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Environmental Flows of Lowland Rivers with Disturbed Hydrological Regime on the Example of Mała Wełna River

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1. Introduction

To achieve good water status in rivers it is necessary to establish their volume of environmental flows. Environmental flows are defined as a part of the watercourse's flow volume which must be maintained to keep high values of aquatic ecosystems and water-dependent ecosystems with respect to requirements of environmental protection (Tharme 2003, Młyński et al. 2015). According to hydrological practice, the flow which ensures sufficient conditions for biological life is called a contractual flow, i.e. instream flow. The obligation to maintain hydrological instream flow is imposed in water legal permits (UPW 2001), and since 2017 according to the new Polish Water Law (UPW 2017) also in water agreements covering water permits, water applications and water assessments. The water assessment is required for all investments and actions which might affect environmental goals' achievement. Instream flow is calculated as a product of k-coefficient and annual mean low flow. It relates only to flow capacity within riverbed, therefore does not include the requirements of wetlands and other water-dependent ecosystems (Fabjański 2003, Pullin 2005), while flows fulfil water requirements of water and water-dependent ecosystems. Additional factors affecting water's biological life are: water quality, riverbed's and river valley's hydromorphological conditions and anthropogenic transformation of a habitat (Dunbar et al. 2012, Parasiewicz et al. 2013, Pusłowska-Tyszewska & Rychalski 2015).

2. Research area

The Mała Wełna river is a left-bank tributary of the Wełna river and its outlet is located in Rogoźno village. The field studies and analysis of water management within the boundaries of the Mała Wełna river catchment up to Kiszkowo cross-section (area of 339.41 km^2) were conducted by Poznań University of Life Sciences' Institute of Land Improvement, Environmental Development and Geodesy in 2000-2010 period.

According to the hydrographic division of Poland, the catchment of Mała Wełna river up to Kiszkowo cross-section is divided into 9 Surface Water Bodies (SWB), which are as follows: PLRW6000251866539 Mała Wełna to the outflow from the Gorzuchowskie Lake (covers the major share of this catchment's area – 265.51 km^2), PLRW600024186675 Mała Wełna from the outflow from the Gorzuchowskie Lake to the Rejowiec's inflow (only partially within the catchment's boundaries, covers an area of 94.09 km^2) and 7 other SWB (catchments of the Mała Wełna's inflows, which cover an area from 10.55 km^2 to 29.16 km^2) (Fig. 1).

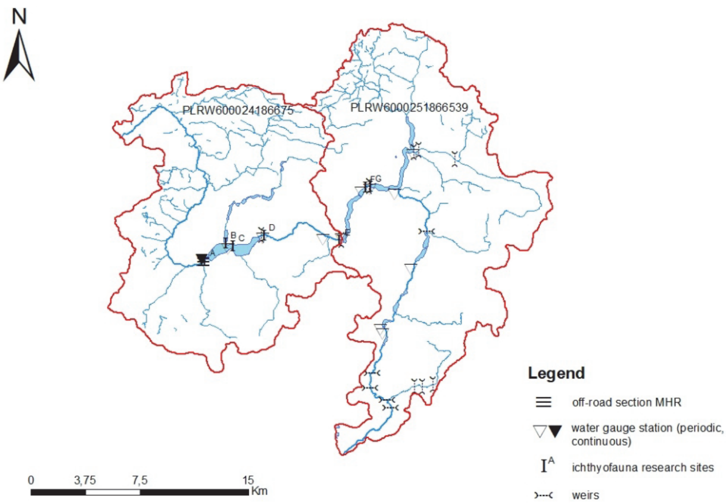


Fig. 1. Catchment area of Mała Wełna to an outflow from the Gorzuchowskie Lake and Mała Wełna from an outflow from the Gorzuchowskie Lake to the Rejowiec's inflow

Rys. 1. Położenie zlewni rzeki Małej Wełny do wypływu z Jeziora Gorzuchowskiego i Małej Wełny od wypływu z Jeziora Gorzuchowskiego do dopływu z Rejowca

Physiographic conditions and abiotic types of the analysed SWB are varied. Table 1 presents metric parameters for two largest SWB in the Mała Wełna river catchment up to Kiszkowo cross-section. The abiotic type of the Mała Wełna river from its source to the outflow of the Gorzuchowskie Lake was determined as the 25th type (natural waters and waters connecting lakes), while the next section up to the Rejowiec's inflow as the 24^{th} type (river in the area under the influence of peat-forming processes).

Table 1. Physiographic conditions of chosen Surface Water Bodies within Mała Wełna river catchment
Tabela 1. Charakterystyka warunków fizjograficznych zlewni badanych JCWP Małej Wełny

Characteristics	Symbol or formula	Unit	SWB Mała Wełna	
			to an outflow from the Gorzuchowskie Lake	from an outflow from the Gorzuchowskie Lake to the Rejowiec's inflow
Area	A	km^2	265.51	94.09
River length	L	km	31.974	22.711
Maximum elevation	H_{max}	m above sea level	129.60	132.20
Outlet's height (minimum elevation)	$H_o = H_{min}$	m above sea level	92.00	77.50
River's source's elevation	H_s	m above sea level	108.00	94.70
Average elevation	$H_{av} = \frac{H_{max} + H_{min}}{2}$	m above sea level	110.80	104.85
Elevation difference	H_{max} - H_{min}	m	37.60	54.70
River longitudinal slope	$\frac{H_S - H_O}{L}$. 1000	‰	0.50	0.76

Approx. 18% of the Mała Wełna to the outflow from Gorzuchowskie Lake SWB is urbanized. while 35% is covered by agricultural lands. 29% by forests. 12% by meadows and only 6% by water bodies. Whereas the dominant share of the Mała Wełna from the outflow from Gorzuchowskie Lake to the Rejowiec's inflow SWB is covered by agricultural lands (65%). Forests and meadows cover approx. 31% of this SWB. while both urbanized area and water bodies cover 2%.

3. The aim, scope and methodology

The aim of this paper was to analyse the characteristic and contractual flows of a lowland river with disturbed hydrological regime and their impact on the ecological status of this river's water.

Daily, characteristic and contractual flows were calculated based on the field studies which included daily water level measurements at the Kiszkowo cross-section and monthly hydrometric measurements at several cross-sections along the course of the river.

The ecological status of water in this river was determined based on biological (ichthyofauna), hydromorphological and physicochemical conditions. The research of ichthyofauna structure in Mała Wełna river were conducted by Poznań University of Life Sciences' Department of Inland Fisheries and Aquaculture in 2008 (Murat-Błażejewska et al. 2010) (Fig. 1). Hydromorphological conditions of the river were analysed based on MHR (hydromorphological monitoring of rivers) methodology developed by Ilnicki et al. (2009) with respect to four elements: hydrological regime, river continuity, riverbed's and river valley's morphology. Physicochemical conditions of Mała Wełna river were diagnosed based on concentration of 14 parameters indicating thermal and oxygen conditions, salinity, acidity and presence of biogenic compounds (Sojka et al. 2010).

Environmental flow rate was calculated with three following methods: Tennant's. Tessmann's and method based on flow duration curves ($Q_{70\%}$ and $Q_{90\%}$). In the Tennant's method the water-habitat conditions of water ecosystems and water-dependent ecosystems depend on multiannual mean flow in winter season (since October to March) and summer season (since April to September).

According to the Tessmann's method the environmental flow values are related to multiannual monthly mean flow (SSQ_{mc}) and multiannual mean flow (SSQ). Instream flow was calculated as a product of annual mean low flow and k-coefficient which relates to river's hydrological type and catchment's area.

According to the Resolution of the Regional Water Management Authority (RZGW) Director in Poznan of 2 April 2014 r. on the conditions of use of the waters of the Warta water region, the proven method for environmental flow calculation is specified in the first and currently the only regulation defining conditions upon which the water can be used within the boundaries of water regions. The proper methodology is proposed for each water region individually with respect to its distinctive conditions.

The requirement is set to maintain environmental flow in all natural watercourses as the necessary condition to achieve their good ecological state or potential. The minimal acceptable flow in the given cross section of the natural watercourse must not be lower than calculated with the presented method unless other regulations decide otherwise:

$$Q_e = k \cdot SNQ \tag{1}$$

where:
Q_e – environmental flow [$m^3 \cdot s^{-1}$],
k – coefficient "k",
SNQ – average men low flow [$m^3 \cdot s^{-1}$].

$$Q_e > NNQ \tag{2}$$

where:
Q_e – environmental flow [$m^3 \cdot s^{-1}$],
NNQ – the lowest low flow [$m^3 \cdot s^{-1}$].

The values of the coefficient "k" for given rivers in each water region. The values of the coefficient "k" for the same watercourse between the neighboring cross-sections are interpolated proportionally to the increase of the basin area (Operacz et al. 2018).

4. Results and discussion

The flow rates at Kiszkowo cross-section in 2000-2010 period were ranging from 0.021 $m^3 \cdot s^{-1}$ (multiannual low flow) to 3.183 $m^3 \cdot s^{-1}$ (multiannual high flow), while multiannual mean flow was equal to 0.644 $m^3 \cdot s^{-1}$ (Fig. 2).

The largest amplitude of flow variability occurred in February and March (Fig. 3).

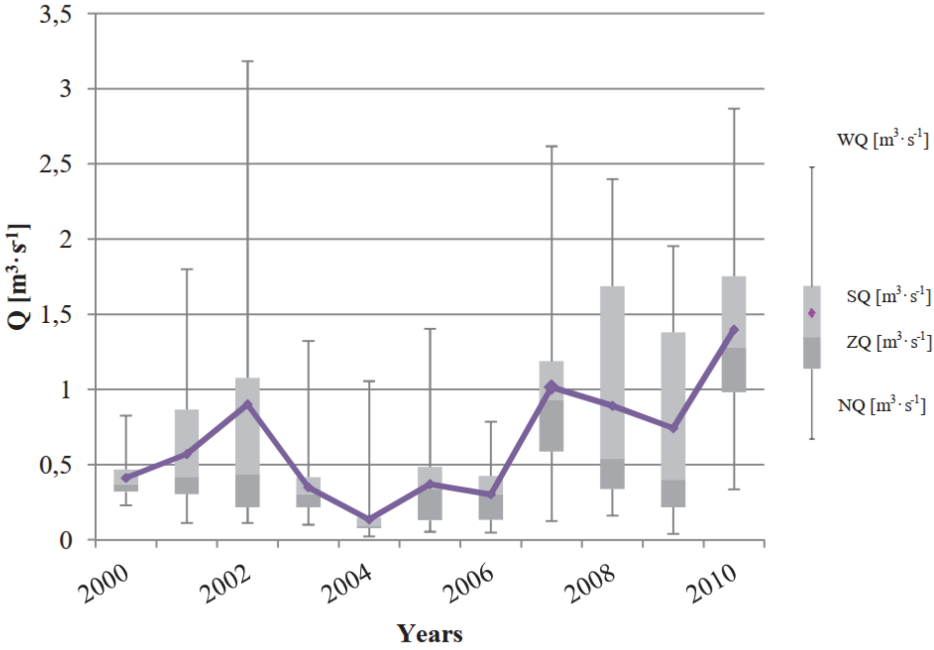


Fig. 2. Annual flow course in Mała Wełna river at Kiszkowo cross-section in 2000-2010 period
Rys. 2. Hydrogram charakterystycznych rocznych przepływów rzeki Małej Wełny w profilu Kiszkowo w latach 2000-2010

Results showed that water management of fish ponds (112 ha) located in Kiszkowo within the course of Mała Wełna river not only affects discharge rates in the river and its distribution curve, but also water quality (Murat-Błażejewska & Kanclerz 2005, Sojka et al. 2010, Murat-Błażejewska et al. 2009). According to the Polish Regulation of the Minister of the Environment of 22 August 2008 on the on the method of classification of the state of surface water bodies (Journal of Laws no. 162 item 1008, 2008) in the analyzed period, the waters of Mała Wełna did not meet the standards due to the physicochemical state of water.

Analysis of the ichthyofauna structure in seven sections located along the course of the river showed that both their number and biomass were varied.

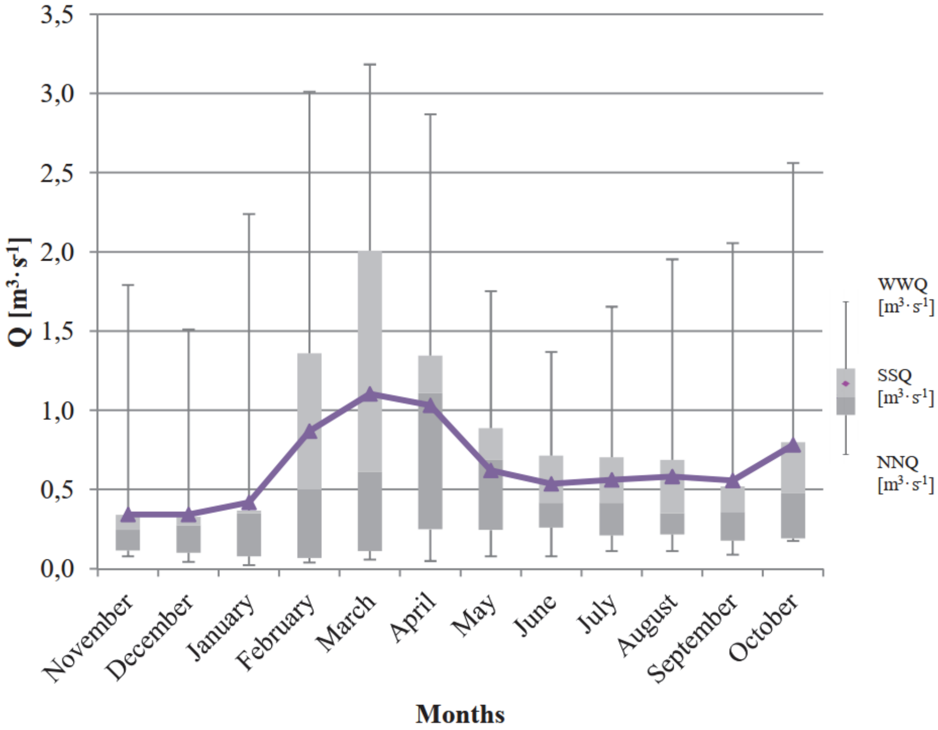


Fig. 3. Monthly flow course in Mała Wełna river at Kiszkowo cross-section in 2000-2010 period

Rys. 3. Hydrogram charakterystycznych miesięcznych przepływów rzeki Małej Wełny w profilu Kiszkowo w latach 2000-2010

Among 18 fish species found in the Mała Wełna river, 5 were qualified as low-risk endangered species and 3 as endangered with extinction. Water's ecological state was evaluated as moderate based on ichthyofauna structure and water quality (Sojka et al. 2010). Hydromorphological conditions of the Mała Wełna river's two Surface Water Bodies (Mała Wełna to an outflow from the Gorzuchowskie Lake SWB and Mała Wełna from an outflow from the Gorzuchowskie Lake to the Rejowiec's inflow SWB) were moderate mainly due to interrupted continuity of the river (Sojka et al. 2010). The results of State Environmental Monitoring for Surface Water Bodies (SWB) carried out since 2013 (PIEP Report 2014) indicate that ecological status or potential of Mała Wełna SWB doesn't fulfil environmental goals due to physicochemical and biological elements classification.

By the Tennant's method favourable water-habitat conditions of water ecosystems and water-dependent ecosystems are created depending on multiannual mean flow. Environmental flow rate in Mała Wełna river in Kiszkowo cross-section in winter season (since October to March) was equal to 0.129 $m^3 \cdot s^{-1}$ and in summer season (since April to September) – 0.258 $m^3 \cdot s^{-1}$.

Recommended rates for environmental flow calculated by Tessman's method was 0.258 $m^3 \cdot s^{-1}$ since November to January and since May to September with respect to multiannual mean flow (0.644 $m^3 \cdot s^{-1}$), while in February, March, April and October it reached 40% of multiannual monthly mean flow rates equal to: 0.347; 0.441; 0.413; 0.313 $m^3 \cdot s^{-1}$ (Table 2).

Environmental flow rate in Mała Wełna river at Kiszkowo cross-section, calculated with method based on flow duration curves for 70% cut-off level ($Q_{70\%}$) was equal to 0.24 $m^3 \cdot s^{-1}$ and for 90% cut-off level ($Q_{90\%}$) – 0.121 $m^3 \cdot s^{-1}$ (Fig. 4).

Table 2. Environmental flow volume in Mała Wełna river in Kiszkowo cross-section calculated with Tessman's method

Tabela 2. Wartości przepływów środowiskowych rzeki Mała Wełna w profilu Kiszkowo obliczonych metodą Tessmana

Month	Multiannual monthly mean flow [$m^3 \cdot s^{-1}$]	40% of multiannual monthly mean flow [$m^3 \cdot s^{-1}$]	Category	Recommended minimal monthly flow volume [$m^3 \cdot s^{-1}$]
November	0.343	0.137	SSQ_{mc}>0.4 SSQ	0.258
December	0.342	0.137		
January	0.418	0.167		
February	0.868	0.347	0.4 SSQ_{mc}>0.4 SSQ	0.347
March	1.103	0.441	0.4 SSQ_{mc}>0.4 SSQ	0.441
April	1.032	0.413	0.4 SSQ_{mc}>0.4 SSQ	0.413
May	0.620	0.248	SSQ_{mc}>0.4 SSQ	0.258
June	0.536	0.214		
July	0.561	0.224		
August	0.582	0.233		
September	0.556	0.222		
October	0.782	0.313	0.4 SSQ_{mc}>0.4 SSQ	0.313

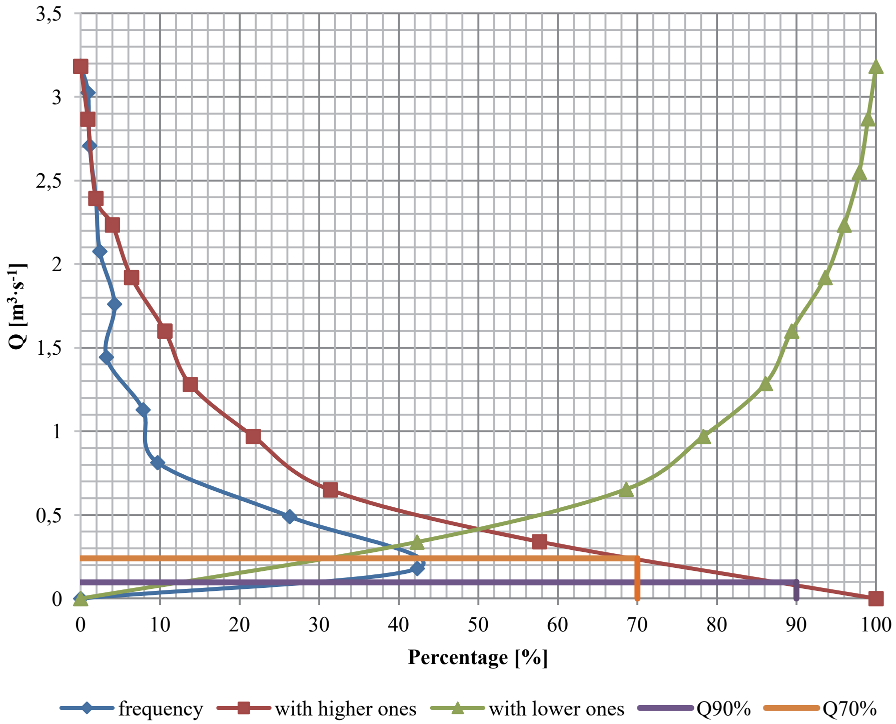
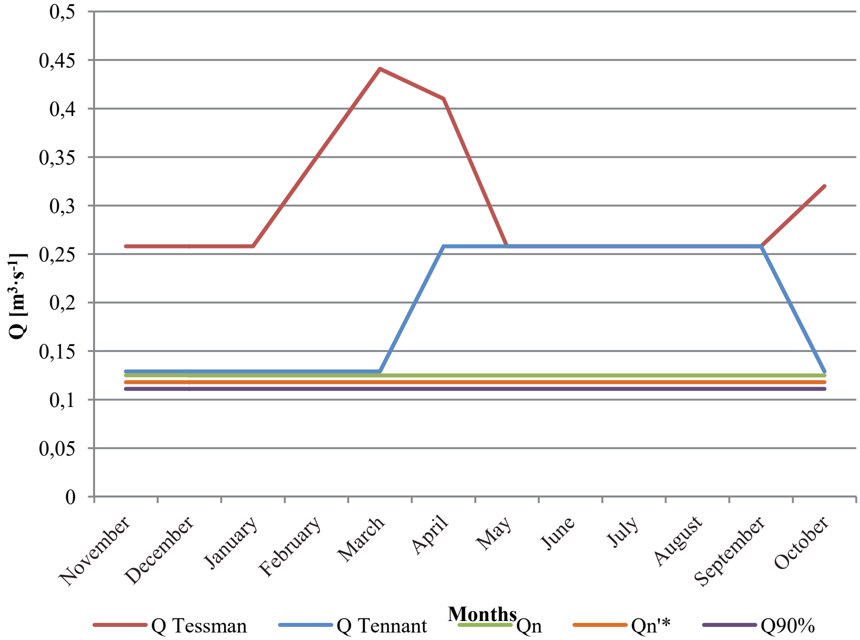


Fig. 4. Flow duration curves for Mała Wełna river at Kiszkowo cross-section in 2000-2010 period
Rys. 4. Krzywa sum czasów trwania przepływów wraz z wyższymi i niższym w latach 2000-2010 dla rzeki Małej Wełny w profilu Kiszkowo

Environmental flow volumes calculated by the three methods were ranging from 0.121 $m^3 \cdot s^{-1}$ to 0.441 $m^3 \cdot s^{-1}$ (Fig. 5). The highest flow rates were obtained by the Tessman's method ($Q_{Tessman}$) which in March and April were equal 0.441 $m^3 \cdot s^{-1}$ and 0.413 $m^3 \cdot s^{-1}$ respectively and were three-times higher than instream flows (0.121 $m^3 \cdot s^{-1}$) and two-times higher than in other months (0.258 $m^3 \cdot s^{-1}$). Environmental flow rates calculated with Tennant's method ($Q_{Tennant}$) since October to March were equal 0.129 $m^3 \cdot s^{-1}$ and since April to September – 0.258 $m^3 \cdot s^{-1}$, which is even to $Q_{Tessman}$ for 8 months. Whereas environmental flow volumes calculated with method based on flow duration curves for 90% cut-off level ($Q_{90\%}$) was 0.121 $m^3 \cdot s^{-1}$ which was equal the instream flow.



*Qn' – Qn for Warta Water Region's Waters

Fig. 5. Environmental and instream flow rates in Mała Wełna river at Kiszkowo cross-section
Rys. 5. Zestawienie wartości przepływów środowiskowych i przepływu nienaruszalnego dla rzeki Małej Wełny w profilu Kiszkowo

5. Summary

In order to achieve a good ecological status of water in rivers with disturbed hydrological regime and those which do not fulfil water quality environmental goals it is crucial to determine environmental flows in those rivers. Environmental flow rates in Mała Wełna river at Kiszkowo cross-section calculated by the three following methods: Tennant's. Tessman's and method based on flow duration curves ($Q_{70\%}$ and $Q_{90\%}$) were ranging from 0.121 $m^3 \cdot s^{-1}$ to 0.441 $m^3 \cdot s^{-1}$. Results showed that it is necessary to develop a methodology for calculating environmental flows in cross-sections closing the SWB of flowing waters. According to data collected in diagnostic monitoring of rivers in 2010-2015 period approx. 75% of the SWB of flowing waters did not achieve good ecological status or potential.

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Przepływy środowiskowe rzeki nizinnej o zaburzonym reżimie hydrologicznym na przykładzie Malej Wełny

Streszczenie

W pracy, na podstawie obserwacji i pomiarów hydrologicznych, badań hydrochemicznych wody oraz struktury ichtiofauny rzeki Mała Wełna w okresie 2000-2010 określono przepływy charakterystyczne i umowne w tym hydrologiczne: przepływy nienaruszalne oraz przepływy środowiskowe. Wielkości przepływów nienaruszalnych określono według wymagań warunków korzystania z wód regionu wodnego Warty, zaś przepływów środowiskowych obliczono trzema metodami: Tennanta, Tessmana oraz metodą odcięcia poziomów 70% i 90% krzywej czasów trwania wraz z wyższymi. Przeprowadzona analiza wyników obliczeń wykazał, że natężenia przepływów środowiskowych były znacznie wyższe od obecnie wymaganych natężeń przepływów nienaruszalnych.

Abstract

This work presents the rates of characteristic and contractual flows of Mała Wełna river, including hydrological instream flows and environmental flows based on hydrological observations, hydro-chemical analyses and ichthyofauna structure accomplished in the years 2000-2010. The volume of instream flows were established according to requirements for the usage conditions of the Warta water region's waters, while environmental flows were calculated by three following methods: Tennant's, Tessman's and method based on flow duration curves ($Q_{70\%}$ and $Q_{90\%}$). Results showed that the environmental flow rates were significantly higher than currently required instream flow rates.

Słowa kluczowe:
rzeka nizinna, stan ekologiczny wód, przepływy środowiskowe

Keywords:
lowland river, ecological water status, environmental flows