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RESTORING RIVER CONNECTIVITY IN LINE WITH EUROPEAN LEGISLATION

BY

ALEXANDRU MOLDOVEANU[1,2] and DANIELA POPESCU[1,*]

[1]"Gheorghe Asachi" Technical University of Iaşi, Faculty of Machines Manufacturing and Industrial Management, 59A Prof. D. Mangeron Blvd., 700050, Iaşi, Romania
[2]National Institute of Hydrology and Water Management-Romania,
97 E Şoseaua Bucureşti – Ploieşti, 013686, Bucharest, Romania

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Abstract. Water Framework Directive defines the river longitudinal continuity as "undisturbed migration of aquatic organisms and sediment transport". Electrical energy production from hydro sources is the main risk that generates hydromorphological alteration of surface waters by disconnecting the rivers. The flow reduction on the river sector from the water intake to the restitution point of the small hydropower plant is also considered as a hydromorphological alteration that can modify the natural hydrological regime.

This paper presents good practices for ensuring the river longitudinal connectivity while Small Hydropower Plants are implemented. In order to restore the river longitudinal connectivity for fish migration, some types of fish passages used within the hydropower facilities from Europe are presented and discussed.

The recommended solutions are important to mitigate the small hydropower plants' negative effects on river ecosystems and it can contribute to the increase of energy power units based on renewables.

*Corresponding author; *e-mail*: daniela.popescu@academic.tuiasi.ro
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Keywords: River longitudinal continuity, small hydropower plants, fish passages, ecological flow, renewable energy sources.

1. Introduction

The Directive 2009/28/CE on the promotion of the use of energy from renewable sources and subsequent amendments, is considered the main document for the European Union Energy Strategy regarding renewable energy sources promotion (European Commission, 2009). The environmental and energy policies frameworks are developed at centralized level and are mandatory for all the Member States in order to achieve the European Directives requirements by transposing within the national legislation. In the actual context, characterized by the increasing demand of electricity at an affordable price correlated with less availability of conventional resources, the development of hydropower is an important topic. The implementation of the Directive 2009/28/CE must be performed in line with the Water Framework Directive 60/2000/EC environmental objectives (European Commission, 2000) to assure the continuity of the river, the minimum ecological flow downstream the barriers and to preserve clean water bodies (European Commission, 2012), (European Commission, 2015).

The electricity generation from renewable energy sources is expected to increase more and more, but one barrier in the development of production from hydro resources is the requirement to achieve clean energy production without major environmental impact. A solution is implementation of run on the river environmentally friendly micro water turbines (up to 100 kW), able to produce electricity from very low hydraulic potential (Moldoveanu *et al*., 2017; Moldoveanu and Popescu, 2019).

To explore small hydro resources by more profitable solutions, the accumulation of water in basins is needed. In the last years, the environmental policies restricted construction of new small hydropower plants (up to 10 MW), by new regulations. The measures were necessary, because hydro-technical works, especially dams are physical barriers that can lead to river habitat fragmentation and to fish population isolation. In some countries, such as Latvia new legislation on small hydropower forbids the built of dams and in Estonia, the country's installed Small Hydro Power capacity decreased by almost 19% from 2016 to 2019 (UNIDO, 2019).

This paper presents good practices for ensuring the river longitudinal connectivity, while small hydropower plants are designed and constructed. In order to improve the river longitudinal connectivity for fish migration, several types of fish passages used within the hydropower facilities from Europe are presented and discussed. The paper aims to present an integrated approach for finding solutions to mitigate the small hydropower plants' negative effects on

river ecosystems and reduce/eliminate the hydromorphological alteration of surface waters generated by the electrical energy production from hydro sources.

2. The Renewable Energy Sources in the Water Management Field

Water Framework Directive defines the river longitudinal continuity as "undisturbed migration of aquatic organisms and sediment transport". Electrical energy production from hydro sources is the main activity generating hydromorphological alteration of surface waters by disconnecting the rivers. Even, the fluid flow rate reduction on the river sector from the water intake to the restitution point of the small hydropower plant can generate hydromorphological alteration by modifying the natural regime, when the minimum fluid flow rates are not ensured.

Fish passages are highly recommended solutions, because the ecological flow on the river sector from the water intake to the restitution point of the small hydropower plant is guaranteed. The solution not only mitigates the small hydropower plants' negative effects on river ecosystems, but it is also fully in line with the environmental objectives of the Water Framework Directive. Implementation of the fish passages is a solution to make possible the classification of a hydropower plant in the category power generation unit based on renewable energy sources (RES). Such classification, make the power unit eligible for financial support programmes by green certificates (GC) scheme (ANRE, 2019).

The main conditions for a Small Hydropower Plant (SHP) that must be fulfilled in order to be considered a renewable energy sources (RES) power unit are the following:

- The installed power of the SHP must be less than 10 MW;
- The river longitudinal connectivity is not interrupted by a barrier (weir);
- There is a minimum ecological flow rate, permanently maintained downstream of the barrier (weir), which is variable accordingly to the natural hydrological regime of the river.

3. Good Practices for Ensuring the River Longitudinal Connectivity on the Rivers with Operational Small Hydropower Plants

Fish passages are structures that facilitate the fish fauna to move upstream/downstream of an artificial barrier (Jungwirth and Pelikan, 1989). This hydrotechnical works are used to restore the river longitudinal connectivity in order to mitigate the fragmentation of the ecosystem for migratory and sedentary species.

The fish passages design projects must take into consideration the hydraulic characteristics of the water bed (roughness, hydraulic slope, water velocity, fluid flow rates), as well as the characteristics of the fish species and habitat (Stanciu and Runceanu, 2018).

The measures to improve the river longitudinal continuity are various from the technical point of view, but for the SHP facilities the most used fish passages types are classified as the following:

- *Rock ramps* which are built in general by natural material and are totally/partially placed within the riverbed.
- *Bypass channels* or pool-type fish passages that are nature-like or technically constructed.
- *Technical fish-passages* with regulated channel made in general by artificial materials (concrete or plastics) or processed natural material (wood) guiding the fish through the barrier (*e.g.* pool-pass type) (Schmutz and Mielach, 2013).

Small Hydropower Plants must comply with complementary measures/solutions referring to the fish friendly good practices, such as fish friendly turbines or fish screens.

The rock ramps can be constructed of rocks or of artificial material like concrete blocks, in order to create pools and small falls that can replicate the natural habitat of fish fauna. An example is presented in Fig. 1. This type of fish passage is recommended for medium size rivers with small slopes and with a height of barriers up to 2 meters.



Fig. 1 – Bremer River rock ramp fishway.

The fish passages of bypass channel type are low-gradient channels that reproduce the structure of natural rivers and the conceptual layout is presented in Fig. 2.



Fig. 2 – Rock ramp bypass channel. River Almond at Howden Bridge Weir (Scotland).

Technical fish passages with geometrical channel design are built from artificial material that guides the fish through the barrier (*e.g.* pool-type fish passages).

Pool-type fish passages are the most used fish passage within Europe. They are made of successive interconnected pools separated by transversal walls with orifices (surface or submerged), as it can be noticed in figure 3. The vertical-slot fish passage is used at large scale because of its effectiveness with native fish being appropriate for mountain rivers typology.



Fig. 3 – Pool-fish passage. Elbe River (Germany).

In the following, some fish passages from Romania are presented as examples of good practices for ensuring the river longitudinal connectivity on the rivers with operational small hydropower plants.

3.1. The bypass channel nature-like constructed on the Fancel River

Figure 4 presents the bypass channel nature-like located on the Fancel River within the Mures River Basin from Romania. The bypass channel was constructed in order to ensure the river continuity and for the mitigation of the hydromorphological alteration generated by the weir of the Fancel small hydropower plant (SHP) at the water intake. It is built of natural materials (local river rocks) and is provided with deflectors arranged alternately to reduce the water velocity.

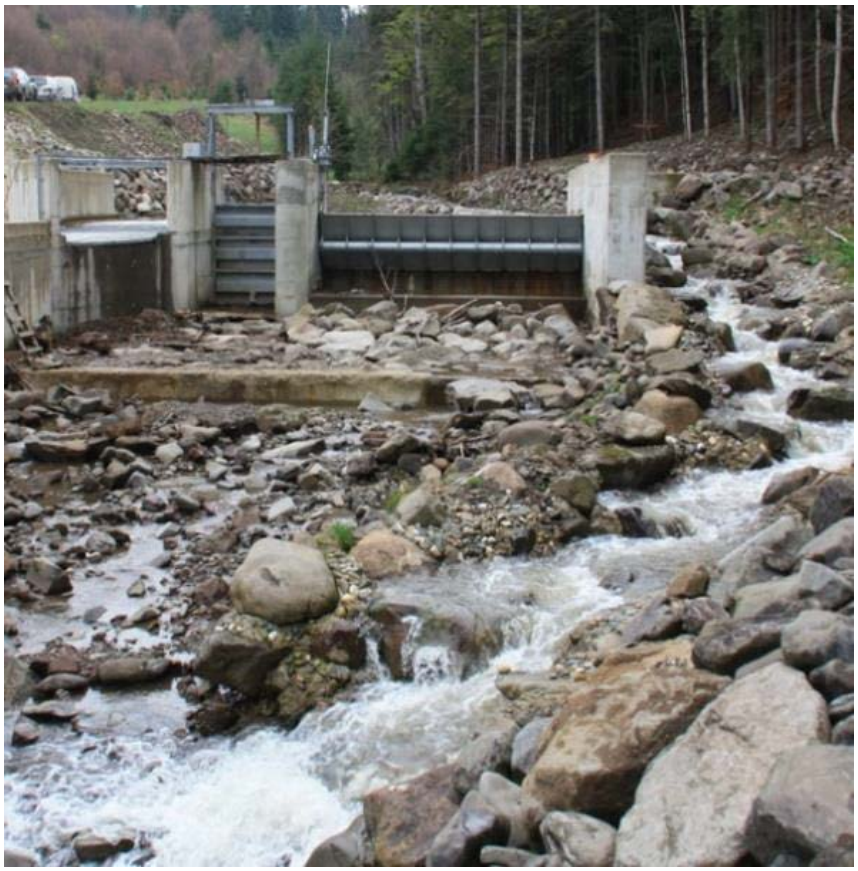


Fig. 4 – Bypass channel on the Fancel River (source: Risnoveanu *et al*., 2021).

The Fancel SHP, located within the Ibanesti locality, has an installed power of 1.2 MW. The spillway height and length are H = 1.40 m; L = 6.50 m.

The bypass channel characteristics are: the servitute flow (including the ecological flow) $Q_{servitute}$ = 0.126 m^3/s, minimum water depth h = 0.20 m and the maximum water velocity v = 1.0 m/s. The bypass channel is constructed to the left riverbank, on the opposite side of the water intake.

The monitoring activity for the representative fish species of the mountain river type (trout different species) revealed that the bypass channel is functional and allows fish migration upstream and downstream of the water intake weir of the Fancel SHP.

3.2. The technical fish passage on the Salard River constructed of artificial material

In the Fig. 5, the fish passage located on the Salard River within the Mures River Basin from Romania is presented.



Fig. 5 – Fish passage on the Salard River (source: Risnoveanu *et al*., 2021).

The fish passage was constructed in order to ensure the river continuity and for the mitigation of the hydromorphological alteration generated by the weir of the Salard small hydropower plant (SHP) at the water intake. It is built of reinforced concrete with embedded natural riverbed materials (boulders and gravel).

The Salard SHP, located within the Salard locality, has an installed power of 0.09 MW. The spillway height and length are H = 1.20 m; L = 9.0 m.

The fish passage characteristics are: the servitude flow (including the ecological flow) $Q_{servitute}$ = 0.521 m^3/s, minimum water depth h = 0.30 m and the maximum water velocity v = 0.4 – 0.5 m/s. The fish passage is built to the left bank of the river, on the opposite side of the water intake and has the length of L = 7.4 m and the width of l = 0.8 m. A manually operated dam valve is mounted on the fish passage and the opening field of the fish passage has the following dimensions 0.8 x 0.9 = 0.72 m^2.

The monitoring activity for the representative fish species of the mountain river type (trout different species) revealed that the bypass channel is functional and allows fish migration upstream and downstream of the water intake weir of the Salard SHP.

4. The main parameters for designing a fish passage with vertical slots

The main physical and hydraulic parameters that should be considered for designing fish passage with vertical slots are the following: water velocity, slope of the fish passage, head loss between two successive compartments (pools) of a fish passage and turbulence.

The maximum water velocity within the fish passage it can be measured in situ by using the head loss between two successive compartments. The water velocity is connected to the fish passage slope parameter and must be correlated with the native fish species needs for swimming. Also, this parameter should be interpreted together with turbulence. The slope of the fish passage can be determined by using the head loss divided to the compartment length.

The equation of the flow determination within a fish passage with vertical slots:

$$Q = Cd * (v * A) \quad (1)$$

where: Q is discharge (m^3/s); Cd is coefficient of discharge (usually 0.7); v is water velocity (m/s) and A represent the slot area.

Figure 6 presents a vertical slot and a compartment (pool) with vertical slots.

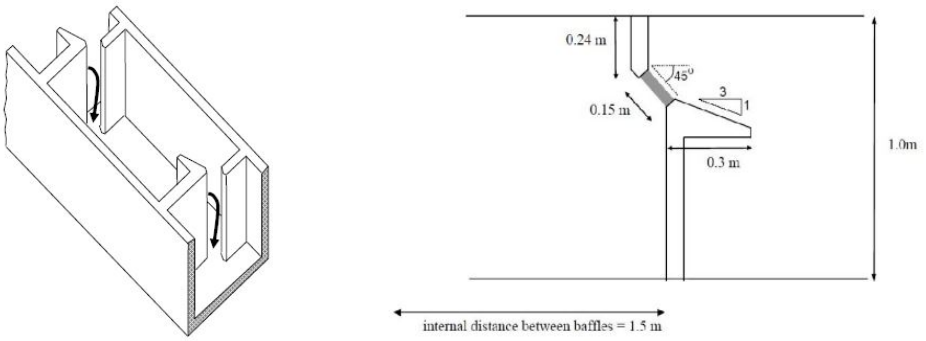


Fig. 6 – Schematic representation of a fish passage with vertical slots (O'Connor *et al*., 2017).

According to the literature, the number of compartments (n) can be determined from the equation:

$$n = \frac{h_{tot}}{\Delta h} - 1 \tag{2}$$

where: h_{tot} is the maximum difference between headwater and tailwater, Δh is the water level difference between two successive compartments (should be considered as a threshold value for the difference in water level $\Delta h \leq 0.20$ m).

The total number of compartments is used for the fish passage length determination by using the following formula:

$$I_{tot} = n * I_b \tag{3}$$

where: I_{tot} is the total fish passage length; I_b is the length of a compartment and n is the total number of compartments of the fish passage.

The Δh is influencing the maximum water velocity (v_{max}) within the slots, which can be computed by the following equation:

$$v_{max} = \sqrt{2g\Delta h} \tag{4}$$

where: g is the gravitational acceleration (9.81 m^2/s), Δh is the water level difference between two successive compartments.

Figure 7 presents a scheme of a longitudinal view within the fish passage with vertical slots.

The parameters presented above, indicate that increasing the number of compartments (n) leads to the reduction of the maximum velocity (v_{max}) on the fish passage with vertical slots.

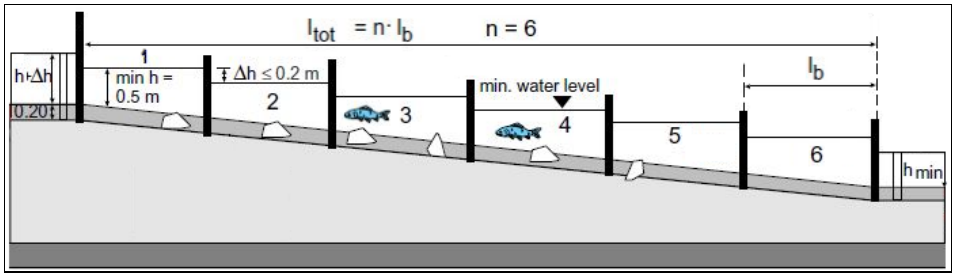


Fig. 7 – Schematic representation of a fish passage with vertical slots - longitudinal view (FAO, 2002).

The fish passages with vertical slots are recommended both for small and medium water courses and can be appropriate for small fish specimens or for the fish fauna that have not good capabilities of swimming.

5. Conclusions and recommendations

Taking into consideration the large number of the existing SHP, over 8000 at European level according to ICPDR Report (ICPDR, 2013) as well as their heterogeneity from the structural point of view, their location and size, the selection of the most suitable fish passages structures must be analysed case by case, depending on a series of elements (available space on the river banks, native fish species, barrier height, river slope, flow).

These elements represent a starting point for the designing process of the optimal structures for the fish passages allowing the fauna migration upstream and downstream of the transversal structures in rivers.

At the European level, there is a hierarchy of fish passages selection. Lately, nature-like ones are preferred. Technical solutions, namely fish passages with pools and holes, with vertical slots, Alaska type, Denil type are easy to construct, but are not environmentally friendly and can damage a beautiful touristic area.

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DESPRE REFACEREA CONECTIVITĂȚII LONGITUDINALE A RÂULUI ÎN CONFORMITATE CU LEGISLAȚIA EUROPEANĂ

(Rezumat)

Directiva Cadru a Apei definește continuitatea longitudinală a râului ca „migrația neperturbată a organismelor acvatice și transportul sedimentelor”. Producția de energie electrică din surse hidro este principala activitate generatoare de alterare hidromorfologică a apelor de suprafață prin fragmentarea continuității râurilor. Reducerea debitului pe sectorul râului de la captarea apei până la punctul de restituție a microhidrocentralei este considerată o alterare hidromorfologică și datorită modificării regimului hidrologic natural.

Lucrarea prezintă soluții recomandate pentru asigurarea conectivității longitudinale a râului în cazul construcției de microhidrocentrale. Pentru a restabili conectivitatea longitudinală a râului și a permite migrația peștilor, sunt discutate unele tipuri de pasaje pentru pești utilizate în cadrul instalațiilor hidroenergetice din Europa.

Soluțiile recomandate sunt importante pentru atenuarea efectelor negative generate de hidrocentralele mici asupra ecosistemelor râurilor și pot contribui la creșterea unităților de producere a energiei electrice din surse regenerabile.