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HYDRAULIC CONDITIONS OF WATER FLOW IN SEMINATURAL FISH PASS, A CASE STUDY OF THE SKÓRKA BARRAGE ON THE GŁOMIA RIVER

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Abstract. The article presents results of a field study of the fish pass located within the Skórka barrage on the Głomia river. The aim of the study was to identify water flow conditions in particular chambers of the fish pass. On the basis of results of the field study, the hydraulic conditions of water flow through the fish pass were determined and referred to the optimum performance parameters of the construction. The results obtained make a basis for discussion of possible problems related to construction and operation of the fish passes resembling „close to nature" structures.

Key words: fish pass, fish pass passability, hydraulic parameters, water flow, barrage, river

INTRODUCTION

Every action taken with the best intentions to improve conditions of water management interferes with the natural environment. Often the necessary measures to improve water management include introduction of hydraulic structures. Such structures can vary from small hydraulic engineering objects to large facilities such as power plants, reservoirs or barrages. Hydraulic structures have a significant impact on their immediate surroundings [Laks et al. 2013, Wiatkowski 2015, Laks et al. 2017]. They change natural habitats of living organisms, particularly those prevailing in rivers [Mazur et al. 2015, Michalik et al. 2015, Radecki-Pawlik 2015]. Building a dam or a barrage across the river hinders animals from migrating up or down its course. Only a few species of fish demonstrate a low migratory activity, living within a single limited habitat. The majority of them undertake closer or further migration, essential for their life cycle [Książek et al. 2011]. In particular, the anadromous fish species, which undertake long migration between freshwater and sea, are at risk.

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In order to enable fish and other aquatic organisms to overcome obstacles when migrating, fish passes, that allow restricted migration, are constructed. They enable the fish to overcome the difference in altitude between the ordinates of upper and lower water level of hydraulic structures. Construction of fish passes (e.g. technical type fishway or bypass fishway) makes it easier for aquatic life to pass the difference in altitude and extends migrating routes of aquatic organisms. At present, the diversity of needs of fish during up and down migration is increasingly drawing attention. The aim is to build bi-functional devices that enable both types (technical type fishway or bypass fishway) of migration or even to construct two separate units for this purpose [Wierzbicki 2013].

So far , the most common fish passes have been built generally as technical structures in the form of concrete beds, or semi-natural structures, reflecting conditions of the natural watercourse bed with a significant drop (rapids, mountain streams, etc.). Therefore, this fish pass are of natural materials, such as river bed load, wood, stone, wicker [Tymiński and Kałuża 2013, Walczak et al. 2013].

According to Bartnik et al. [2010] in order to provide the conditions for maintaining biological stability, the design and operation of fish passes require meeting the following criteria: alluring stream criterion, terminal velocity criterion, criterion of admissible fish pass filling, and for transom fish passes – criterion of admissible loss for the transom fish pass discharge. Apart from the distribution of flow velocity values, terminal velocity values between particular zones of the fish pass and stream turbulence are also important factors. An accurate determination of water turbulence phenomena at the bottom is particularly significant in the situation when the continuity of ecological watercourse must be restored.

The experience gained during operation of fish passes allows a better understanding of essential aspects of environmental and technological solutions for their construction and efficiency [Bartnik et al. 2015]. However, despite numerous studies and even more sophisticated techniques of fish pass design and construction, it is still of great importance to continuously monitor the structures taking into consideration i.e. variable flow conditions and technical status [Rembeza 2008, Michalec 2013].

DESCRIPTION OF THE FACILITY

The studies were carried out within the Skórka barrage on the Głomia river. The objective of field research was to identify water flow conditions in each chamber of a semi-natural fish pass. The difference between water levels in different chambers of the fish pass help to determine the water velocity at slots. The Skórka barrage consists of a weir, a newly constructed fish pass and a hydroelectric power plant on the derivational channel [Zawadzki et al. 2015]. The Głomia river is a left tributary of the Gwda river, which it joins below Dobrzyca (village). The mean discharge flow by the Głomia river is equal 3.25 $m^3 \cdot s^{-1}$. The catchment area of this river is 570,0 km^2 in its estuary cross-section and the total length of watercourse is 57 km. It is a lowland river and characterized by the average slope of 0.9‰ [Zawadzki et al. 2015].

In 2012 the modernization of the weir, bridge and fish pass on the Głomia river in Skórka was completed. The Skórka weir is located at km 11+132 km, the drainage area in

Fig. 1. View of Skórka barrage from the bottom
Ryc. 1. Widok stopnia wodnego Skórka od strony dolnej wody

the cross-section is 568,7 km^2 (Fig. 2). A view of the weir and the fish pass at the Skórka barrage on the Głomia river is shown in Figure 1. The damming structure corresponds to the fourth class of importance of hydrotechnical structures according to the Regulation of the Minister for the Environment of 20 April 2007 concerning the technical conditions for hydrotechnical structures and their locations [Regulation… 2007]. It is a dock, reinforced concrete structure consisting of three spans with steel single-casement valves. Each span has a width of 3.0 m, thus the total cross section is 9.0 m. The barrage allows a reliable flow discharge, equal to SSQ = 2.81 m$^3 \cdot$ s^{-1}, for which the weir was designed, gross head of the dam is 2.59 m.

At a distance of approx. 45 m from the river there is a run-of-river derivational hydroelectric power plant on the right bank. The power plant chamber is provided with a Kaplan turbine. Water is supplied to the turbine chamber via an earthwork channel of approximately 800 m, that is connected to the Głomia river at 10+550 km.

The fish pass on the right bank of the river is constructed in the form of trapezoidal (cross section) step-pool construction with chambers formed as overflows within a wooden palisade. The fish pass is located directly at the weir and separated with a retaining wall built of reticular-stone gabions. The water inlet (fish outlet) is a reinforced concrete dock structure with a profiled rectangular bed having a bottom width equal to 2.0 m. The technical part of the fish pass consists of three chambers. Then the fish pass becomes a semi-natural structure consisting of 11 chambers with a length of approx. 3.50 m each and a bottom width of approx. 1.50 m. This part of the fish pass is characterised by a length of 39.0 m. The fish pass slots are located in baffles of wooden structure having a width of approx. 0.30 m. The fish pass water outlet (fish inlet), regulated with a steel valve, is located directly at the right fish pass head, at the altitude of 78.30 m above sea level. The fish pass outlet ends with a stilling basin with a length of approx. 3.0 m.

Fig. 2. Plan of the Skórka barrage (http://earthexplorer.usgs.gov/)
Rys. 2. Plan stopnia wodnego Skórka (http://earthexplorer.usgs.gov/)

RESEARCH METHODOLOGY

The study of water flow hydraulic conditions and evaluation of geometric parameters of the fish pass was carried out on 9 July 2014. The scope of the study included measurements of water surface elevation state and water flow rate in the fish pass. The water surface elevation in fish pass chambers was determined using a TOPCON AT-G6 optical levelling instrument. Measurements of water flow velocity values were taken with Valeport 801 electromagnetic flow meter. The device gives the average value of ten measurements and a standard deviation value, its measurement accuracy is ±5% from a reading + 5 mm $\cdot$ s^{-1}.

Measurements of flow velocity were carried out at steps in slots between selected chambers (Fig. 3). Detailed measurements of velocity distribution were carried out in the chamber 3 of the fish pass (Fig.4). The flow measurements were taken on baffles in chambers 1, 2, 3, 4, 6, 8, 10, at the inlet and outlet to the concrete part of the fish pass, and in 7 vertical points in chamber 3. These measurements provided the vertical velocity distribution as well as the average and maximum velocity at a given vertical point.

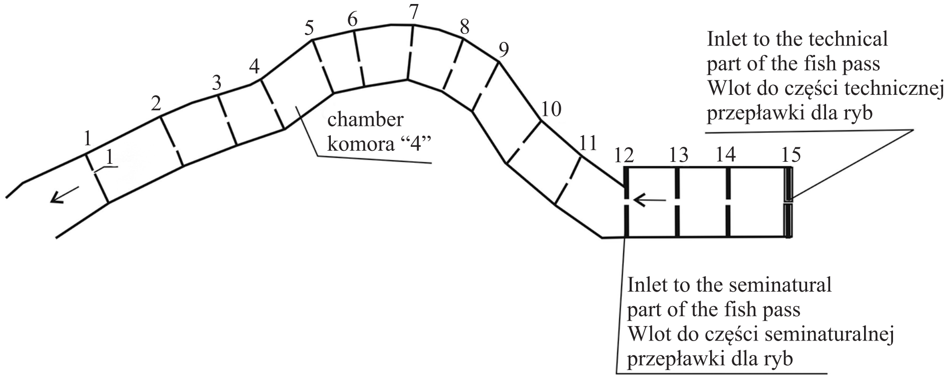

Fig. 3. Diagram of fish passes along with the location of hydrometric vertical [Szustakowska 2015]

Rys. 3. Schemat przepławki wraz z umiejscowieniem pionów hydrometrycznych [Szustakowska 2015]

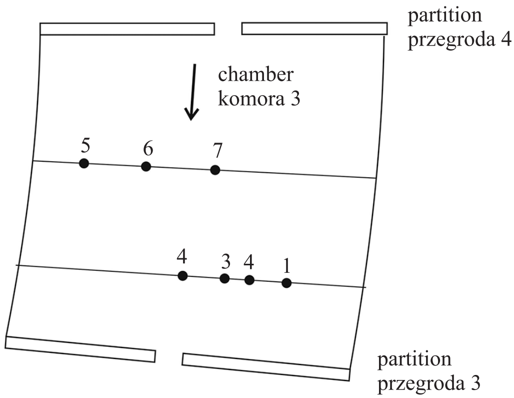

Fig. 4. Diagram of chamber 3 with marked points of vertical water velocity measurements (top view) [Szustakowska, 20015]

Rys. 4. Komora 3 z zaznaczonymi punkami pomiarów prędkości (widok z góry) [Szustakowska, 20015]

RESULTS AND ANALYSIS

On the basis of the measurements, a scheme of longitudinal profile of the fish pass was drawn, with the numbering of chambers and the water table topology in chambers (Fig. 5).

Analysis if the water table topology and depth values in particular chambers shows that the depths of the chambers are low because according to WWF [2016] the minimal water depth in a fish pass should be between 0.3–0.6 m, and in a vertical slot fish pass the minimal water depth should be 0.5 m. The average depth value is 0.29 m. The most unfavourable conditions of depth are in the chamber 11, where the water depth is only 13 cm.

Equally important are differences in water table values between chambers (drop) that fish need to overcome. The average drop is approx. 8 cm, although locally these values are significantly higher (unacceptable for this fish pass type). For example it is approx. 25 cm between chambers 11 and 12, and approx. 18 cm between chambers 10 and 11. The most unfavourable conditions are at the interface between the technical and semi-natural part of the fish pass. The fish pass can be divided into three sections in terms of its slope. The outlet area between chambers 1 and 5, where the slope are the lowest (the averaged value is 0.49%). The middle area (between chambers 6 and 11) that is characterized by the highest slope for the entire section of 3.51%. Although locally, the slope value of the bottom between chambers 10 and 11 is as high as 7.37%. Whereas at the inlet to the fish pass (between chambers 12 and 14) slope values are slightly lower than in the middle area and the mean slope is 1.49%.

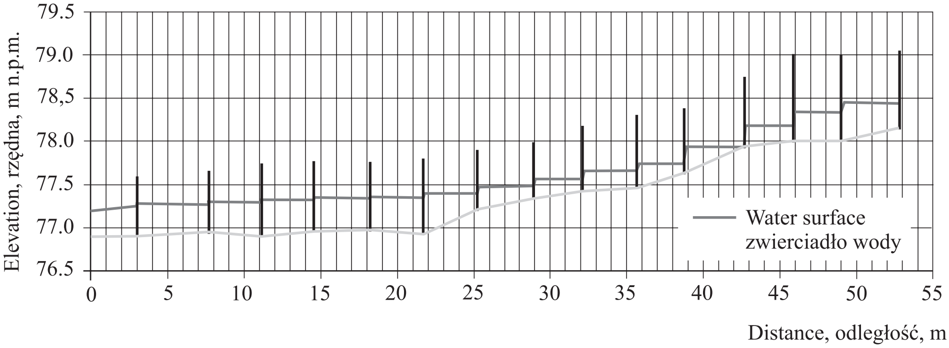

Fig. 5. Longitudinal profile of the fish pass together with the number of chambers and the water surface level in the chambers

Rys. 5. Schematyczny profil podłużny przepławki wraz z numeracją komór oraz układem zwierciadła wody w komorach

The water velocity in the outlet section chambers is significantly lower than in the middle area, where the slope is high. The average water velocity at the vertical point in the slot of baffle 1 was 0.19 $m \cdot s^{-1}$, and the average velocity in the slot of baffle 10 was 0.466 $m \cdot s^{-1}$. The above observations also applies to the maximum velocities. For example, the maximum velocity in the slot of baffle 2 was 0.366 $m \cdot s^{-1}$ (Fig. 6a). While at the slots of baffles 6 and 10, where the bottom drop values are significantly higher, the maximum measured velocity was 0.612 $m \cdot s^{-1}$ (for chamber 6) and 0.623 $m \cdot s^{-1}$ (for chamber 10 – Fig. 6b), respectively.

Maximum water velocity in slots of baffles in all studied hydrometric vertical points do not exceed 0.8 $m \cdot s^{-1}$. Slightly different conditions prevail in the technical section of the fish pass. A key area here is the inlet to the fish pass and the connection with the semi-natural fish pass. Water flow velocity values at the inlet and outlet of the technical section of the fish pass are presented in Figure 7.

The average water velocity at the vertical point of the technical part outlet was 0.31 $m \cdot s^{-1}$, and the maximum value was 0.407 $m \cdot s^{-1}$. The average water velocity the vertical point of the concrete part outlet of the fish pass, due to its compact size, was

1.6115 m · s^{-1} and the maximum was 2.701 m · s^{-1}. These velocities far exceed the limit values, which may hinder fish migration, because the maximum water velocity according to WWF [2016] in a chamber should be 2.0 m · s^{-1} and in bypass channels it is between 1.6 m · s^{-1} and 2.0 m · s^{-1}.

Apart from average water flow velocity values in slots of baffles between successive chambers there were also measured water flow velocity values in the chamber 3. Due to the fact that field measurements took place during the vegetation period, the bottom of the chamber 3 was overgrown with luxuriant vegetation. This resulted in creating numerous areas with reduced flow velocity and small whirlpools, which changed water flow conditions of the fish pass and limited the flow preferred from the viewpoint of fish migration. On the other hand, vegetation created places where migrating organism could rest. Velocity measurements, along with the identification of measurement points are shown in Table 1.

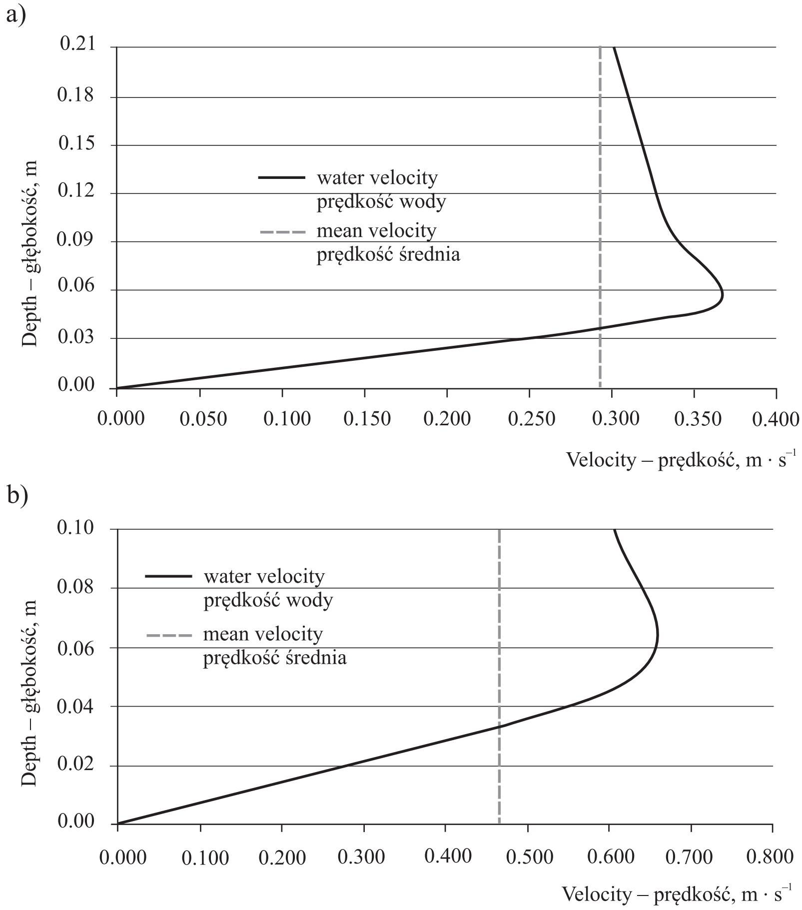

Fig. 6. Water velocity and average water velocity in the slot: a) No. 2, b) No. 10
Rys. 6. Prędkości wody w pionie oraz prędkość średnia w szczelinie przegrody: a) nr 2, b) nr 10

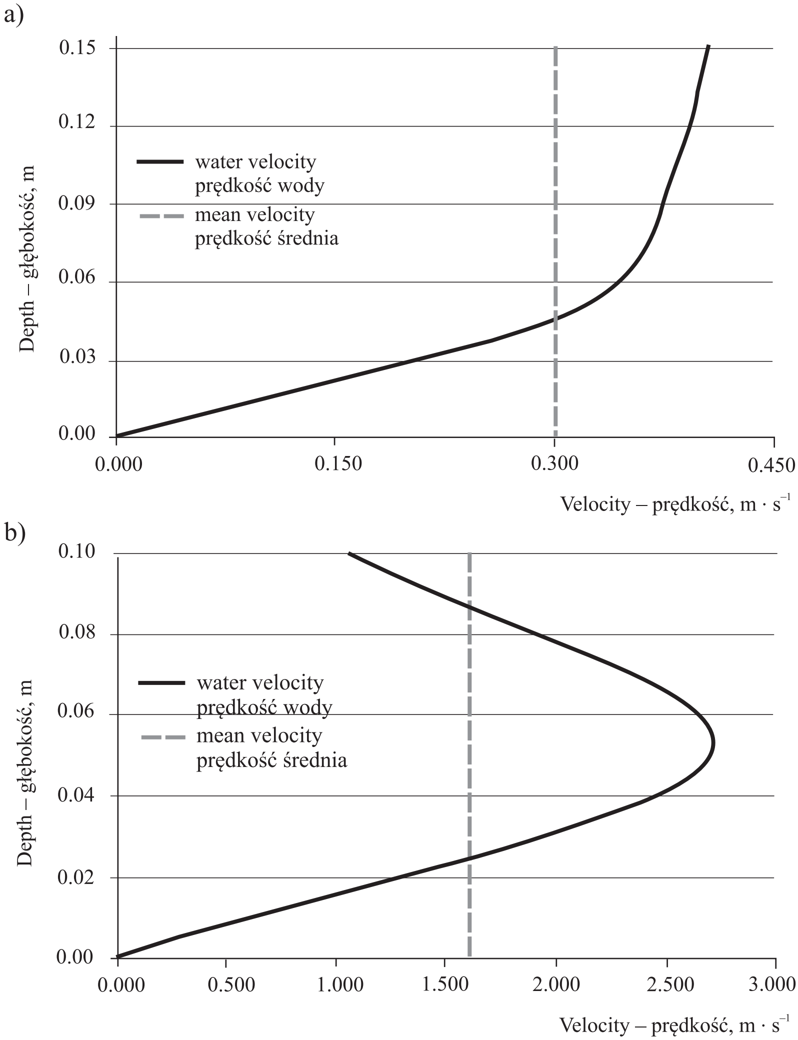

Fig. 7. Water velocity and average water velocity: a) outlet of the technical section of the fish pass, b) inlet to the technical section of the fish pass

Rys. 7. Prędkości wody w pionie oraz prędkość średnia: a) na wylocie z technicznej części przepławki, b) na wlocie do technicznej części przepławki

Point no. 3, at which vertical velocity measurement were made, was located on a flat bottom without vegetation. Because of the lack of obstacles that would slow down the current, the measured average velocity was up to 0.2578 $m \cdot s^{-1}$, so high in comparison with other measurements in the same chamber. In comparison, the average water velocity at point no. 5 was almost zero (–0,0058 $m \cdot s^{-1}$). A negative value indicates reverse currents caused by turbulence in the area of very dense vegetation. The results of measurements and direct observations support the thesis on high vegetation impact on flow conditions of the fish pass.

Table 1. Results of velocity measurements, the distance of vertical measuring points from the banks and partitions of fish passes
Tabela 1. Pomiary prędkości i lokalizacja pionów pomiarowych od brzegów oraz przegród przepławki

Vertical No. Numer pionu	Distance from the bank Odległość od brzegu		Distance from partitions Odległość od przegród		Vertical mean velocity Średnia prędkość
	left lewego	right prawego	3	4	
–	m	m	m	m	$m \cdot s^{-1}$
1.	0,80	–	0,75	–	0,0082
2.	1,17	–	0,75	–	0,1443
3.	1,42	–	0,75	–	0,2578
4.	1,85	–	0,75	–	0,0092
5.	–	0,47	–	1,30	–0,0058
6.	–	1,10	–	1,30	0,4023
7.	–	1,80	–	1,30	0,0204

DISCUSSION

The principles of good design of fish passes are based on the assumption that a fish pass should be efficient at all water levels enabling fish migration. Other additional conditions ensuring the optimal work of the fish pass should also be met, such as: proper filling, not exceeded velocity values admissible in slots and creation of an alluring stream in the lower area of the fish pass. The analysed fish pass within the Skórka barrage on the Głomia river is effective but to certain limitations. Because of different slopes of the bottom for which the fish pass was designed and constructed, the conditions of water flow during the vegetation season in multiple locations constitute a serious impediment to fish. For example, due to the insufficient flow depth (e.g. in chamber 11 where the filling of water is only 13 cm) migration of large specimens can be significantly impeded. A similar issue is related to the drop between chambers, e.g. between chambers 11 and 12 where the difference is approx. 18 cm and between chambers 10 and 11 where the drop is 18 cm. The most unfavourable conditions are present at the interface between the technical and semi-natural part of the fish pass because the maximum difference in water elevations between the chambers is 20 cm. The water velocity at slots are within the accepted range. Maximum water velocity at all studied points does not exceed 0.8 $m \cdot s^{-1}$. The flow rate right at the inlet to the concrete part of the fish pass is equal to 2.7 $m \cdot s^{-1}$, which makes an insurmountable barrier for most fish that use the fish pass. Similar problems have been studied by Bartnik et al. [2010] and Wierzbicki [2013].

A separate issue is to provide an alluring stream in the lower area of the fish pass, where the fish pass joins the river. Based on observations and velocity measurements carried out in this area, the fish pass is hardly tempting to fish as the average velocity value is here approx. 0.3 m · s^{-1}. The stream of water flowing out of the fish pass cannot perish in the stream of the river, i.e. the water velocity in the fish pass should much higher than in the river (alluring stream). The impact of alluring stream has been also considered by Bartnik et al. [2010] and Wyżga et al. [2014]. Bartnik has shown the results of numerical modelling of 400-meter part of a river that includes coated weir, small hydroelectric power station and a fish pass. The action taken concentrated on such formation of the water discharge in the ladder and modification of the bed configuration in the hydro mouth that would make an alluring stream. Similarly as for the Skórka Barrage, the study by Bartnik et al. [2010] have shown that the velocity of water flowing out of the fish pass depends on the water velocity in the pass but also on the conditions of water movement in the main river bed.

SUMMARY

The fish pass at the Skórka barrage is a very interesting nature-like solution, however the resemblance to natural conditions also causes problems with its operation, particularly during the vegetation season. Analysis of the field results shows that the fish pass design was not effective. Vegetation found in the fish pass had a significant effect on the velocity distribution in the riverbed. Intensified development of macrophytes can be seen at the bottom. All this significantly reduces the fish pass capacity.

Escarpments and riverbanks of chambers are mainly overgrown (vegetation uncovered from water). Overgrown riverbanks, where velocity values are low and water gives the shade provide a natural rest area for fish.

The analysed example of the seminatural fish pass indicates that numerous aspects that can affect its correct operation need to be taken into account while designing and constructing this type of unconventional objects. The necessity of taking into consideration all hydraulic conditions and criteria affects the „ichthyologic" verification of this type of facility. Problems with fish pass on the Głomia river could be avoided by testing on models (e.g. numerical). It is a now widely applied method.

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WARUNKI HYDRAULICZNE PRZEPŁYWU WODY W PRZEPŁAWCE SEMINATURALNEJ NA PRZYKŁADZIE STOPNIA WODNEGO SKÓRKA NA RZECE GŁOMII

Streszczenie. W pracy przedstawiono wyniki badań terenowych dotyczących parametrów hydraulicznych przepławki dla ryb zlokalizowanej w obrębie stopnia wodnego Skórka na rzece Głomii. Celem badań było rozpoznanie warunków przepływu wody w poszczególnych komorach przepławki seminaturalnej. Na podstawie wyników badań terenowych określono warunki hydrauliczne przepływu wody przez przepławkę, odnosząc uzyskane rezultaty do optymalnych parametrów pracy przepławki. Uzyskane wyniki stanowią podstawę do dyskusji na temat możliwych problemów budowy i eksploatacji „bliskich naturze" konstrukcji przepławek dla ryb.

Słowa kluczowe: przepławka dla ryb, drożność przepławki, parametry hydrauliczne

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