Flexible Fish Fences

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ABSTRACT: The Flexible Fish Fence is a new fish protection system, developed at the Unit of Hydraulic Engineering of the University of Innsbruck Austria. The concept consists of horizontally arranged steel wires, which pose a mechanical barrier upstream of hydropower plants. Thus, fish are physically and behaviorally detained from passing the turbines. During normal operation, the wires are in place, whereas during high flows they are released and hence lying on the river bed. The entire cross section is then available for discharge of water, bed load and floating matter. The steel wires are cleaned during the releasing process. In case of local clogging during normal operation, individual wires or wire clusters can be released in order to clean the inflow area. The concept can be implemented at overflowed power plants or existing power plants, where the ecological continuity has to be recovered. Floating matter entering the inlet structure during a flood or during the cleaning process can be discharged over the plant or rather be extracted by existing trash rack cleaning system. First experiments were performed in the hydraulic laboratory of the University of Innsbruck to demonstrate operating conditions and the functionality of the Flexible Fish Fence. The Flexible Fish Fence can be located in front of the power house, connecting the river bank and the middle pier in an inclined exposition. Due to the horizontal inclined inflow condition, fish are guided along the screen to a fish pass located in the middle pier. In addition the horizontal position of the wires offers a better fish protection than vertical arranged bars. Oscillations of the wires induced by the flow might have an additional deterrent effect and thus enhance the protective purpose. Additional ecological and technical investigations are on the way.

KEY WORDS: fish protection, downstream migration, hydro power, ecological continuity.

1 INTRODUCTION

The European Union committed the reduction of greenhouse gas emissions of up to 20 % compared to 1990 until 2020 in order to prevent the effects of global climate change. Thus a set of binding legislation was implemented by the EU concerning emission and energy policy and particularly the expansion of renewable energies is supported by financial incentives (European Commission, 2011). In 2010 renewable energies contributed about 13% of the gross final consumption of energy in Europe, around 19 % of this amount was derived from hydro power (Šturc, 2012). The energetic use of water has a high significance, especially in mountain areas like Austria, where the topographical constraints are convenient and a high level of experience due to a long tradition is available. Around 29 % of the total energy production in Austria is derived from hydro power and further expansion of this sector is in the focus of the energy strategy of Austria (BMWFJ, 2010). Hydroelectric power plants, especially run-of-river power stations, provide base load power by using a domestic and constantly available energy source. But the realization of new hydro power projects is at odds with other European guidelines, especially the Water Framework Directive and the Habitats Directive. Hydroelectric power plants pose an interruption to the ecological continuity and particularly to fish migration. Considering only the requirements of river continuity, the design and permission of new power plants is confronted with a great challenge regarding required standards. Besides, also old sites need to be adapted to meet the enhanced requirements.

While the barrier to upstream migration can be solved by a variety of means of bypass channels, which are well validated by a number of investigations, efficient and feasible solutions for fish protection and downstream migration are still not available. Downstream connectivity means on the one hand a sufficient protection of fish from a passage through turbines or from pressing on the screen surface. On the other hand it requires a well detectable and passable bypass (Ebel, 2013). The lack of efficient and feasible fish protection facilities was the motivation for the University of Innsbruck to develop a new concept as a possible solution for overflowed power plants and old hydropower sites. The Flexible Fish Fence consists of horizontally arranged steel wires, which are situated upstream of hydropower plants and pose a mechanical and behavioral barrier.

2 FISH PROTECTION SYSTEMS

Fish protection systems prevent fish from entering the turbines either through a mechanical or behavioral barrier effect. At the majority of European hydroelectric power plants mechanical thrash rack systems are installed. The former task of conventional mechanical barriers like trash rack systems was to protect the turbines from floating matter and thus the spacing between the bars was around1/30 of the diameter of the turbine runner (Mosonyi, 1966). Nowadays the construction has a high significance for fish protection purposes and hence clear widths of 10 – 20 mm are required. Moreover fish protection systems should have a guidance effect towards a nearby downstream bypass (Ebel, 2013).

Mechanical Barriers detain fish physically from the turbine intake by bars or meshes, which are impermeable to pass. Besides they affect the behavior of fish due to a change of visual and tactile stimuli in a deterrent way, provided that flow conditions at the screen surface enable fish to a reaction. The efficiency of protection systems regarding downstream migration depends on the one hand on technical characteristics like the exposition to the inflow or the direction of the bars and on the other hand on their biological characteristics including the permeability and effect to fish behavior (Ebel, 2013).

According to Pavlov (1989) and Larinier (2008) screens, which are placed in a horizontally inclined position to the flow and equipped with a bypass at the downstream end of the facility are most effective regarding their guiding function (Ebel, 2013). Furthermore the direction of the bars plays an important role. In comparison to conventional screens with vertical bars, horizontal screens with the same clear width offer a better fish protection. This is due to the fact that fish normally do not change their natural swimming position (Holzner & Blankenburg, 2009). Thus clearance of the bars can be adapted to the body height, which is commonly greater than the body width, especially with alpine fish fauna. Moreover the risk of injuries through a contact with the bars of the facility is lesser in comparison to vertical thrash rack systems (Ebel, 2013).

As mentioned above the clear width between the bars is a very important parameter in the design of a mechanical barrier. The physically permeability can be described by the dimensionless ratio of body height and clearance of the bars, called permeability index (Ebel, 2013). According to investigations of Pavlov (1989), the maximum protection was observed at ratios < 3.

Behavioral barriers make use of the biological factors on the orientation and behavior of fish by a change of light, turbulence, electrical charge and sound stimuli. This type of barriers were mainly implemented as a deterrent of fish from entering water intakes, applications on hydro power plants exist but with a high uncertainty regarding their efficiency (DWA, 2005). The fish protection efficiency is strongly influenced by parameters like lighting conditions (e.g. daytime, turbidity), water temperature and particularly the flow conditions expressed by the flow velocity. In literature a threshold flow velocity of commonly 0.5 m/s is stated (DWA, 2005; Ebel, 2013).

A hybrid facility which combines the physical and behavioral retention of fish from the turbine intakes might cause an improvement to the protective purpose. Thus natural oscillations of the wires of the flexible fish fence and additional artificial stimuli like light, sound and electrical charge have the potential to deter fish from the intake.

3 FUNCTIONALITY OF THE FLEXIBLE FISH FENCE

The principle of the flexible fish fence is based on horizontally arranged wires, which are situated upstream of the turbine inlets of a run-of-river power plant. During normal operation, the wires are in place and fish protection can be ensured. Local clogging at the surface caused by small branches, leaves or grass cuttings are cleaned by releasing individual wires or wire clusters. Since the main part of floating matter is carried during higher discharges, wires are slacked off and hence lying on the river bed during these events. The wires are cleaned during this process and floating matter is transported further downstream. The cleaning process works well at overflowed power plants, where floating matter entering the inlet structure can be discharged over the plant and thus remains in the river. Furthermore, it is applicable for the ecological upgrading of existing hydro power plants, where a trash rack cleaning system in front of the turbine intakes exists. During the wires are lying on the river bed, turbines are switched off and thus do not pose any danger to fish. As the entire cross section is available for discharge of water, the danger of driftwood jams in case of a flood event is strongly mitigated.

4 PRELIMINARY TEST

4.1 Test Design

In a first test the flexible fish fence was observed regarding its basic functions on a scale of 1:5. 40 wires with a length of 18 m, a diameter of 2 mm and a clear width of 8 mm were installed over a height of 0.4 m on two supporting beams. This corresponds to a length of 90 m, a height of 2.0 m and a clear width between the wires of 40 mm in nature. The different modes of operation are displayed in Figure 1. At the operation mode the wires are clamped, which represents the state while turbines are in operation (see first sketch in Figure 1). From a certain discharge threshold the wires are released and laid down on the river bed (second sketch in Figure 1).

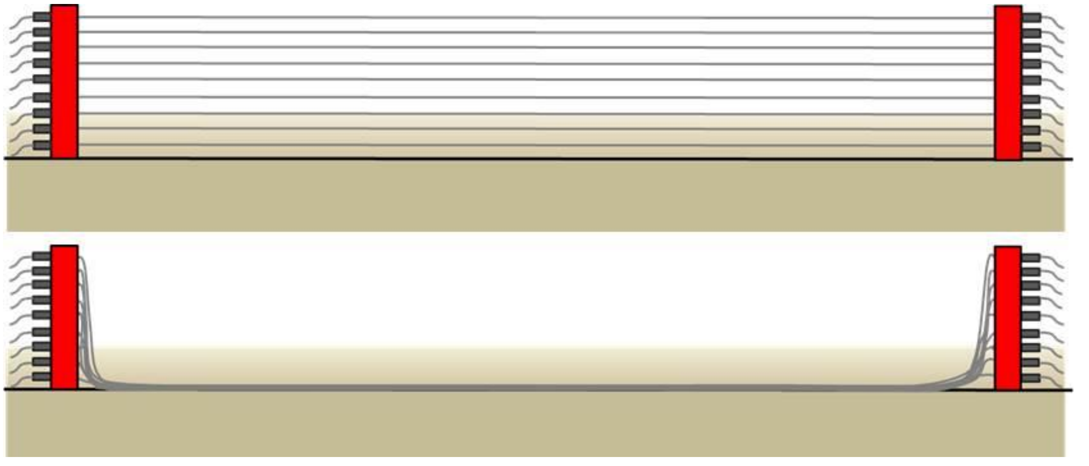

Figure 1 Operating mode and released mode of the flexible fish fence

4.2 Results

The shift between the different modes worked well. The wires were intentionally placed in a disadvantageous, jumbled way in order to test the transition of two modes of the flexible fish fence. Figure 2 displays the two main modes of the flexible fish fence and the movable support structure used in this preliminary test.

During the operating mode a slight sag of the wires was noticed, which is due to the limited capacity of the support beam. Furthermore, oscillations of the wires were investigated by stirring them with an artificial trigger. The motion of the wires was evaluated by videos and photos of the process. Within the medium air, significant oscillations up to the double clear width were observed. Thus a constant clear width between wires could not be guaranteed during oscillations.

Figure 2 Flexible fish fence in operation mode (1 and 2); released mode of flexible fish fence (3 and 4)

5 MODEL TEST

5.1 Test Design

Within a second main investigation the flexible fish fence was implemented in a channel of an existing model test at the laboratory of the Unit of Hydraulic Engineering, University of Innsbruck, and tested under flow conditions. Thereby the same construction as in the preliminary test was used, thus the scale of the model was 1:5 and the geometric parameters correspond with the first test except width. The flexible fish fence was integrated in the channel with an inclination of 45° against flow direction. The total width of the model fish fence was 5.37 m, which corresponds to a width of 27 m in nature. Figure 3 displays the layout of the model test with its basic components.

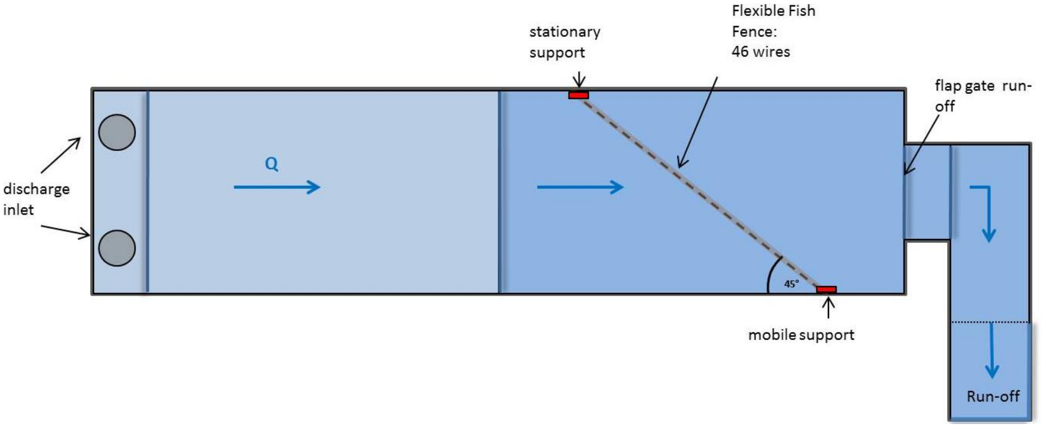

Figure 3 Layout of the model test

To achieve kinematic similarity for the hydraulic conditions, discharge and velocity scale followed the model law of Froude.

Again the main focus on the investigation was to test the basic functions and oscillations of the wires during the different modes. Additionally, the scenario of a driftwood jam in case of higher discharges was modeled by an input of leaves and branches during the experiment. Furthermore, the behavior of the wires regarding oscillations, the sag of the wires or rather the warranty of a constant clear width and the self-cleaning effect in case of a driftwood jam were investigated. Figure 4 displays the flexible fish fence in operation mode, where all wires are in place. In Figure 5 all wires are laid on the ground. Here it is important to note that with the used construction it was not possible to completely deposit the wires on the ground (see highlighted areas in Figure 5). This fact causes a higher risk of a driftwood jam, especially in the sharp angle of the facility. In nature, the support structure has to be chosen in such a way, that the wires can be completely laid down to the river bed.

Figure 4 Model test fish fence in operation mode

Figure 5 Released mode of the model test fish fence

After the first tests with floating matter were finalized, a new optimized geometry was created to enhance the cleaning capacity of the flexible fish fence. Thereby only the profile of the construction was changed from a vertical to an inclined position of 70° to the ground, which is demonstrated in Figure 6. This configuration was chosen in order to create a more constant relaxation and re-tension of wires.

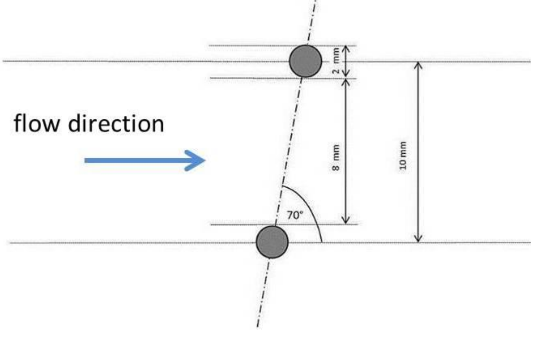

Figure 6 Optimization of the wire arrangement

The behavior of the wires was observed by submerged videography for several discharge conditions (load cases) without floating matter.

Two main hydraulic load cases were evaluated and are represented in Table 1. In both cases the highest discharge, which was possible regarding the existing infrastructure and channel capacity, was used. In the first hydraulic load case all wires are submerged. In the second hydraulic load case the water depth is reduced in order to get the maximum discharge velocity and thus the highest dynamic pressure.

Table 1 Hydraulic conditions of model test

Load case	Q_{model} [l/s]	Q_{nature} [m³/s]	Water $depth_{model}$ [m]	V_{M_model} [m/s]	V_{M_nature} [m/s]
1	311	17.4	0.37	0.22	0.49
2	311	17.4	0.56	0.14	0.31

5.2 Results

5.2.1. Cleaning function

As mentioned above, the functionality of the flexible fish fence was observed regarding its cleaning function and reaction of the wires due to increased input of floating matter. The first set of pictures (Figure 7) show model test results with leave input under load case 2. The transition from the initial state (operation mode), where the wires are in place, to the released mode, where floating matter is washed out, and back to the initial state is shown in the figures. The final state in Figure 7 shows that the main part of the cross section area was cleaned during the transition process. Some material got caught in the sharp angle and at the upper region of the fish fence. The material accumulated in a non-compacted way, thus the release was induced very quickly during the process of depositing the wires on the ground.

Model test results with input of branches are demonstrated in Figure 8. As shown in the last picture of Figure 8 the main part of the floating matter was flushed away. Individual densely branched wood got caught among the wires, but almost the total amount of branches was flushed within the transition process. It is strongly assumed that this type of floating matter is increasingly transported by the river during flood events, when wires are already deposited on the river bed.

In summary it could be shown, that the cleaning process during the transition process of the wires works well. The main part of the remaining floating matter was detected in the sharp angle of the model test arrangement. This is due to the disadvantageous arrangement of the supporting structure, which does not allow to completely lay down the wires on both sides. This has to be improved by a clever design of the supporting structure. Furthermore the floating matter, which was employed for the tests, was not adjusted to the model scale in order to be on the safe side.

Figure 7 Test with leaf input: (1) initial state, (2) relaxation of the wires, (3) transition to operation mode, (4) final state after cleaning

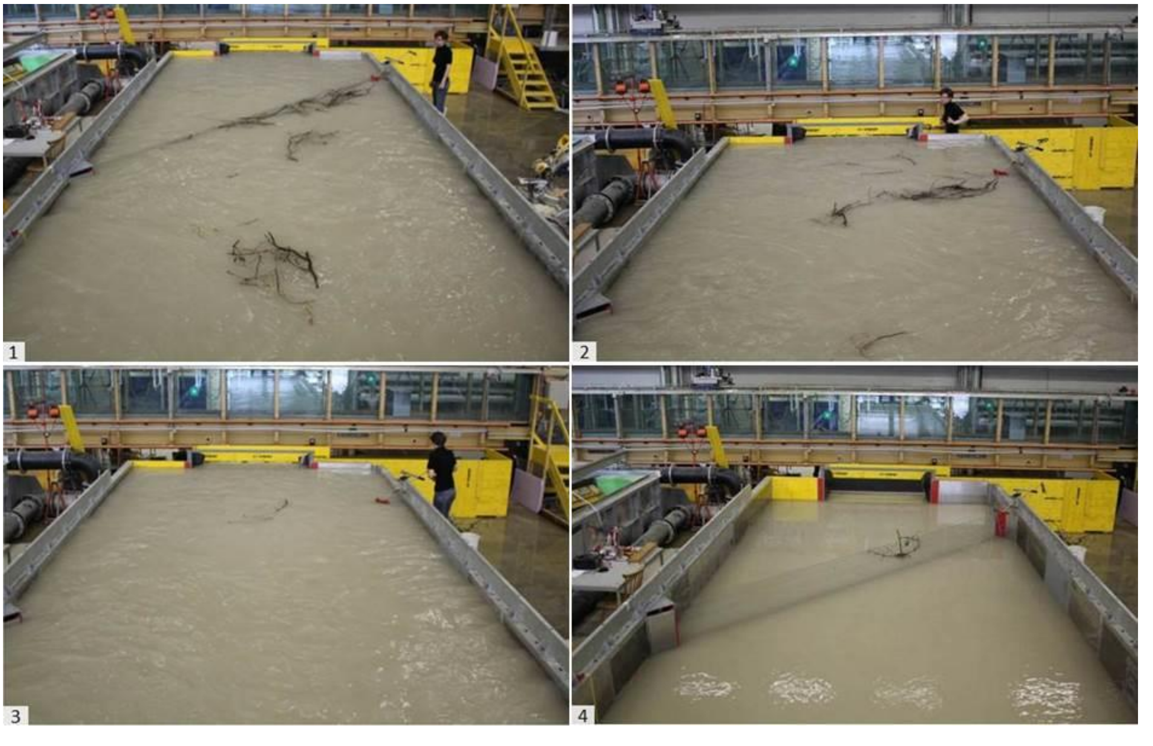

Figure 8 Test with branch input: (1) initial state, (2) relaxation of the wires, (3) transition to operation mode, (4) final state after cleaning

In summary it could be shown, that the cleaning process during the transition process of the wires works well. The main part of the remaining floating matter was detected in the sharp angle of the model test arrangement. This is due to the disadvantageous arrangement of the supporting structure, which does not allow to completely lay down the wires on both sides. This has to be improved by a clever design of the supporting structure. Furthermore the floating matter, which was employed for the tests, was not adjusted to the model scale in order to be on the safe side.

5.2.2. Oscillations of wires

In contrast to the preliminary test, oscillations of the wires were strongly reduced by the water. The magnitude of the oscillations did not exceed the clear width of the wires in any load case. Furthermore, it was observed that with an increase of flow velocity, the frequency of oscillations rises and thus the amplitude declines. Oscillations do not affect the suitability of the flexible fish fence for fish protection in a negative way.

6 APPLICATIONS

Many options for the layout of the fish fence at hydro power plants exist. Some of them are shown in Figure 9 below. Depending on the layout of the power plant, the fish fence can be situated between the two river banks or between one bank and the middle pier. With a horizontally inclined exposition to the flow, a guiding effect is generated. The fish passage facility should be located at the downstream end of the flexible fish fence in order to use this effect. The position of the flexible fish fence can be easily modified in terms of several requirements regarding geometry or fish protection purposes. This offers a high potential for the ecological upgrading of large scale hydro power plants due to a high degree of adaption on the existing structures.

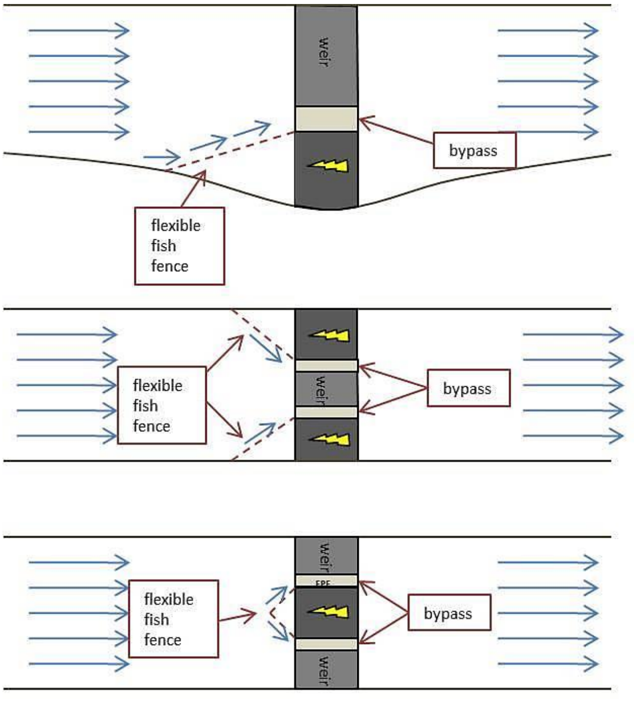

Figure 9 Layout of the flexible fish fence at different hydro power plant arrangements

7 CONCLUSIONS

The two model tests demonstrated the basic functionality of the flexible fish fence regarding the different modes of operation. While in the preliminary test strong oscillations were observed, only marginal and high-frequency movements were noticed under submerged conditions. Regarding the fish protection purpose it was shown, that the clear width between the wires of the flexible fish fence remained constant. The weak oscillations of the wires caused by the flow conditions might have an additional deterrent effect on fish.

The cleaning effect worked well in the model test considering the strongly simplified supporting and clamping technology and the not-to-scale floating matter. Besides, in reality the fence would be in released mode during certain higher discharges, where a high amount of floating matter is expected to occur. Thus the driftwood jam, which was reproduced in the tests, showed an extreme situation.

The flexible fish fence is located in front of the power house, connecting the river bank and the middle pier. By widths of up to 100 m, large cross-section areas are generated, which minimize velocities in front of the fence. Thus the risk of injuries or mortality due to a collision with the wires can be reduced. Furthermore, the horizontal arrangement of the wires is beneficial due to the fact, that the clear width of the wires can be based on the body height of fish and other aspects mentioned in chapter 2. Through a horizontal inclined exposition against flow and a bypass at the downstream end of the flexible fish fence, a guiding system is generated, which supports the downstream migration. Moreover, oscillations of the wires due to flow conditions may have an additional deterrent effect on fish. The flexible fish fence can be easily enhanced by artificially transmitted stimuli such as light, sound waves or electrical charge, which may result in a better fish protection.

At the moment, a concept for the technical realization of the flexible fish fence is being developed. By implementing a prototype at an existing hydro power site, the technique as well as the effect on fish protection is planned to be investigated and optimized in detail.

References

BMWFJ (2010): Erneuerbare Energien – Daten und Fakten. http://www.bmwfj.gv.at/EnergieUndBergbau/Energieversorgung/Documents/Erneuerbare%20Energien_Daten%20und%20Fakten.pdf

Böttcher, H. (2012): Modellversuch Drahtseilrechen. Study Project. Technische Universität München. Lehrstuhl und Versuchsanstalt für Wasserbau und Wasserwirtschaft.

DWA (2005): Fischschutz- und Fischabstiegsanlagen – Bemessung, Gestaltung, Funktionskontrolle. 2. Korrigierte Auflage, Hennef.

Ebel, Guntram (2013): Fischschutz und Fischabstieg an Wasserkraftanlagen – Handbuch Rechen- und Bypasssysteme. BGF, Mitteilungen aus dem Büro für Gewässerökologie und Fischereibiologie Dr. Ebel (Band 4); Halle (Saale).

European Commision (2011): Europe 2020 targets. http://ec.europa.eu/europe2020/index_en.htmHolzner, M. & Blankenburg, D. (2009): Vorversuche zur Eignung horizontaler Rechenanlagen für den Schutz von Fischen an Kraftwerkseinläufen – Ergänzende Ausführungen. Mskr., 5 S., Mengkofen.

Larinier, M. (2008): Fish passage experience at small-scale hydro-electric power plants in France: Hydrobiologica: 97-108.

Mosonyi, E. (1966): Wasserkraftwerke. Düsseldorf (VDI-Verlag) 2 Bände, zus. 2391 S.

Pavlov, D.S. (1989): Structures assisting the migration of non-salmonid fish. USSR. FAO Fisheries Technical Paper 308, 97 S., Rome (Food and Agriculture Organization of the United States).

Šturc, Marek (2012): Renewable energy – Analysis of the latest data on energy from renewable sources. Eurostat - statistics in focus. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-12-044/EN/KS-SF-12-044-EN.PDF