Evaluation of Fish Passage Design: A Case Study in Vereinigte Weißeritz River

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Abstract

Small hydropower project development has been, for the last decade, one of the sectors in the energy field that has been very active. One of the main environmental challenges of small hydropower development is related to fish passage both upstream and downstream. In order to tackle these challenges, ecohydraulics approach should be adopted to understand the reason behind why these fish passages nearby hydropower plant does not work properly. The existing fish passage is one vertical slot type of fish passage and a small hydro power plant is located nearby WKA Bienertmühle weir at Vereinigte Weißeritz River. This fish passage was found to be not functional therefore, a novel fish passage design was proposed.

Key words: Fish migration, fish passage, hydropower plant, ecohydraulics, retrofitting

1. Introduction

Fish passage can be defined as any form of conduit, channel, lift, other device or structure which facilitates the free passage of migrating fish over, through or around any dam or other obstruction, whether natural or man-made, in either an upstream or a downstream direction. Fish passage is considered a necessity where a dam separates a target species from needed habitat. Fish are generally unable to pass upstream of a hydropower dam unless some fish passage facility is present. Decisions about the need for fish protection measures at dams are often based on the perceived or measured impacts on one or more species at the site. Fish populations may be adversely affected by hydropower facilities and many other activities and facilities (e.g., multiple use, flood control, and water supply dams; land use practices like grazing and forestry; and facilities like coal-fired power plants that cause acid rain). Migrations and other important fish movements can be blocked or delayed. The quantity, quality, and accessibility of up and downstream fish habitat, which can play an important role in population sustainability, can be affected. Fish that pass through power generating turbines can be injured or killed. Increased predation on migratory fish has also been indirectly linked to hydropower dams (e.g., due to migration delays, fish being concentrated in one place, or increased habitat for predatory species).

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The objective of this thesis was to seek a consideration for the functionless fish passage and propose a novel fish passage design that serves both upstream and downstream migration for existing fish passage facility near small hydropower plant in Vereinigte Weißeritz River.

2. Study area

WKA (Windkraftanlage: Wind turbine) Bienertmühle weir is located under Hege Reiter Bridge in Plauen Grund valley towards the direction of the town Freital. WKA Bienertmühle weir has small hydro power plant and fish passage structure adjacent to its location. Vertical slot fish passage of WKA Bienertmühle weir on Vereinigte Weißeritz River is chosen as a study area of this thesis. Vereinigte Weißeritz River is formed by the confluence of the Wilde (Wild) Weißeritz River and Rote (Red) Weißeritz River at the town of Freital between 50° 58' 54" N (northern latitude) and 13° 37' 46" E (eastern longitude). Vereinigte Weißeritz River also named as United Weißeritz or Weißeritz River, which is a confluence river of Weißeritz River catchment (Figure 1), is a 14.2 km short left tributary of the River Elbe which flows through 5.5 km in Freital (District: Sachsishe Schweiz- Osterzgerbirge), 8.7 km in Dresden (District: Dresden, Stadt) and opens up to Elbe River (61.5th km of the River Elbe) in Cotta-Dresden between 51° 3' 48" N (northern latitude) and 13° 41' 12" E (eastern longitude). In detail, it flows through (upstream to downstream) Freital-Hainsberg, Plauenscher Grund, Stadtgrenze Dresden, Plauen, Cotta respectively [1].

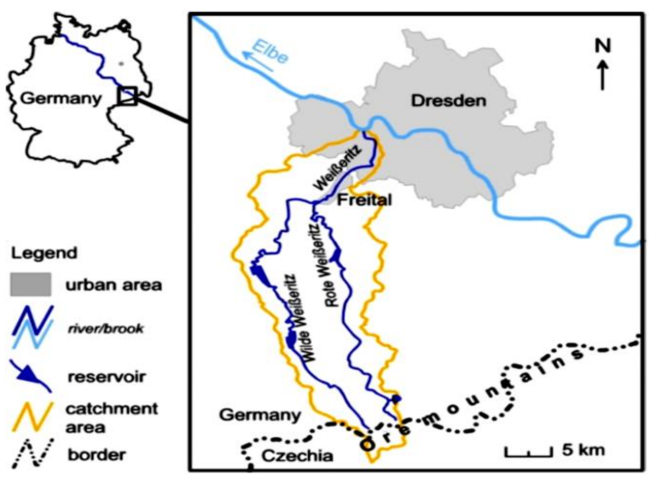

Figure 1. Catchment area of the case study [2].

Vertical slot type of fish passage (Figure 2) has lots of advantages in regard to other technical fish passages. Slot passes (vertical slot passes) are well suited to guarantee ascent by both fish species that are weak swimmers and small fishes. Relatively high discharges can be sent through, thus good attraction currents can compose. They are more reliable than conventional pool passes because of the lower risk of clogging of the slots. Vertical apertures that stretch over the whole height of the cross-walls are suited to the swimming behaviour of both bottom-living and open-water fish. Also, it can tolerate reasonably large upper and lower water level fluctuations.

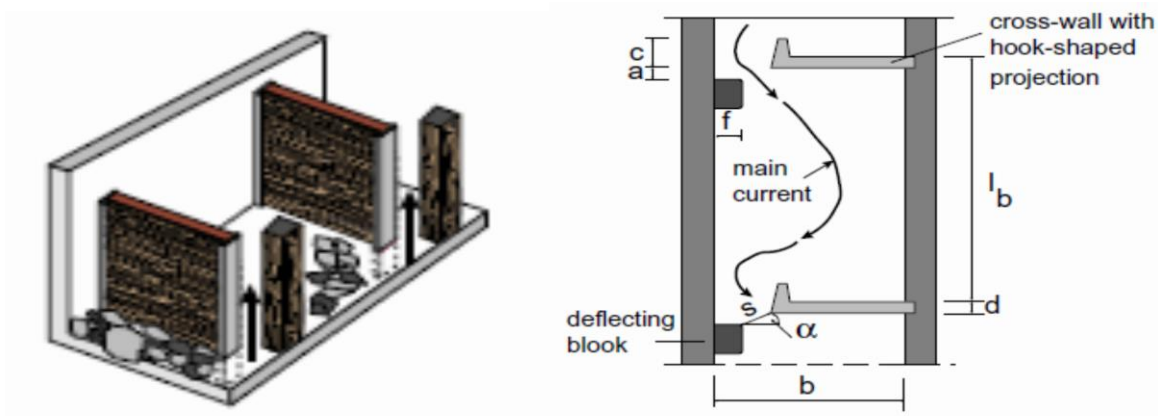

Figure 2. Cross section and plan of one vertical slot type of fish passage [3].

Existing fish passage has only provides fish migration for upstream direction. Native (resident) species of the Vereinigte Weißeritz River are mostly European grayling (Thymallus thymallus) fish species. The objective of the thesis was to propose a novel fish passage design that serves both upstream and downstream migration for existing fish passage facility in Vereinigte Weißeritz River (Figure 3). In order to execute that two separate fish passage must be conducted at the site. Hence, same type of fish passage must be chosen for the novel fish passage design.

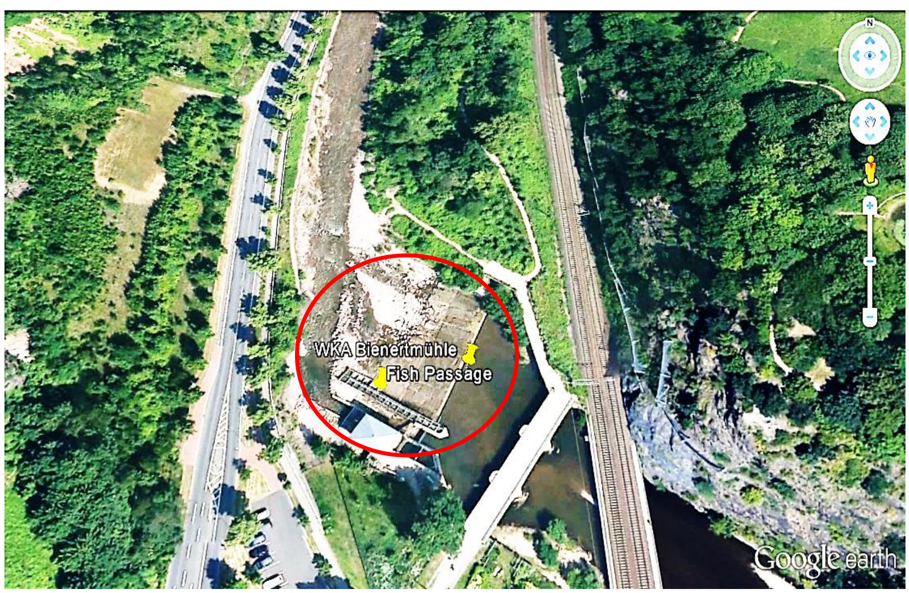

Figure 3. Satellite view of fish passage near WKA Bienertmühle weir at 307 m [4].

2.1. Materials

One vertical slot type of fish passage and small hydro power plant with intake screen were constructed between the years of 1998 and 2000 near WKA Bienertmühle (Figure 4).

Figure 4. WKA Bienertmühle weir, fish passage and hydro power plant [5].

In consequence of personal communication with Gloger, L. (2014), following information was acquired. 6% of the fish passage pass consists of C20/25 concrete whereas 94% of the fish passage comprises of durable wood which has a service life of 15 to 25 years. Flow rates which were observed in the river at WKA Bienertmühle weir are 0.36 m^3/s as a lowest flow rate, 2.0 m^3/s as a mean flow rate and 100-160 m^3/s as highest flow rate so far. The waterbodies that move forward to tailwater of WKA Bienertmühle weir structure can be summarized as follows: a flow rate of 0.34 m^3/s directly flows through weir structure and reaches downstream of the river, a flow rate of 0.19 m^3/s flows within the fish passage, a flow rate of 16 m^3/s is directly bypassed and 1-4.4 m^3/s is given by hydro power plant to downstream of the river. Maximum headwater level, minimum headwater level and tailwater level at the river are 134.94 m, 134.64 m, 129.74 m respectively. Other related data about fish passage include level of water inlet (z_e, substrate) that is 134.107 m and level of fish pass bottom (z_e, bottom) that is 133.97 m. Maximum water level difference is 5.20 m whereas minimum water level difference is 4.90 m at WKA Bienertmühle weir. A plan view of typical one vertical slot fish passage (Figure 5) is designed to guarantee upstream fish migration.

Figure 5. Vertical slot fish passage structure next to WKA Bienertmühle weir [5].

In order to deter the fish species entering to the turbines of hydro power plant while downstream migration, 18 mm bar spaced intake screen was located in front of the entrance of the hydro power plant (Figure 6).

Figure 6. Intake screen near small hydropower plant [5].

Specifications and given values of one vertical slot fish passage are given in Table 1.

Table 1. Pool dimensions of the fish passage [3] (*Fish fauna to be considered: Grayling, bream, chub, others (includes Brown trout, salmon, sea trout, huchen)).

Dimension	*Range or Number (m)	Given value (m)
Slot width (s)	0.15-0.30	0.18
Pool width (b)	1.20-1.80	2
Pool length (l_b)	1.90-3.00	1.8
Length of projection (c)	0.16-0.18	0.16
Stagger distance (a)	0.06-0.14	0.08
Width of deflecting block (f)	0.16-0.40	0.16
Thickness of wall in slot pass (d)	0.1	0.1
Minimum thickness of substrate	0.2	0.2
Water level difference (Δh)	0.2	0.233
Water depth below a cross-wall (h_u,h_{min})	0.50-0.75	0.6
Water depth above a cross-wall (h_o)	> 0.5	0.74

3. Methods of Approach

Ecohydraulics (subdiscipline of ecohydrology) is one of these emerging fields of research that has drawn together biologists, ecologists, fluvial geomorphologists, sedimentologists, hydrologists, hydraulic and river engineers and water resource managers to address fundamental research questions that will advance science and key management issues to sustain both natural ecosystems and the demands placed on them by contemporary society. Adopting an ecohydraulics to fish passage research would advance the methods used to define suitable design criteria, and could be used to identify, quantify and understand responses of fish to the hydraulic environment relevant scales. For fish passage, ecohydraulics allows hydraulic features of interest to be quantified and linked to the swimming performance and behavioural response of fish. Understanding the fundamental reasons why fish reject or progress through fish passes, be it due to physiological ability or behaviour, will greatly improve our capacity to facilitate more efficient passage or to deter fish from entering potentially hazardous locations. With this in mind, ecohydraulics must not be constrained to linking hydraulic and ecological processes, but should focus on bridging gaps between disciplines.

4. Results

WKA Bienertmühle weir was constructed between the years of 1998 and 2000 in accordance with the design manual that is published in 1996. The project was examined and evaluated in accordance with the fish passage standards issued in 2014. In the field of ecohydraulics, existing fish passage was evaluated as non functional. Therefore, novel fish passage design that serves two types of migration (upstream and downstream) is found as more appropriate design for the fish passage at WKA Bienertmühle weir. As a rule, it is not possible to use a fishway for upstream and downstream migraton, simultaneously, as fish behave differently depending on whether they migrate upstream or downstream. Nevertheless, when planning a fishway, the basic principles and site constraints applying to fish downstream migration must be taken into account to ensure that the project does not create obstacles to a potential construction of a fishway for downstream migration at a later stage and/or that some synergistic effects are produced. This is particularly relevant with regard to the space available in relation to the space required for a fishway for upstream migration aid and a fishway for downstream migration aid as well as the possibility of one common auxiliary conduit for both facilities. In accordance with the new standards in 2014 (Merkblatt DWA-M 509), slot width, pool length, water level difference, velocity and flow rate must be selected again. Downstream fish passage facility (i.e. one vertical slot) must be located near upstream fish passage facility (i.e. one vertical slot) as a second fish passage.

5. Discussion

5.1 Operation criteria

Important considerations are whether diadromous fish are adversely impacted by project structures and operations that block or impair fish movements and whether the specific fish passage design will provide for the efficient, effective, timely and safely upstream and downstream passage to fish to mitigate this impact. For the operation of the fish passage, these following six criteria must be investigated: i) efficiency, ii) effectiveness, iii) time, iv) safe, v) monitoring&evaluation, vi) maintenance.

i) Efficiency (quantitative concept): It means that the number of fish entering the fish passage equals to the number of fish exiting the fish passage. To enhance the efficiency of the fish passage for multiple species, there is a need to quantify swimming performance and behaviour under realistic hydraulic conditions for a range of locomotory guilds. To achieve this, there is a need to: (1) create and quantify hydraulic conditions at biologically relevant scales, (2) quantify swimming performance under conditions where natural behaviours can be expressed, using appropriate metrics.

ii) Effectiveness (qualitative concept): It means that the pass is capable of letting all target species pass through within the range of environmental conditions observed during the migration period. As a rule, it is not possible to use a fishway for upstream and downstream migration simultaneously as fish behave differently depending on whether they migrate upstream or downstream. Nevertheless, when planning a fishway the basic principles and side constraints applying to fish downstream migration must be taken into account to ensure that the project does not create obstacles to a potential construction of a fishway for downstream migration at a later stage and/or that some synergistic effects are produced.

iii) Time: Avoiding eddy flow is extremely important within the fish passage to have timely fish passage conditions. The cause of eddy is usually the difference in static head between normal tailwater elevation near the shore and the lower water-surface elevation at the upstream end of the hydraulic jump at the base of the spillway. This difference in elevation causes a velocity from the shore toward the base of the spillway, where the water is at its lowest level. If the eddy can be eliminated or damped to a point where velocities in it are not high enough to give fish a directional stimulus, then the downstream velocity of water leaving the fishway entrance will be the chief attraction to fish reaching this area, and there will be no delay in entering fishway.

iv) Safe: Downstream migrants swept through hydroelectric plants will face similar risk of mechanical damage. In order to have a safe fish passage, several methods have been attemped for diverting fish away from the entrances to power plants or turbines. Physical barriers to migration may be effective in situations where behavioural barriers are ineffective. Screens and similar physical barriers represent a compromise between interference with water flow and the blocking of fish entry. The more complete the barrier to fish the greater the loss of flow. For an intake on a flowing stream or canal, a wire mesh screen is normally used. Instead of conventional turbines, an improved turbine design (environmental friendly turbines) which has redesigned gates with rounded edges & fewer gaps, curved walls, reduced places where fish may be pinched and blade, hub and outlet designs work together to reduce the turbulence in order to reduce injury and mortality.

v) Monitoring & evaluation: Recording system (monitoring and assessment) of how many fish species are getting inside or outside of that particular passage will show the precise data about efficiency of the fish passage. Altough it requires capital and labor work, observation of the fish species is crucial with regard to their own migration patterns. Conventional fish-tracking techniques are best suited to reach-scale studies of movements, quantifying the location of tagged individuals within a general area rather than their absolute position, or confirmed passage at a fixed point, e.g. dam, weir or associated fish pass. Passive Integrated Electromagnetic Transmitter (PIT) tag detection system can be implemented inside of the fish species to monitor movements and survival of fish at the site.

vi) Maintenance: Optimum operation time for fish passage must be 300 days in a year. According to the seasonal changes of the weather, different hydrodynamic conditions will occur. Operation of the fish passage during the extreme conditions would be very limited and, therefore, care must be taken into account to quantify and qualify the effect of these extreme conditions. A maintenance schedule can be drawn up or adjusted on the basis of operational experience of the type and frequency of malfunction of the fish pass in question.

5.2 Novel fish passage design

Existing fish passage design connoted that flow rate (Q), velocity (V) and water level difference (Δh) in the pools are above of critical values. Furthermore, the selection of pool length and width was not chosen within the range (Table 2).

Table 2. Comparison of design parameters [3], [6].

Parameter	Symbol	1996 (Manual)	2000 (Design)	2014 (Manual)
Pool length (m)	l_b	1.90-3.00	1.8	1.95-3.00
Pool width (m)	b	1.20-1.80	2	1.50-2.25
Slot width (m)	s	0.15-0.30	0.18	0.20-0.35
Water depth below a cross-wall (m)	h_{min}	0.50-0.75	0.6	0.50-0.80
Water level difference (m)	Δh	0.2	0.233	< 0.15
Velocity (m/s)	V (V_{min}, V_{max})	2	2.14	0.3-1.9
Flow rate at WKA (m^3/s)	Q_{30}, Q_{330}	160	169	150,180

Hence, implementation of more up-to-date design for optimising the existing fish passage must be considered based on the new design manual that was released by DWA in 2014 for both upstream and downstream migration. Since it was constructed in the year of 2000, it must be retrofitted in such a way that it would provide an improvement in terms of operation criteria at the one vertical slot fish passage. According to the new design manual [6], design flow rates must be based on 300 operational days and $Q_{30} = Q_{min}$ (average annual minimum flow rate) and $Q_{330} = 1.5 * Q_{mean}$ (average annual mean flow rate) flow rates must be used in the designing phase. In addition, screens must have a sufficiently small spacing or mesh dimension to physically prevent fish from passing. Sufficient screen area is much smaller than the determined value (i.e. 15 mm, Fisheries Law). To determine the optimum location of a fishway within a barrage structure that may consist of several functional units (weir, power plant, lock(s), upstream and downstream fishways, boat channel, etc.) it is important to take account of the power plant and weir operation strategies, flow patterns and discharge distributions in the downstream area. Based upon the new design manual in 2014, pool length and slot width must be retrofitted in the novel fish passage design. Fish transport relies on water velocities not exceeding the swimming abilities of migrating species. Water level difference, velocity must be calculated and flow rate at the weir must be chosen again in accordance with the new design manual in 2014.

Comparison of impacts for fish passage alternatives is discussed before retrofitting the existing fish passage. At the end of the discussion, one vertical slot fish passage (technical type of fish passage) is determined upon personal communication with Reservoir Adminstrator of Saxony State. As understood from Figure 7, the right side of the fish passage must be relocated near the turbine. A new fish passage on the side of the power station (to use the turbine's leading current) must be implemented. This new design of fish passage that is demonstrated in Figure 7 at the recent site with the inflow must be located towards the middle of the weir and the entry at the turbine's mouth. Completely new construction of vertical slot fish passage left of the power station that has downstream fish passage must be considered in the novel design.

Figure 7. Plan and close-up views of potential novel fish passage at WKA Bienertmühle weir [5].

In order to extend the area of intensity of velocity of outflow from the fish entrances to attract more fish and provide velocities in fish transportation channels of sufficient magnitude to encourage the migrating fish to keep moving in the required upstream and downstream direction, attraction (or if it is needed auxiliary) water must be implemented. The geometry of the facility is defined by the largest species and the maximum flow speed by the weakest swimmers. Upstream migration must be based on the fact that migration capability of the fish (i.e. adults of anadromous species, juveniles of catadromous species) that is considered when designing a fish passage at WKA Bienertmühle weir. Because of much less advanced than that for upstream fish passage facilities, attention should be drawn to downstream fish passage facilities. For the downstream migration, fish (i.e. juveniles of anadromous species, adults of catadromous species) passing through hydraulic turbines are subject to various forms of stress likely to cause high mortality.

Since there is no monitoring and evaluation system which includes both biological and hydraulic parameters in the river, DART (Data Access Real Time) system must be set up or developed in order to count fish species daily, monthly and on annual basis, fish migration periods, fish species count for each fish passage, fish behaviour monitoring and timing of migration peaks, spawning location, estimated timing of each life stage, estimated periods of upstream and downstream migration, predator species expected to be present. Also, flow frequency analysis, discharge rating curve, characteristic velocity profile should be performed and low, average, high flows (therefore water levels for each situation) must be specified for the fish passage. And, design passage flows for upstream and downstream passage for each target species across life stages during both high and low flow conditions are needed. To control the fish passage facility in flood seasons, upstream flood control structures can be built in order to sustain progression of the system. Hence, a regular maintenance program should be provided for the river. In addition, fishery management plans or comprehensive water resources plans and security plans and facility features to guard against unauthorized human activity, poaching, vandalism, etc. must be proposed. Structurally, all components of the fish passage must be designed accounting for all possible external, internal and superimposed loads and pressures. External loads include soil and hydraulic pressure, hydraulic uplift, impact from flowing water or sub-merged & floating objects and surcharges such as equipment and vehicles. Internal loading is normally hydraulic pressure depending on differences in outside and inside water levels or full hydraulic head, e.g., plugged baffle slot(s). This requires extensive knowledge of engineering and hydraulic principles as well as experience in the design and construction of fishway or fish passage structures.

Conclusions

In conclusion, this case study is a sample model for the existing non functional Turkish fish passage facilities. Having a better future of ecosystems sustainability is extremely prominent, especially when dealing with such biased facilities in the history. Before construction, environmental impact assessment must be conducted. Compatible fish passage structures for site specific fish species and river hydrodynamic conditions should be designed by placing emphasis on terrain, river species equilibrium. Fish passage location, entrance and exit are extremely important for the operation of fish passage. Monitoring and computer aided sytems, maintenance and control programs should be set up in order to provide longevity of the fish passage facility. The fish passage design process for upstream and downstream migrating fish provides an opportunity to develop safe, timely, effective and efficient fish passage facilities appropriate for the site specific and target species. Identifying the most appropriate and cost effective fishway design to achieve this goal will help in meeting fishery management objectives, including minimizing injury, stress and migration delays, restoration and sustainable diadromous fish populations in the future. To sum up, after the comparison of design manuals in 1996 and 2014, a retrofitted existing fish passage design and operation in lieu of existing fish passage that is constructed in 2000 is proposed.

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