INFLUENCE OF GEOMETRY OF FISH SHELTERS IN RIVER BANKS ON THEIR ATTRACTIVENESS FOR FISHES DURING HYDROPEAKING

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ABSTRACT

A systematic ecohydraulic study was performed with the purpose to find optimum refuge configurations which the fishes can find to take shelter during hydropeaking. In a 12m long and 1.2m wide artificial channel, a lateral rectangular fish refuge of 1.2 m depth and 2 m length was installed. The system was continuously fed with fresh river water from the reservoir of Maigrauge dam. Velocity patterns were measured throughout the vertical section, that is between the shelter and the main channel.

A transverse wall element was installed in the middle of the refuge in order to favour the water exchange between the main channel and the refuge and to create attractive velocity currents for the fish. By changing the angle of this wall towards the upstream and the downstream directions, water exchange and velocity distribution between main channel and refuge could be varied in a wide range.

All configurations were tested with the juvenile wild brown trout (0+ and 1+) caught by electrofishing. These trout were released at the upstream end of the main channel under normal flow conditions. The discharge was then increased during 3 hours to a hydropeaking factor of 10. The movement of the fish was continuously video recorded and then digitalized. Every configuration was tested with a new sample of 20 wild trout.

Attractiveness of 5 different configurations of fish refuges could be analyzed comparing the velocity patterns to the fish trajectories for the best refuge configuration, more than 80% of the fish found the refuge either by swimming from the upstream or from the downstream during the first 20 minutes after the beginning of hydropeaking.

Keywords: Hydropeaking, fish shelter, juvenile wild brown trout, fish trajectories, UVP.

1 INTRODUCTION

Storage hydropower plants electricity production cycles are responsible for the hydropeaking phenomena. Ecological value of river reaches affected by hydropeaking is therefore significantly reduced, thus considering a highly altered river hydrological regime by restitution of the turbinated water. The Fischnetz study (2004) reveals that the brown trout catch in Swiss rivers has diminished by approx. 60% since 1980. Hydropeaking is mentioned to be part of the reasons for this decrease.

When hydropeaking occurs fish are weakened by the increase of flow velocities, which can go up to causing mortality amongst population along with invertebrates (Jungwirth et al.
2003). When turbines are closed, rapid lowering of the water surface level bring the fish to be trapped on the substrate of the high water channel (Baumann and 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 (Meile 2008, 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) have demonstrated the relevance of the lateral bank refuge. They can protect fish and other organisms from rapid hydraulic parameters variations.

2 METHODOLOGY AND INVESTIGATIONS
In order to find optimum refuge configurations, fish have been exposed to hydropeaking circumstances in a channel outfitted with a lateral refuge. An ecohydraulic channel was built to that purpose in the former powerhouse of Maigrauge dam in Fribourg (Switzerland), thus having direct access to an inlet supplying the system with a permanent fresh river water (Fig. 1) as well as 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.

The channel bed is made out of coarse gravel, plugged with mortar and painted white to enhance fish visibility. The refuge is covered with pebbles and stones with the intention of simulating 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 be able to simulate average favourable or disfavourable velocities regarding the preferred habitat plots (Vismara et al. 2001) of the fario trout (Salmo trutta fario) at a juvenile stage (0+ and 1+). Maximum channel inflow is 220 l/s, thus average velocities go from 0.2 m/s for the base flow condition of 20 l/s to 1 m/s when hydropeaking occurs. Waterlevels go from 0.10 m to 0.20 m (Fig. 2).
Tests were performed with brown trout (*Salmo trutta fario*) at its juvenile stage (0+ and 1+). Whilst the species was chosen for its representativeness of the fish population in Swiss rivers, the growth stage was chosen to express vulnerability. Additionally, numerous biological studies related to the hydropeaking phenomena focus on this species (Murchie et al. 2008, Gouraud 2008, Flodmark 2006, Valentin 1995, Scruton 2003).

Electrofishing took place in a river of the Swiss plateau. 20 wild individuals were captured at a time. A size range of 14 to 20 cm was used. Fish were kept alive on the experimental site in an aquarium fed with fresh river water and live macro invertebrates. Marking was used in order to separate the sampled fish into two batches of 10 individuals each. Both groups had to undergo one at a time to five hydropeaking sequences of 3 hours each, evenly arranged throughout a 3 weeks period of time. Fish were brought back to the capture site after this time period. Then they were replaced by a new 20 individuals sample in order to prevent habit, thus altering their instinctive aptitude for finding the refuge.

Multiple studies regarding water temperature (Küttel et al. 2002, Jungwirth et al. 2003) reveal that the optimum vitality of the fish as well as the minimum sensitivity to temperature variations lies between 8°C and 18°C. The tests were therefore arranged to happen in autumn. Additional tests are though meant to be settled in winter, by a 5°C water temperature, as hydropeaking regimes stresses are higher in winter.

Before any test a 20 l/s uniform flow is established in the channel. Then the fish were 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 that value for 3 hours. Position of individuals is visually taken down every 20 minutes during the hydropeaking time interval. Also tracking is registered by a camera placed perpendicularly above the refuge. Each refuge configuration is tested 3 times so as to validate the results. Investigation 1 and 2 are undertaken with the 10 unit sample twice (swapped for validation), whilst the 20 fish take part in investigation 3.

Videos recordings meant to track the fish were analyzed image after image. Observed positions were manually digitalized in ArcGIS.

Local velocity distribution data is required to be able to generate new refuge configurations from the previous design. Velocity measurements had to be undertaken a posteriori, thus considering the severe constraints implicated when investigating with live fish. 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. Vertical component of velocities was examined using a micro current-meter on a decimetric grid pattern. Explored surfaces are the vertical interface between the refuge and the channel, as well as the horizontal plane close to the bottom defined by the fish’s preferential paths (Fig. 3). Transversal distribution was measured in a similar way throughout the channel sections upstream and downstream the refuge. The single horizontal component of the velocity vector was measured considering low waterdepth flows behavior. Velocity fields were interpolated and plotted using Surfer 8.

3 OBSERVATIONS AND RESULTS
The first investigation tests the basic refuge configuration (C0, not illustrated). Experiment shows that attractiveness of the cavity, built as a simple bank indentation, is very weak for the fish (Table 1). Counting of individuals actually 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 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 is equal to 3.5 l/s for the C0 configuration, which corresponds to 1.6% of the total hydropoaking flow only (Table 1).

A vertical panel 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 panel is to increase water circulation in the refuge and the exchange with the channel (Fig. 4, C1). The outer edge of the panel enters the channel section at a 20 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. 4). Indeed, investigation of the C1 configuration resulted in a 75% average frequentation of the refuge. Configurations C2, C3 and C4 are improvement alternatives for the C1 configuration. In these configurations the vertical panel of the C1 configuration which is perpendicular to the flow in the channel is rotated from a +30° angle to a -30° angle around 2 fixed points p1 and p2 (Fig. 4).
Figure 4: Tested refuge configurations created by an inserted panel, velocity field simulated with Basement-2D.

Configurations C3 and C4 show a significant increase in frequentation of the refuge. Maximum frequentation rate is achieved 20 minutes after the beginning of hydropeaking and is maintained throughout the experiment. Individuals remain still in the refuge corners and at the bottom of the refuge walls (fig. 5). Backwater circulation flow behind the vertical panel is clearly visited for both C3 and C4 configurations.

<table>
<thead>
<tr>
<th>Frequentation parameters in the refuge</th>
<th>Configurations</th>
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<tbody>
<tr>
<td>Average frequentation rate [%]</td>
<td>C0</td>
</tr>
<tr>
<td>Minimum-maximum frequentation rates [%]</td>
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</tr>
<tr>
<td>Downstream entry point proportion [%]</td>
<td>55</td>
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<tr>
<td>Transit flow in the refuge [l/s]</td>
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<tr>
<td>Transit flow/hydropeaking flow proportion [%]</td>
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</tr>
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Table 1: Average fish frequentation rate and refuge transit flows for the 3 tested configurations.

Beside the very poor configuration C0, the configurations with inserted panel C1 and C2 as well as C3 and C4 can be grouped according to the frequentation rate and the proportion of individuals entering the refuge from downstream of the vertical panel. C2 and C4 are overall characterized by a smaller transit flow and express in this sense higher performance. They are therefore used to illustrate detailed results of velocity measurements across the interface between refuge and channel. Considering a shallow water flow, velocities are averaged throughout the water depth and considered on the interface abscissa (Fig. 6a). For both tested
configurations, the distribution of the normal velocity component shows on one hand a similar peak and on the other hand higher velocity amplitudes for the configuration C4 than for the configuration C2. Additionally, configuration C4 shows a backwater circulation downstream of the panel. Such a deadwater circulation is observed for configuration C2, although upstream from the panel.

Figure 6: Normal component velocity profiles across the interface between refuge and channel, a) horizontal distribution, computed values for configuration C2 and C4, b) vertical velocity distribution, measured values as a function of distance from upper refuge corner.

In the Fig. 6b it can be seen that the highest measured velocity values occur below 60% of the water depth. Observations indicate that fish move also in the lower part of the water column near the bottom (Scruton et al. 2003). Therefore a 2D simulation assuming shallow water flow is not suitable for the analysis. Therefore UVP velocity measurements will be performed later in regions of fish passage.

Video recordings clearly revealed a preferential path (Fig. 7a) regarding the fish entering the refuge during hydrop peaking from downstream. Indeed, they find a path upward the channel along the right sidewall taking advantage of the relatively low velocities, heading for the downstream corner of the refuge. Individuals recover a few seconds as they reach a low velocity area before they cross a higher velocity field in order to reach enter the refuge behind the derivation panel. They come to a standstill for an instant before they actually enter deeper into the refuge. This rest zone is very important. In configuration C2, fish have been forced back from the refuge into the channel, since the rest zone is confined in a narrow stretch behind the panel. The observations showed that hydraulic conditions with a backwater downstream of the panel and a water exchange between refuge and main channel of about 20 to 25% are most optimal in view of fish attractiveness. The conditions upstream of the panel should show a similar behavior but their influence is less important since fish prefer entering the refuge from downstream.

Velocities for the configuration C4 were measured using a micro current-meter across the horizontal plane of the most favorable pathway (Fig. 3b). Effective and relative traveling velocities of the fish were obtained from a detailed analysis of the video images (Fig. 6b). The trout seems to take advantage from the currents when it is located in the flow recirculation area downstream from the refuge angle, where effective velocity of individual is lower than apparent velocity. It then needs to increase its effective speed to 1.4 m/s in order to swim across the high velocity currents flowing out of the refuge. Effective and apparent velocities then decrease and tend to equalize back into the refuge.
Orientation of the trout body when swimming was analysed by the videos. When fish swim through the high velocity area their bodies are oriented according to the velocity vector, which can be inclined to their swimming trajectory. Obviously they attempt to minimize the drag force on their bodies, as the body axis is oriented as such as to minimize the torque.

4 CONCLUSION

This research study aims to find optimum fish shelter configurations in river banks which can improve conditions during hydropeaking. Juvenile brown trout are used in fresh river water fed channel. At present stage it can be said that a very basic refuge configuration, with low water exchange between refuge and channel, is of no interest to fish. Water exchange was therefore forced by introducing a panel into the refuge. Refuge frequentation can be increased significantly as fish can easily feel the refuge by the exchange flux when finding 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 his lower end but also a backwater zone near the panel. The high velocity field attracts the fish and the close backwater zone allows him to enter the refuge.

The test performed until now reveal that a fish refuge with appropriate flux exchange with the channel can be found by fishes even under severe hydropeaking condition. The configuration will be further improved in order to have the same attractiveness for fishes traveling from downstream and upstream. 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 panel in the laboratory. Microhabitat potential would have to be studied also in detail.

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