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# Inflow of Pollutants to the Bukówka Drinking Water Reservoir from the Transboundary Bóbr River Basin

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## 1. Introduction

Interest in water resource management issues, including water quality, in transboundary areas, is a relatively new phenomenon which has been gaining increased attention in recent years. Problems related to transboundary waters led to the introduction, under the Water Framework Directive (WFD), of a modern approach to water resource management based on the drainage basin model, in contrast to the administrative model used previously [16]. According to the WFD [6], Member States should strive to achieve the objective of at least good water status by defining and implementing the necessary measures through integrated action programs while taking into account the existing Community requirements. Moreover, within a river basin where use of water may have transboundary effects, the requirements for the achievement of the environmental objectives, and in particular all programmes of measures, should be coordinated for the whole of the river basin district. This applies, in particular, to the assessment of the condition of surface waters [16].

The situation becomes of particular relevance when a dam reservoir, which stores retention water for human consumption, is located on a transboundary river. In this case the water quality control in the drainage basin above the dam reservoir is crucial, especially in terms of inflow of pollutants into these waters, both in the transboundary river upstream, and at points further down the course of the river. One of such transboundary rivers is the Bóbr where, by the border with the Czech Republic, the Bukówka reservoir (km 271 + 540) is located. The Bukówka reservoir is a multi-purpose facility. Its basic functions include flood control, water supply in low-water periods for the Marciszów Water Treatment Plant and drinking water supply to the city of Wałbrzych. Currently, however, this function is not fulfilled and water from the reservoir is taken merely for consumption for the villagers of Bukówka and to ensure environmental flow in the riverbed of Bóbr below the reservoir. According to the literature, reconciling the functions of multi-purpose reservoirs, including drinking water reservoir, is often very difficult to achieve [10, 30, 36].

The Bukówka reservoir is exposed to a number of problems, among which the main one is the deterioration of water quality and eutrophication. This is due to the fact that, while Bukówka potentially supplies the population with drinking water and a protection zone of surface water intake is maintained on the reservoir, in the Polish part of the basin continuous monitoring of water quality does not exist.

The aim of this study was to analyse the inflow of pollutants from the transboundary Bóbr River basin to the Bukówka reservoir in view of supplying drinking water for consumption and its retention in the reservoir. The water quality of five watercourses: the rivers Bóbr, Opawa, Złotna, Bachorzyna and Paprotki supplying the reservoir has been analysed. Testing also included both the retention water and the outflow water. The causes of the variability of water quality, both spatial and in terms of time, were also identified. In addition, the study assessed the eutrophication of analysed waters, their vulnerability to nitrogen pollution from agricultural sources and the delivery of matter into the Bukówka reservoir.

## 2. Characteristic of study area

Bukówka reservoir (50°42'47" 15°56'46"E) was established between 1978–1989, in the Bóbr river valley at 271.540km, in place of a dry storage reservoir dam that had existed since 1907. Administratively the reservoir is located between three towns Miszkowice, Bukówka and

Paprotki (Fig. 1). Almost all reservoir basin banks are natural, except for the side dam protecting the village of Miszkowice. The reservoir includes: an earthy front dam, a bottom vent, a transfer surface, and tap water outtake for the Wałbrzych Water and Sewage Enterprise, which is not currently used, a hydroelectric power plant and the Miszkowice side dam. The administrator of the Słup reservoir is Wrocław Regional Water Management [11, 18].

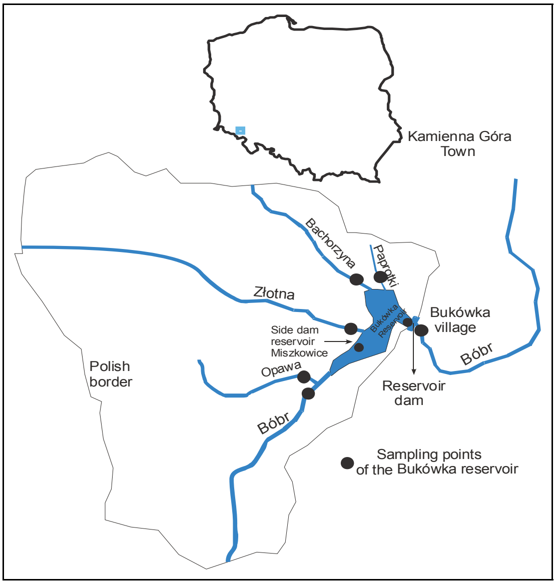


**Fig. 1.** Location of Bukówka reservoir on Bóbr river, including water sampling points for the physicochemical examinations
**Rys. 1.** Lokalizacja zbiornika Bukówka na rzece Bóbr oraz punktów poboru próbek wody do badań fizykochemicznych

From the Bóbr river basin to the Bukówka reservoir dam is approximately 58.5 km$^2$. The Bóbr river flows from the Lasocki Grzbiet located in the great Czech mountains. The river flows on the Czech side for about two kilometers, then for more than four kilometers on the Polish side and then flows into the Bukówka reservoir. There is also a visible basin gradient, mostly from west to east, and in the southern part of the catchment from south west to the north east. The Bukówka reservoir is a recipient of three rivers Złotna, Bachorzyna and Bóbr; it also receives water from several smaller watercourses (Including Opawa and Paprotki) and pumped water from the Miszkowice polder. The basin is dominated by agricultural lands (52%) and forests (45%). Urban areas occupy only a few percent of the area (approx. 3%).

Bukówka reservoir parameters: the operational fill level (NPP) – 534.30 m (12.917 million $m^3$, 167 ha), the maximum fill level (Max PP) – 536.40 meters above sea level (16.790 million $m^3$, 199 ha). Capacity of this reservoir at absolute maximum fill level (537.10 meters above sea level) is 18.215 million $m^3$, and the area of the floodplain 211 ha. The length of the reservoir is approx. 2.8 km and the largest width approx. 1.4 km. Basic hydrological data of the Bóbr river in the reservoir section are: SNQ = 0,13 $m^3 \cdot s^{-1}$, SSQ = 0,89 $m^3 \cdot s^{-1}$, NNQ = 0,04 $m^3 \cdot s^{-1}$, the flow is Q = 0.10 $m^3 \cdot s^{-1}$, the harmless flow (the allowed discharge) Q = 8.0 $m^3 \cdot s^{-1}$ and the highest flow WWQ = 74,50 $m^3 \cdot s^{-1}$ [18].

The Bukówka reservoir basin area is characterized by a cool climate with long winters and high precipitation. The basic data characterizing the climate: the average precipitation in the basin area is approx. 800 mm, the average annual temperature approx. 5.5°C.

## 3. Methods

The study performed between November 2006 and December 2007 involved water quality analysis of watercourses: Bóbr (post B_in_res), Opawa (post O_in_res), Złotna (post Z_in_res), Bachorzyna (post Ba_in_res) and Paprotki (post P_in_res). The aforementioned streams supply the Bukówka reservoir. In addition, the quality of the water impounded in the reservoir at the Miszkowice dam (W1_res post), the water impounded in the reservoir at the face dam (post W2_res) and the outflow of water from the Słup reservoir (post Out_res) were analyzed (Fig. 1). The location of each water sampling points, both in the catchment and in the Bukówka reservoir itself was selected in such a way that on the basis of it one can determine the spatial water quality in the tributaries, the reservoir and of the outflow, as well as whether the Bukówka reservoir affects the quality of the watercourses flowing through it. Samples were carried out on the following dates: 27.11.2006, 16.01.2007, 26.03.2007, 16.04.2007, 29.05.2007, 10.09.2007, 22.10.2007, 19.11.2007 and 10.12.2007.

Particular attention was paid to the important, from the point of view of the proper use of the reservoir, quality of water supplying the reservoir, primarily to the water quality of the Bóbr river, due to its dominant role in supplying the Bukówka reservoir. In order to carry out the water quality characteristics of the Bóbr river flowing into the tank, in addition to our own studies of water quality, similar data was obtained from the Provincial Inspectorate of Environmental Protection in Wrocław (RIEP) for the period 1993–2005 for the border point at km 269.6 [23] (Fig. 1) as well as the data from the Czech Republic concerning the evaluation of the quality of surface waters in the territorial scope of the Elbe's basin in 2012 [8, 9]. The evaluation was performed by analyzing the water quality indicators such as: $NO_3^-$, $NO_2^-$, $NH_4^+$, $PO_4^{3-}$, $BOD_5$, pH, electrolytic conductivity, water temperature, and total suspended solids. In addition, at the position W2_res (at the dam) measurements of water transparency (Secchi depth) were performed. Water pH, electrolytic conductivity and temperature were measured *in situ*, whereas other water quality analyses were made in a laboratory according to Polish standards. Water quality was rated in accordance with binding during led investigates the Decree of the Ministry of Environment on the classification of surface water bodies [29]. An assessment of the eutrophication of the waters analyzed was presented, concerning whether the waters are vulnerable to pollution by nitrogen compounds from agricultural sources based on [27]. The appropriability of the tested water was determined by comparing the studied ratios with the values which should correspond to water destined for human consumption [26], existence of fish [28] and bath [25]. The paper also presents an evaluation of the Bukówka reservoir basin's delivery of substances into the reservoir.

# 4. Results and Discussion

## 4.1. Water quality

The results of the water quality tests from the five watercourses flowing into the Bukówka drinking water reservoir from the transboundary area, the quality of the retention water in the reservoir and that of the outflow from the reservoir are shown in Table 1.

**Table 1.** Characteristics of the quality of water flowing into the reservoir from the reservoir's basin, reservoir's water and the water outflow from the reservoir during the period November 2006–December 2007
**Tabela 1.** Jakość wody dopływającej do zbiornika zze zlewni, wody w zbiorniku i wody odpływającej ze zbiornika w okresie listopad 2006–grudzień 2007

| Sampling point | Value | Water quality indicators | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Nitrates (mg $NO_3^-\cdot dm^{-3}$) | Nitrites (mg $NO_2^-\cdot dm^{-3}$) | Ammonia (mg $NH_4^+\cdot dm^{-3}$) | Phosphates (mg $PO_4^{3-}\cdot dm^{-3}$) | $BOD_5$ (mg $O_2\cdot dm^{-3}$) | Reaction pH | Electrolytic conductivity (μs/cm) | Water temperature (°C) | Total suspended solids (mg·dm$^{-3}$) |
| B_in_res | Average | 3.57 | 0.101 | 0.132 | 0.52 | 3.08 | 7.79 | 220 | 7.0 | 0.9 |
| B_in_res | Max | 5.30 | 0.320 | 0.380 | 1.10 | 10.00 | 8.40 | 714 | 21.0 | 80.0 |
| B_in_res | Min | 1.30 | 0.010 | 0.026 | 0.11 | 1.00 | 7.30 | 122 | 2.1 | 0.0 |
| O_in_res | Average | 7.74 | 0.075 | 0.226 | 0.48 | 3.55 | 7.83 | 210 | 6.8 | 9.8 |
| O_in_res | Max | 17.70 | 0.160 | 0.640 | 1.05 | 11.00 | 8.20 | 661 | 20.5 | 0.0 |
| O_in_res | Min | 1.30 | 0.010 | 0.050 | 0.04 | 1.00 | 7.35 | 113 | 2.1 | 9.0 |
| Z_in_res | Average | 4.22 | 0.025 | 0.064 | 0.32 | 2.01 | 7.9 | 155 | 7.3 | 1.0 |
| Z_in_res | Max | 17.70 | 0.100 | 0.260 | 0.85 | 7.00 | 8.5 | 603 | 19.5 | 20.0 |
| Z_in_res | Min | 0.88 | 0.003 | 0.020 | 0.02 | 1.00 | 7.3 | 86 | 2.2 | 0.0 |
| Ba_in_res | Average | 5.31 | 0.100 | 0.098 | 0.42 | 1.66 | 7.75 | 161 | 8.2 | 7.6 |
| Ba_in_res | Max | 17.70 | 0.239 | 0.140 | 1.05 | 4.00 | 9.20 | 639 | 22.5 | 60.0 |
| Ba_in_res | Min | 0.88 | 0.020 | 0.050 | 0.04 | 1.00 | 7.20 | 74 | 2.3 | 0.0 |
| P_in_res | Average | 4.38 | 0.192 | 0.203 | 0.47 | 1.83 | 7.57 | 126 | 6.6 | 8.0 |
| P_in_res | Max | 8.80 | 0.368 | 0.260 | 1.14 | 3.00 | 8.15 | 174 | 13.0 | 20.0 |
| P_in_res | Min | 1.30 | 0.100 | 0.150 | 0.20 | 1.00 | 7.00 | 89 | 2.2 | 0.0 |
| W1_res | Average | 2.98 | 0.081 | 0.075 | 0.42 | 3.33 | 7.76 | 159 | 8.4 | 0.3 |
| W1_res | Max | 13.30 | 0.446 | 0.130 | 1.28 | 8.00 | 8.60 | 486 | 21.5 | 0.0 |
| W1_res | Min | 0.88 | 0.003 | 0.050 | 0.05 | 1.00 | 7.00 | 96 | 2.0 | 0.0 |
| W2_res | Average | 1.70 | 0.112 | 0.137 | 0.22 | 4.03 | 7.93 | 157 | 8.2 | 2.0 |
| W2_res | Max | 4.40 | 0.532 | 0.365 | 0.95 | 7.00 | 8.70 | 490 | 22.0 | 0.0 |
| W2_res | Min | 0.88 | 0.010 | 0.026 | 0.02 | 1.00 | 6.78 | 102 | 1.8 | 0.0 |
| Out_res | Average | 2.93 | 0.105 | 0.110 | 0.25 | 2.46 | 7.92 | 155 | 7.6 | 5.1 |
| Out_res | Max | 13.30 | 0.558 | 0.280 | 0.88 | 6.00 | 8.60 | 506 | 18.5 | 40.0 |
| Out_res | Min | 0.88 | 0.003 | 0.026 | 0.02 | 1.00 | 7.20 | 97 | 1.9 | 6.0 |

The analysis of the flowing water data shows that the highest average values of nitrate and nitrite were observed at the Paprotki sampling post (P_in_res), ammonia at the Opawa post (O_in_res), phosphates, $BZT_5$ and electrolytic conductivity at the Bóbr post (B_in_res), water pH at the Złotna post (Z_in_res) and water temperature and total suspended solids at the Bachorzyna post (Ba_in_res). In the water of the reservoir (W_res) during the period of the study the highest values were recorded for the following indicators: water pH and water temperature. The analyzed data also shows that at the outflow from the Bóbr reservoir (Out_res), in comparison with the Bóbr post (B_in_res), the highest values of average concentrations of nitrite, water pH, water temperature were recorded.

Graphical comparison of the levels of nitrates, phosphates, ammonia, $BZT_5$, pH, conductivity, water temperature, and total suspended solids in the tested waters in Bukówka reservoir against the background of water quality classes by Decision of the Polish Minister for the Environment of 9 November 2011 [29] is shown in Fig. 2–5.

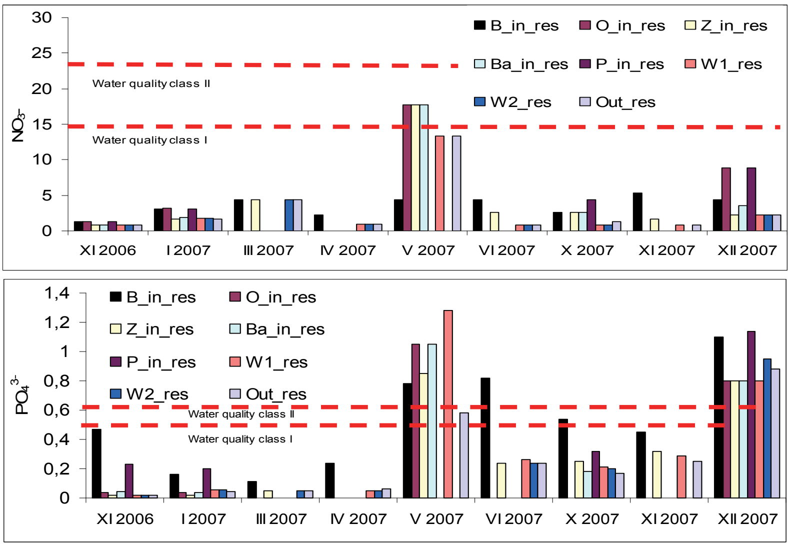


**Fig. 2.** Nitrates and phosphates concentration in the water from Bukówka reservoir in period 2006–2007

**Rys. 2.** Stężenie azotanów i fosforanów w wodzie ze zbiornika Bukówka w latach 2006–2007

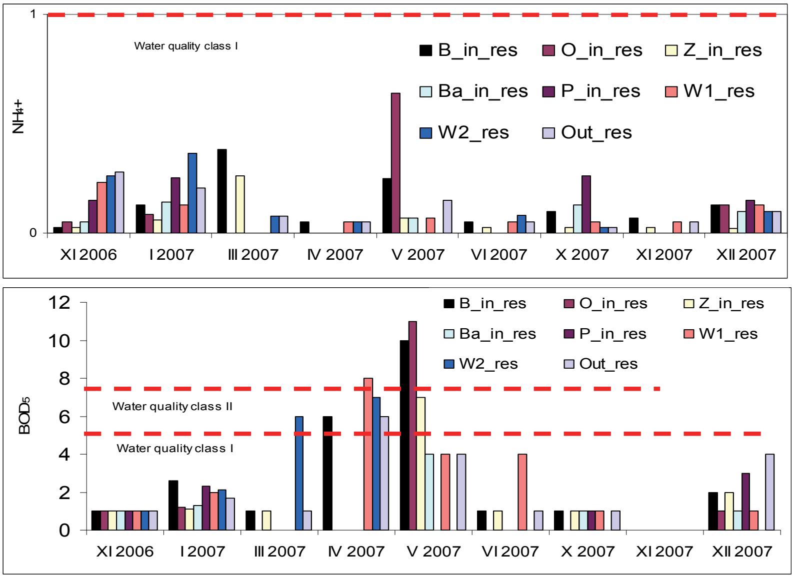


**Fig. 3.** Ammonia and $BOD_5$ concentration in the water from Bukówka reservoir in period 2006–2007

**Rys. 3.** Stężenie jonów amonowych i $BZT_5$ w wodzie ze zbiornika Bukówka w latach 2006–2007

Of the 9 tested indicators of water quality in the Bukówka reservoir, 8 (except nitrites) are taken into account for the classification of the water quality [29]. The highest nitrate concentrations at all five positions on the inflow to the reservoir were recorded in the month of May and the lowest in November (Fig. 2). Nitrate concentrations have qualified water to the class II of water quality, which concerns surface water bodies in natural watercourses such as a river [29].

Higher concentrations of phosphate in the tributaries waters were observed in the autumn and winter of 2007. The exceptions are large phosphate concentrations recorded in May 2007. This could be caused by flooding. According to [10, 20], flood water can bring a significant load of phosphorus and nitrogen in the period of raised water levels. In contrast, the smallest monthly $PO_4^{3-}$concentration was recorded in the spring of 2007 (Fig. 2). An analysis of the results of the study of the water quality in the reservoir showed that the phosphate quantities exceeded the limits for the II class water quality [29].

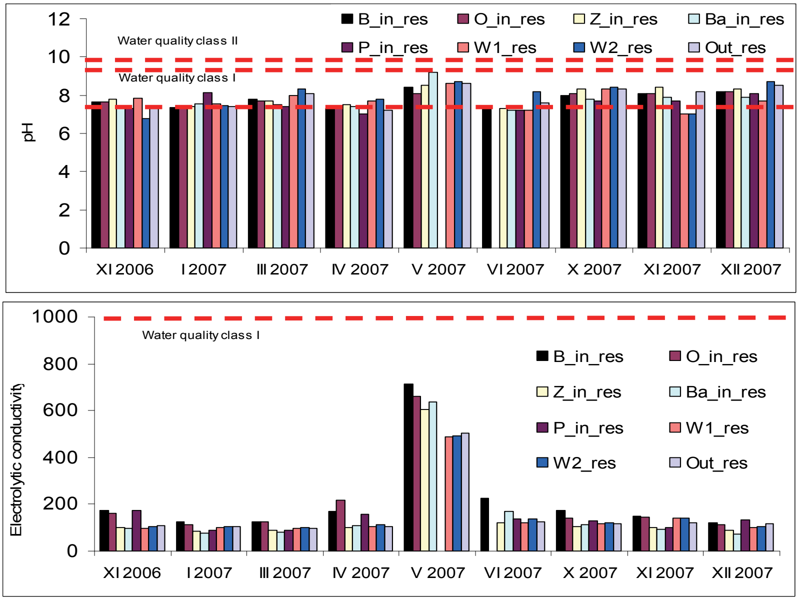


**Fig. 4.** pH and electrolytic conductivity in the water from Bukówka reservoir in period 2006–2007
**Rys. 4.** pH i przewodność wody ze zbiornika Bukówka w latach 2006–2007

An analysis of the results of the study of the water quality in the reservoir showed that the ammonia quantities did not exceed the appropriate limit for class I water quality (Fig. 3). The values of $BOD_5$ exceeded the limits for the class II water quality (Fig. 3). The pH value of the water at all sampling posts, except for Potok Bachorzyna (Ba_in_res) taken in May 2007 (exceeding the water quality II class), passed the test for the class II water quality (Fig. 4) [29]. Electrolytic conductivity qualified them to the class II of surface water quality at all positions (Fig. 4). The maximum values of this index were observed in May 2007.

The water in the reservoir during May 2007 heated up to a nearly same temperature of 21.5°C (Fig. 5). Water temperature values at all measuring stations in addition to water creek Bachorzyna (Ba_in_res) taken in May 2007 (exceeding the water quality I class) passed the test for class I of water quality.

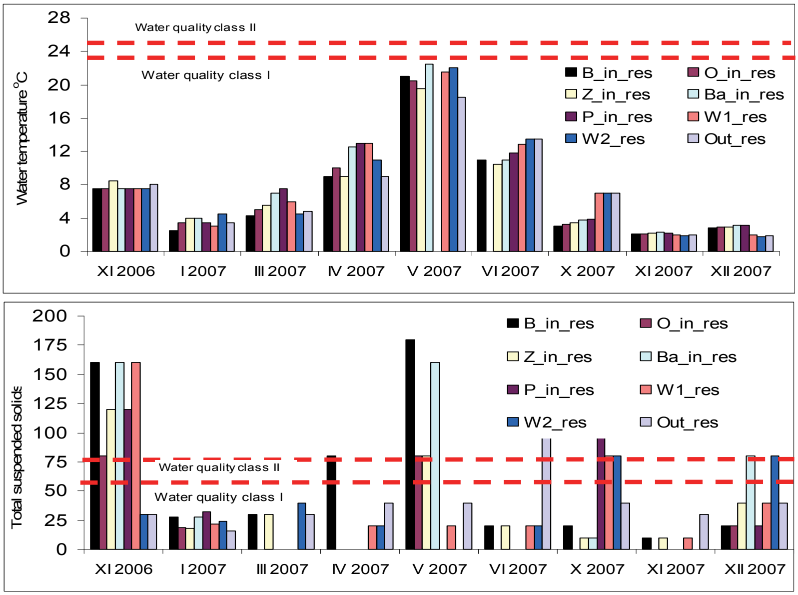


**Fig. 5.** Water temperature and total suspended solids in the water from Bukówka reservoir in period 2006–2007

**Rys. 5.** Temperatura i zawiesina ogólna w wodzie ze zbiornika Bukówka w latach 2006–2007

The highest concentration of total suspended solids – 180 mg·dm$^{-3}$ – were recorded in the waters flowing into the tank (B_in_res) during the freshet in the Bóbr river basin in May 2007 (Fig. 5). High levels of total suspended solids were also recorded in the waters flowing out from the reservoir 140 mg·dm$^{-3}$ (September 2007). Analysis of the results of the water quality showed that the total suspended solids exceeded the limits for the class II water quality, concerning surface water bodies in natural watercourses such as a river [29].

Transparency of the Bukówka reservoir's water, measured as Secchi depth, ranged from 150 cm (December 2007) to 320 cm. The greatest transparency in the waters of the reservoir was recorded in November 2006. Bukówka's water, because of this indicator, was considered eutrophic water. The transparency value did not exceed the border limit of this ratio (2.0 m). Similarly, the water of Opawa, Złotna and Bachorzyna (O_in_res, Z_in_res, Ba_in_res), flowing into Bukówka reservoir, were classified as eutrophic due to the excess of nitrate limits (10 mg $NO_3^-$

$\cdot dm^{-3}$), given in [27]. Moreover, according to the value of transparency given in [29] year, the Bukówka reservoir was also qualified as eutrophic, because the transparency by Schindler modulus (5.0 $m^2/m^3$) should be 1.7 meters. Nevertheless, it was found that the Bukówka reservoir's water is not vulnerable to pollution by nitrogen compounds from agricultural sources, as the nitrate concentration was lower than recommended (50 mg $NO_3^- \cdot dm^{-3}$) in [27].

As is indicated by the above analysis, hydrochemical conditions in the Bukówka reservoir, in terms of functions performed by the tank, are unfavorable for it. This is confirmed by tests of the Bóbr river water quality presented in [17–18, 21–22]. They showed that the main sources of pollution of the Bóbr river are industrial and domestic waste water from urban centers and rural domestic waste water from community centers. The water quality of the Bóbr river in 2005 showed a considerable variability. At the border point an unsatisfactory state of the water was recorded. Water flowing into Poland from the Czech Republic was characterized as a one of an unsatisfactory quality. The classification was decided by a large number of faecal coliform bacteria, very high phosphate and phosphorus concentrations, as well as increased color and phenolic index.

The evaluation of the consumption usefulness of the water outflow from the Bukówka reservoir showed that values of temperature, conductivity, nitrates and ammonia in any period did not exceed the limit of the A1 category domain, i.e. water requiring simple physical and chemical treatment [26]. Water pH values (May 2007) qualified the tested water to the A2 category, i.e. water requiring a typical physical and chemical treatment. However, in the remaining months this indicator did not exceed the limit values of the A1 category. Limit values of the A3 category, i.e. water requiring an efficient physical and chemical treatment were exceeded in terms of total suspended solids (September 2007), phosphate (December 2007) and $BOD_5$ (April 2007) [26]. In view of the fact that the reservoir is under water intake protection „Bukówka", according to the permission OS-6210/8/97 and for the purposes of the planned water treatment plant and water transmission to Wałbrzych [18], the research should be continued. At the time the research was based only on direct sampling of water from the reservoir destined for citizens of Bukówka village, which is located below the dam.

Examination of the Bukówka reservoir's water showed that indicators such as water pH and ammonia nitrogen meet the requirements for inland waters which are the habitat of salmonids and cyprinids in their natural conditions [28]. In contrast, the water temperature meets the requirements for inland waters which are cyprinids' habitat only. The most unfavorable conditions for the existence of fish is caused by nitrites, which exceed the required [28] value of 0.01 mg $NO_2^-\cdot dm^{-3}$ for salmonids and 0.03 mg $NO_2^-\cdot dm^{-3}$ for cyprinids, by the $BOD_5$ value, which exceeds the required 3 mg $O_2 \cdot dm^{-3}$ for salmonids and 6 mg $O_2\cdot dm^{-3}$ for cyprinids and by the total suspended matter value, which exceeds the required on [28] average annual value by 25 $mg\cdot dm^{-3}$.

In the case of the Bukówka reservoir a positive impact on the improvement of water quality in terms of selected indicators has been found. The results obtained indicate that the Bukówka reservoir reduced levels of nitrates, ammonia, phosphate, total suspended solids and conductivity in water outflow from the reservoir in relation to the water flowing into the reservoir. However, in the water below the reservoir higher nitrites values, water pH and temperature were recorded. Another function which has been attributed to dam reservoirs is improvement of surface water quality. There is still no synonymous answer to the question whether hydrotechnical construction deteriorates or improves the quality of water. Generally, it was observed that big reservoirs receiving waters of slight or average pollution level improve their quality [35].

In order to complete the characteristics of the quality of the Bóbr river water flowing into the Bukówka reservoir, the results of the study of water quality of the Bóbr river obtained in year 2006–2007, at the position (B_in_res), were compared with the results of the state monitoring for the period from 1993 to 2005, carried out by the Provincial Inspectorate of Environmental Protection in Wrocław [23], at the border (km 269.9). Table 2 shows this comparison.

The water quality indicators of the Bóbr river show a lower value than the water quality test results obtained from PIEP Wroclaw. In the case of indicators such as $BOD_5$ and conductivity, the situation was reversed.

The water quality of the Bóbr river at the border showed a considerable variability. An unsatisfactory state of waters was registered. Water flowing into Poland from the Czech Republic was characterized as of an unsatisfactory quality. The classification was a result of a large number of faecal coliform bacteria, very high concentrations of phosphorus and increased color and phenolic index. Significant fluctuations in the concentrations of nutrients during every year of the examined period were observed Table 2 [23]. As it is stated by the authors of the report [23], high concentrations of biogenic compounds posed a threat of eutrophication to the Bukówka dam reservoir. Assessment of water quality of the Bóbr river, taking into account the parameters characterizing the process of eutrophication, revealed exceeding the annual average concentrations of phosphate and nitrate. Similar results, concerning the large pollution of the Bóbr river flowing from the Czech Republic, are presented in the paper Vodohospodářská bilance za rok 2011, období 2006 – 2011 a výhledu k roku 2021 Zpráva o hodnocení jakosti povrchových vod pro území ve správě Povodí Labe, státní podnik Odbor péče o vodní zdroje [8, 9]. It recommended that the Bóbr river water flowing out from the Czech Republic was classified to class II of water quality, due to the high content of total phosphorus.

**Table 2.** The results of the quality of river Bóbr water flowing into the reservoir at B_in_res post and the average annual values of selected water quality indicators from PIEP Wrocław for the period 1993–2005
**Tabela 2.** Wyniki jakości wody rzeki Bóbr wpływającej do zbiornika na posterunku B_in_res oraz średnio roczne wartości wybranych wskaźników jakości wody na podstawie WIOS Wrocław w latach 1993–2005

| Indicator | WIOS investigations (1993–2005) | | Self investigations (2006–2007) | |
|---|---|---|---|---|
| | Bóbr – border point, km 269.6 | | Bóbr (post B_in_res) | |
| | Min. (Year) | Max. (Year) | Min. (Date) | Max. (Date) |
| Nitrates (mg $NO_3^{-}\cdot dm^{-3}$) | 12 (1998) | >50 (1993, 1994, 1995, 1996, 2000, 2004) | 1.30 (XI 2006) | 5.30 (XI 2007) |
| Phosphates (mg $PO_4^{3-}\cdot dm^{-3}$) | 0,20 (1997) | >2.00 (1993, 1994, 2000, 2003, 2004) | 0.11 (I 2007) | 1.10 (XII 2007) |
| $BOD_5$ (mg $O_2\cdot dm^{-3}$) | 5,0 (1997, 1999,2003) | 9.0 (1995) | 1.00 (XI 2006, I, IX, X 2007) | 10.00 (V 2007) |
| Electrolytic conductivity ($\mu S\cdot cm^{-1}$) | 200 (1997, 1998, 1999) | 470 (1994) | 122 (XII 2007) | 714 (V 2007) |

### 4.2. Bukówka reservoir's basin and the material supply to the reservoir

Water reservoirs have a great ability to capture migrating matter from the basin [14]. Water qualities in the reservoirs as well as a content of the phosphorus compounds are both largely determined by an external input [2]. The rate of eutrophication of a natural reservoir depends on its basins' physiogeographical structure, which functions as a continuous supplier of various forms of matter (including biogenic) to the reservoir, as well as morphometric parameters of the reservoir and its hydrological regime [1, 31–33]. The physiogeographical structure of a basin can promote area flows or limit them. On the other hand, the physical structure of a reservoir may be more, as well as less favorable to the maintenance of an existing reservoir's water shield. Reservoir's susceptibility to eutrophication can be assessed based on the system proposed by Bajkiewicz-Grabowska [1]. Natural features of a basin's physiogeographical environment cause that a reservoir's direct basin may accelerate or suppress the delivery of matter (including biogenic) to the reservoir.

The influence of a basin on the rate of matter supply to the reservoir is evaluated by bonitation of each of the aforementioned characteristics on a scale of 0 to 3 points, where 0 means a very weak impact on the supply of matter and the impossibility of it reaching the reservoir, and 3 means a high impact and rapid delivery of matter to the reservoir [1]. Characteristics that describe the degree of interaction basin and reservoir include Lake Ohle factor and the lake balance type. The degree of influence of the direct basin is described by: endorheicity of the area, an average decrease of the basin, a river network density, surface features and the way of the reservoir's exploitation. Table 3 presents an assessment of the Bukówka reservoir basin as a supplier of matter to the reservoir, according to the Bajkiewicz-Grabowska criteria [1].

Final assessment – the average of grades obtained from the evaluation of individual features is 1.33 and qualifies the Bukówka reservoir's basin as the second group of susceptibility: the basin is characterized by low susceptibility to launching cargo deposited in its area, and a small possibility of it reaching the reservoir. According to [34], the type of use of the basin areas of the reservoirs located in the basin of the Odra has a significant impact on the quality of water in these reservoirs. Currently, the supply of biogenic compounds from point and area sources (including agriculture), causing an anthropogenic eutrophication of water, is a major threat on the way towards a good status of waters in Poland and around the world [12, 13, 15]. Water pollution is a common problem throughout the world. Of course, there are many research methods which may determine different sources of water pollution, its scale and its impact on the environment [7]. Eutrophication is one of the most serious threats to the quality of inland waters. It is an important problem not only in Poland, but also in other countries of the European Community [3–5, 7, 19, 24, 33, 36].

**Table 3.** The valuation of the Bukówka reservoir's basin – from which the matter flows into the body of water of the Bukówka reservoir
**Tabela 3.** Ocena zlewni Bukówki – z której materia wpływa do wód zbiornika Bukówka

| Characteristic of the Bukówka reservoir basin | | Criterion by [1] | Amount of points |
|---|---|---|---|
| Factor lake by Ohle | 35.03 | 10–40 | 1 |
| Balance type of tank | Flow | Flow | 3 |
| Potamology parameters<br>– density of river network<br>– average river basin slope | <br>0.6<br>11.5 | 0.5–1.0<br>10–20 | 1<br>2 |
| Geological structure of river basin | Slope and eluvium clay, Dusty clay, Peat soil | Clay, Peat | 0 |
| River basin use | woodland 45%, arable land 52%, built-up areas 3% | Forest-agricultural, grassland-agricultural | 1 |
| Mean value | | | 1.33 |

## 5. Conclusions

1. The results of water quality testing in the period 2006–2007 show that due to the concentration of phosphates, $BOD_5$ and total suspended solids, the water flowing into the Bukówka reservoir from the transboundary drainage basin exceeds the limits of class II water quality indicators for water bodies in natural watercourses such a river. Meanwhile, the concentrations of $N\text{-}NO_3^-$ and the pH qualify this water as class II (in terms of the classification of water bodies in natural watercourses, such as a river).

2. It was found that the tested water in the Bukówka reservoir basin is not vulnerable to nitrogen pollution from agricultural sources. The Bukówka reservoir is not very susceptible to the displacement of pollutants deposited in its drainage basin; the likelihood of them getting into the reservoir is small.
3. In terms of eutrophication, the hydrochemical conditions occurring in the Bukówka reservoir catchment are unfavourable to the functions performed by the reservoir. The main reason for this is the high concentration of phosphorus from domestic waste water of localities in the studied drainage basin.
4. Evaluation of the suitability for consumption of outflow water from the Bukówka reservoir showed that the values for temperature, electrolytic conductivity, nitrates and ammonia did not exceed the A1 category limit values. The pH value qualified the tested water to the A2 category. The A3 category limit was exceeded in terms of total suspended solids and $BOD_5$.
5. Water from the Bukówka reservoir is not suitable as habitat for salmonids and cyprinids due to the presence of nitrites, $BOD_5$ and total suspended solids.
6. The Bukówka reservoir had a positive influence on the water quality of the river Bóbr and the other four tributaries: Opawa, Złotna, Bachorzyna and Paprotki. During the research, the highest values in the reservoir were observed for water pH and temperature. Compared with the water flowing into the reservoir, the outflow was characterized by higher average concentrations of nitrites and higher average water pH and temperature.
7. Due to the transboundary nature of the Bóbr River where the Bukówka reservoir is located, it is important to limit the inflow of pollutants into it and monitor the cleanliness of water in the watercourses and in the reservoir. Comprehensive hydrological and water quality monitoring in the reservoir catchment basin will help protect water in the catchment and will enable rational water management in the Polish and Czech part of the basin. The most important measures for water crossing the Polish-Czech border should relate to combating pollution and improving water quality.

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# Dopływ zanieczyszczeń do zbiornika wody pitnej Bukówka z obszaru transgranicznego zlewni rzeki Bóbr

## Streszczenie

Obecnie istnieje zwiększone zainteresowanie zarządzaniem zasobami wodnymi, w tym jakością wody, na obszarach transgranicznych. Sytuacja nabiera szczególnego znaczenia, gdy na rzece transgranicznej zlokalizowany jest zbiornik zaporowy, m.in. wykorzystujący retencjonowane wody do celów zaopatrzenia w wodę. Wówczas niezmiernie ważne sa badania jakości wód w zlewni powyżej zbiornika, przede wszystkim w aspekcie wprowadzania do tych wód zanieczyszczeń, zarówno w górnym biegu rzeki transgranicznej, jak i w kolejnych punktach biegu rzeki.

Praca przedstawia analizę dopływu zanieczyszczeń z obszaru transgranicznego zlewni rzeki Bóbr do zbiornika wody Bukówka, w aspekcie jej retencjonowania w zbiorniku. Przeanalizowano jakość wody pięciu cieków zasilają-

cych zbiornik: rzeka Bóbr, Opawa, Złotna, Bachorzyna i Paprotki, jakość wody retencjonowanej w zbiorniku i odpływającej ze zbiornika oraz rozpoznano przyczyny jej przestrzennego zróżnicowania a także czasowej ich zmienności. W pracy ponadto przedstawiono ocenę eutrofizacji analizowanych wód, oceniono czy badane wody są wrażliwe na zanieczyszczenie związkami azotu ze źródeł rolniczych, do spożycia oraz wykonano ocenę zlewni zbiornika Bukówka pod kątem dostawy materii do zbiornika. Ocenę jakości wody w analizowanych ciekach i zbiorniku wykonano analizując takie wskaźniki jak: $NO_3^-$, $NO_2^-$, $NH_4^+$, $PO_4^{3-}$, $BOD_5$, odczyn wody, przewodność elektrolityczną, temperaturę wody i zawiesinę ogólną. Wyniki badań własnych jakości wody rzeki Bóbr uzupełniono wynikami uzyskanymi z WIOŚ Wrocław i z Czech.

Wyniki przeprowadzonych w okresie 2006–2007 badań jakości wody na terenie polskiej części zlewni zbiornika Bukówka wykazały, że wody te ze względu na stężenia fosforanów, $BZT_5$ i zawiesiny ogólnej przekroczyły wartości graniczne wskaźników jakości wód odnoszące się do jednolitych części wód powierzchniowych w ciekach naturalnych takich jak rzeka właściwe dla klasy II. Natomiast stężenia $N\text{-}NO_3^-$ i odczyn zakwalifikowały wody do II klasy jakości wód, odnoszących się do jednolitych części wód powierzchniowych w ciekach naturalnych, takich jak rzeka.

W pracy stwierdzono, że badane wody z terenu zlewni zbiornika Bukówka nie są wrażliwe na zanieczyszczenie związkami azotu ze źródeł rolniczych. Natomiast zlewnia zbiornika Bukówka charakteryzuje się małą podatnością na uruchomienie ładunku zdeponowanego na jej obszarze i niewielką możliwością dotarcia jej do zbiornika.

Z punktu widzenia procesu eutrofizacji uwarunkowania hydrochemiczne występujące w zlewni zbiornika Bukówka, w aspekcie realizowanych przez zbiornik funkcji, są dla niego niekorzystne. Główną przyczyną tego stanu są wysokie stężenia fosforu pochodzącego ze ścieków bytowych z miejscowości położonych w badanej zlewni.

Wody zbiornika Bukówka nie nadają się do bytowania ryb łososiowatych i karpiowatych. Natomiast ocena przydatności wody odpływającej ze zbiornika Bukówka do spożycia wykazała, że wartości: temperatury wody, przewodności elektrolitycznej, azotanów i amoniaku nie przekroczyły wartości granicznych kategorii A1. Wartości odczynu wody zakwalifikowały badane wody do kategorii A2. Wartości graniczne kategorii A3 przekroczone zostały pod względem zawiesiny ogólnej i $BZT_5$.

W pracy wykazano, że zbiornik Bukówka wpływał korzystnie na zmiany jakości wody rzeki Bóbr i innych czterech dopływów: Opawa, Złotna, Bachorzyna i Paprotki. Woda odpływająca ze zbiornika w porównaniu z wodą dopływającą do zbiornika charakteryzowała się większymi wartościami średnich stężeń azotynów, odczynu wody i temperatury wody.

Ze względu na transgraniczny charakter rzeki Bóbr, na której zlokalizowany jest zbiornik Bukówka, istotne jest ograniczenie dopływu zanieczyszczeń do niej oraz monitorowanie stanu czystości wody w ciekach i zbiorniku. Kompleksowy monitoring hydrologiczny i jakości wody w zlewni zbiornika będzie pomocny do podejmowania działań na rzecz ochrony wód w zlewni oraz umożliwi prowadzenie racjonalnej gospodarki wodnej na obszarze polskiej i czeskiej części zlewni. Najważniejsze działania dla wód przekraczających granicę polsko-czeską powinny dotyczyć ochrony tych wód przed zanieczyszczeniami, poprawy stanu gospodarki wodno-ściekowej w zlewni oraz poprawy jakości wody.

**Słowa kluczowe:**
zbiornik wodny, rzeka, zlewnia, wody transgraniczne, jakość wód

**Keywords:**
water reservoir, river, basin, transboundary waters, water quality