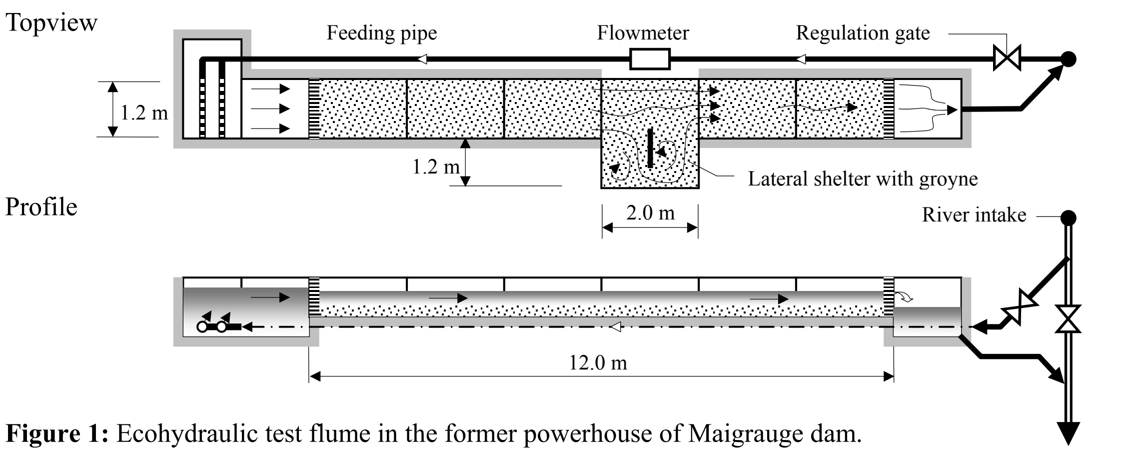


Figure 1: Ecohydraulic test flume in the former powerhouse of Maigrauge dam.

The channel bed is made out of coarse gravel, plugged with mortar and white painted to enhance fish visibility. The refuge is covered with pebbles and stones with the purpose to simulate the juvenile trout's favorite substrate (Vismara et la. 2001, Valentin et al. 1996). Hydropeaking occurs when opening the regulation gate. Flow and water temperature are then continuously measured.

The channel is designed to simulate average favourable or disfavourable velocities regarding the preferred habitat plots (Vismara et al. 2001) of the brown trout (Salmo trutta fario) at a juvenile stage (0+ and 1+). Maximum channel inflow is 220 l/s, thus average velocities lie between 0.2 m/s for the base flow condition of 20 l/s and 1 m/s when hydropeaking occurs. Water depth varies from 0.10 m to 0.20 m.

Before any test a 20 l/s uniform flow is established in the channel. Then the fish are introduced in the channel entrance in a temporarily separated compartment for getting used to the water conditions. They are then released and the flow in the channel is increased from 20 to 220 l/s in a few minutes time interval, and maintained to the maximum value for 3 hours. Position of individuals is visually taken down every 20 minutes during the hydropeaking period (Fig. 2).

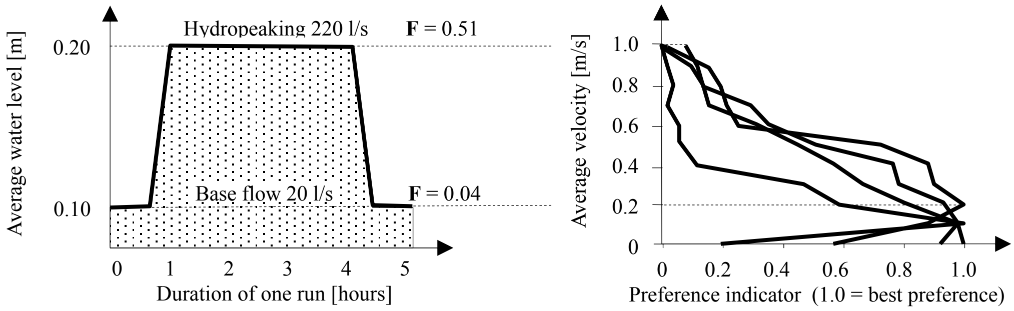


Figure 2: Channel hydraulic parameters related to preference plots for the fario trout at a juvenile stage, according to Vismara et al. 2001 (results of different studies).

Fish tracking is also registered by a camera placed perpendicularly above the refuge. Videos recordings are analyzed image after image. Each refuge configuration is tested 3 times with two groups of 10 fishes and one of 20 fishes. Tests were performed with wild brown trout (*Salmo trutta fario*) at its juvenile stage (0+ and 1+) (Murchie et al 2008, Gouraud 2008, Flodmark 2006, Valentin 1995, Scruton 2003), captured by electrofishing in a river of the Swiss plateau. 6 series of 20 fishes were used for 36 sequences corresponding to the 12 configurations tested. Tests were organized to happen in spring and autumn, when the water temperature lies between 6°C and 16°C (Fig. 3) (Küttel et al. 2002, Jungwirth et al. 2003).

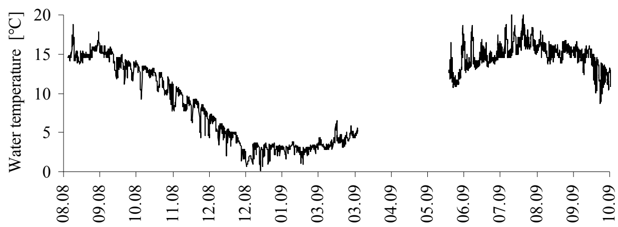


Figure 3: Water temperature recording, in the inlet river.

Local velocity distribution is required to compare different shelter configurations. Velocity measurements had to be undertaken a posteriori, thus considering the severe constraints implicated when investigating live fish behaviour. A preliminary analysis was made using a 2D simulation model as dealing with low waterdepth flows. BASEMENT « BASic EnvironMENT for simulation of natural flow and hazard simulation » (Fäh *et al.* 2008) was used to that purpose. The model considers alternatives by solving unsteady flow equations at an average depth using the finite volumes numerical pattern. SMS « Surface Water Modeling System » was used to build the grid, to pre and post process the data and to illustrate the results (Fig 5). BASEMENT was also used for computing the flow through the refuge.

Horizontal component of velocities was measured by means of an Ultrasonic Doppler Velocity Profiler (Metflow SA, UVP Duo). Explored surfaces are the vertical interface between the refuge and the channel, as well as the horizontal plane sector close to the bottom covering the fish's preferential paths (Fig. 4). Transversal distribution was measured in a similar way throughout the channel sections upstream and downstream from the shelter. The single horizontal component of the velocity vector was measured considering low water depth flows behavior. Velocity fields were interpolated and plotted using Surfer 8. Validation measurements were locally performed with a micro current-meter.

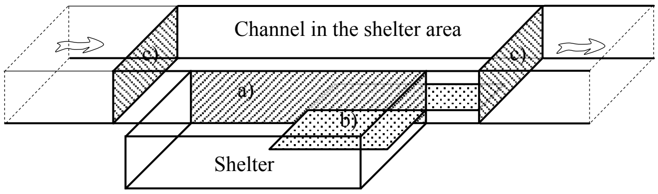


Figure 4: Velocity field measurement planes, a) Vertical interface between channel and shelter, b) Horizontal plane sector defined by the fish's preferential paths, c) Channel transversal sections upstream and downstream from the refuge.

Results and Discussion

The first tests were performed with the basic refuge configuration (C0). Experiment shows that attractiveness of the cavity, built as a simple bank indentation, is very weak for the fish. Counting of individuals shows an average frequentation of the refuge of 33%, as well as a strong inconsistency during the 3 hours of the investigation period. Lack of interest can be linked to the very low flux exchange between the refuge and the main channel. Transit flow in the refuge can be computed by integrating the simulated velocities through the vertical plane separating the refuge from the main channel. It ascends to 3.5 l/s for the C0 configuration, which corresponds to 1.6% of the total hydropeaking flow only.

A vertical groyne was inserted in the refuge over the whole water depth intersecting the center of the vertical interface between the channel and the refuge. The aim of this wall is to increase the water circulation in the refuge and the exchange with the channel (Fig. 5). The outer edge of the wall protrudes the channel section at a 30 cm distance. Inner edge is 50 cm from the refuge sidewall. These values were maintained throughout all the tested configurations by changing the angle of the panel with the flow direction (Fig. 9). Indeed, investigation of the C1 configuration resulted in a 75% average frequentation of the shelter with a diverted discharge of 58 l/s. Video recordings clearly reveal a preferential path (Fig. 5) regarding the fish entering the shelter from downstream, during hydropeaking. Indeed, they find a path upward the channel along the right sidewall taking advantage of relatively low velocities, leading to the downstream corner of the refuge. Individuals recover a few seconds as they reach a low velocity area before crossing a higher velocity field in order to reach the shelter behind the derivation wall. They come temporary to a standstill before entering deeper into the refuge.

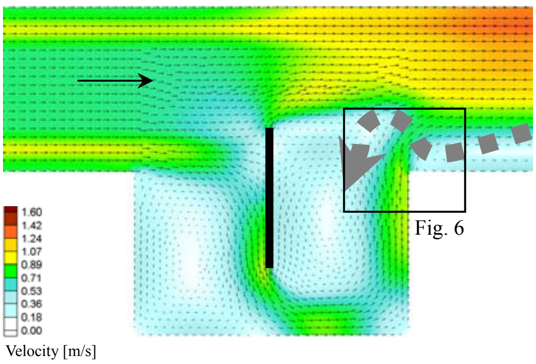


Figure 5: Configuration C1, velocity field simulated with Basement-2D. Fish trajectories at the entry in the shelter (dashed arrow)

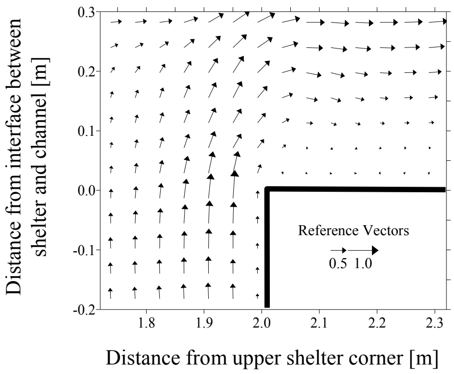


Figure 6: Configuration C1, Velocity field on the downer shelter corner, measured by UVP flow mapping.

The horizontal velocity field was measured in the neighbourhood of the exit corner of the refuge, in order to get more accurate data on the path taken by the fishes entering the shelter (Fig. 6). These measures where conducted with UVP (Flow-mapping). A detailed distribution of fish entries through the interface section was recorded in order to build up a customized base for other configurations analyses and comparisons. Figure 7 shows this distribution stacked with UVP average velocity distribution.

Regarding the flow velocity distribution through the interface section, the representativity of the 2D data averaged over the whole water depth has been scrutinized knowing that the fishes are moving next to the bottom (Scruton et al., 2003). The UVP measures analysis show that within the most contributing sectors, the horizontal normal velocity components are weakly varying over the vertical profiles, except near the bottom where a strong decrease can be noticed for a depth of about 3cm. For the same purpose, the normal velocity components over the water depth simulated by BASEMENT where compared to the UVP and to the micro current-meter measures (Fig. 8). If all the curves have overall the same shape, the extreme UVP values stand out, especially along the sidewalls at the centre and the exit of the shelter. These observations confirm that the 2D simulation with BASEMENT is interesting for the global analysis of configurations, provided local verifications are done.

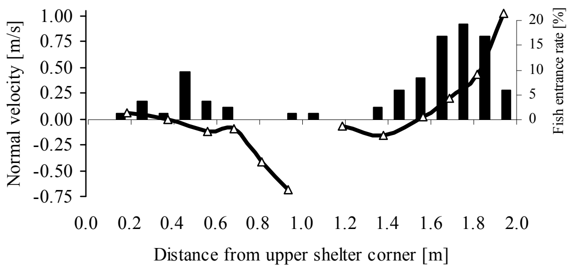


Figure 7: Configuration C1, ■ fish entrance rate stacked with —Δ— UVP velocity and referred to distance from upper shelter corner.

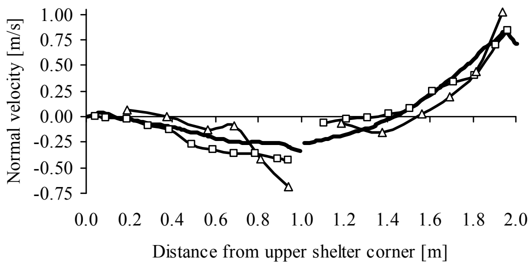


Figure 8: Normal component velocity profiles across the interface between shelter and channel, for configuration C1, ▬▬ computed with Basement 2D, —□— measured with micro current-meter, —Δ— measured with UVP.

Based on the observations and results, the C1 configuration has been referred as the starting point for enquiries and analysis of more attractive configurations. Keeping constant the impounded surface of the C1 wall in the channel, different positions were tested by varying the wall's angle of ± 30° around the perpendicular position of C1 to the axis of the channel. 3 fixed points were chosen: 2 at the C1 panel's extremities (Fig. 9, points A and V), and one on the interface's line (Point X). Subsequently, 3 configurations were tested for each fixed point: 2 simple configurations and one constituted of two walls. The aim of the procedure was to examine the fish behaviour in term of refuge frequentation and trajectories as well as two main hydraulic conditions: the variability of the diverted discharge and the velocity profile through the interface section. Overall, 12 configurations were tested (Figure 10).

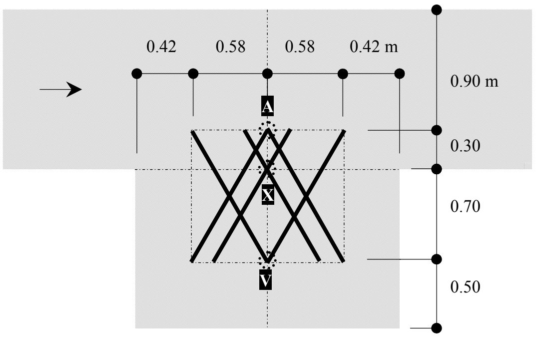


Figure 9: Geometry of fish shelter and wall positions, characterized with fix points A, X, V

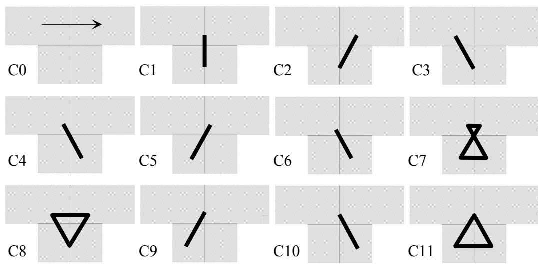
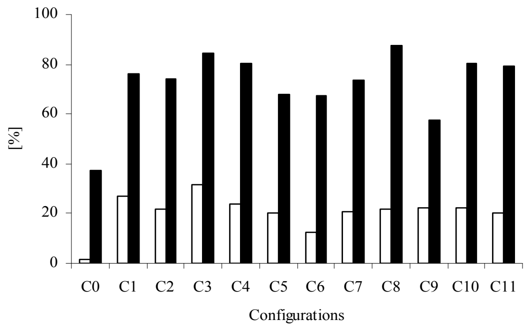


Figure 10: Position and inclination of the vertical wall for configuration C0 to C11.

Globally, each configuration is represented by the derived discharge through the shelter and the average fish frequentation rate of the shelter (Fig. 11). A correlation between these two parameters is evident for the C0 to C5 configurations, but not for the C6 to C11. A tendency can be observed between these two parameters (Fig. 12). This tendency shows that the frequentation rate is not noticeably affected by the derived discharge.

The C8 configuration gives the maximal frequentation rate (87%) for a diverted discharge of 47 l/s (21%). For this reason, the C8 configuration is presented (Fig.13) as a comparative example to the C1 configuration in this paper (Fig. 5, 7). Characterised by a deflecting groyne shaped like an equilateral triangle, it is a combination of the C2 and C3 configurations. The velocity variability is almost linear along the interface line. The video recordings showed that almost all the fishes entered the shelter from downstream (Fig. 13).



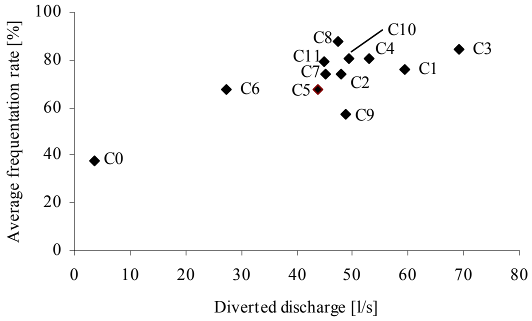
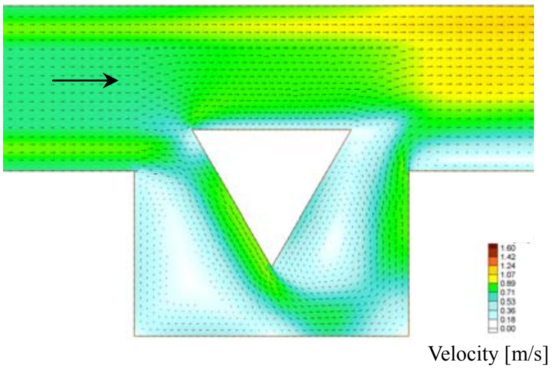


Figure 11: For configuration C0 to C11, ■ Average frequentation rate of the shelter by the fishes, □ Diverted discharge related to hydropeaking flow.

Figure 12: Average frequentation rate of the shelter by the fishes reported to the relative diverted discharge,



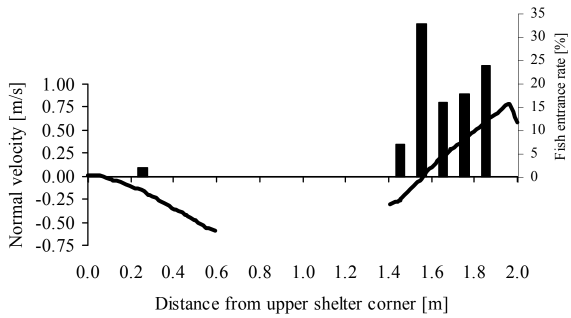


Figure 13: Configuration C8, fish entrance rate stacked with UVP velocity measurements and referred with distance from upper shelter corner.

Regarding the distribution of the fish entries within the shelter, most of them enter by the downstream end corner of the shelter (Fig. 14). As for this specific configuration, the fishes enter the refuge travelling up the current from the channel exits; it reveals the importance of the appealing current generated by the exiting flux from the shelter. However, it must be noticed that for each configuration, a different entry distribution applies for the upstream and downstream end of the wall. Regarding fish entries in the shelter from upstream, C10 configuration reveals as the best (Fig. 14) having also a high average frequentation rate (Fig. 11).

To get a more detailed picture of the fish behaviour, it is interesting to understand where they enter the shelter. For this purpose, the fish were counted for each configuration, except for C0 and C6, through a 0.10 m interval along the interface section, using video recordings treatment. For the same interval, the normal UVP velocities were measured at a water depth of 0.025 m (+ sign indicates a vector oriented outside of the refuge). Based on these observations, the number of fish entries from upstream and downstream of the wall was reported to the normal velocities, combining all configurations. A distribution of fish entries was established by order of increasing velocities with an interval of 0.1 m/s (Fig. 15). For 560 downstream entries, 330 were reported for the 0.0 to 0.2 m/s velocity interval. Around this interval, the number of entries sharply decreases. For the positive velocities side of the distribution, a similitude can be noticed with the velocities preferences of the juvenile stage brown trout established by Vismara et al. (2001), (Fig. 2). A lack of interest of the fish can also be noticed for the flows entering the shelter, expressed by negative velocities. This statement is equally valid for the downstream and upstream sides of the wall.

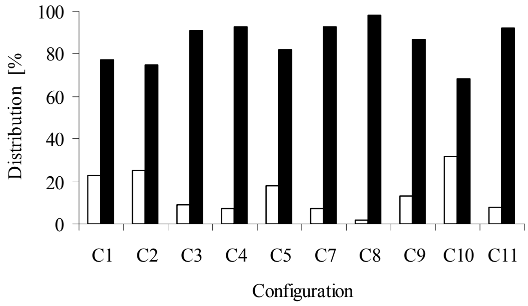


Figure 14: Distribution of fish entries in the shelter, □ upstream / ■ downstream of the wall, for each configuration.

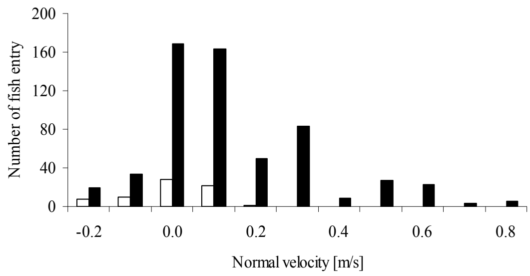


Figure 15: Number of fish entries in the shelter combining all configurations, related to normal velocity, □ upstream / ■downstream of the panel.

Conclusion

This research study aims to find optimum fish shelter configurations in river banks which can improve survival conditions during hydropeaking in channelized rivers. Juvenile brown trout are used as a reference in fresh river water. At the present stage it can be said that a very basic refuge configuration, with low water exchange between shelter and channel, is not interesting for fish. When forcing a water exchange by introducing a deviation wall into the shelter, its frequentation can be increased significantly. The fish can easily detect the refuge by the exchange flux when searching its way upstream. The refuge attractiveness can be optimized by testing different panel orientations which create an expanded velocity field close to the exit and the entrance. Important is a high velocity field leaving the refuge at its lower end but also a backwater zone near the wall. The high velocity field attracts the fish and the close backwater zone allows him to enter the refuge.

The tests performed reveal that a fish refuge with appropriate flux exchange with the channel can be found by fish even under severe hydropeaking conditions. The configuration will be further improved in order to have also a good attractiveness for fish swimming from upstream. An example towards this goal is the C10 configuration. For prototype configurations it is important also to consider the sedimentation problem by fine sediments. Of course the refuge geometry would have to be smooth with a groyne reproducing the effect of the wall used in the laboratory. Microhabitat potential would have to be studied also in detail.

The interdisciplinary research is supported in the framework of “The integrated management of river systems” by the Swiss Federal Office for Environment and the Swiss Innovation Promotion Agency, KTI-CTI contract No 9676.1.

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