

INFLUENCE OF THE PRE-DAM RESERVOIR ON THE QUALITY OF SURFACE WATERS SUPPLYING RESERVOIR „NIELISZ”

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Summary. The paper presents an analysis of the influence of the pre-dam reservoir on the quality of waters supplying the primary reservoir. Water samples were collected at quarterly intervals at the inflow and outflow from the reservoir. Analysis of the results clearly indicates that the pre-dam reservoir under study contributes to a significant improvement of the quality of water flowing into the primary reservoir. The greatest reduction of pollutant concentrations in the pre-dam reservoir on river Por occurred during the period of intensive growth of macrophytes. The efficiency of operation of the reservoir is high, however, it is not able to eliminate all contaminants flowing into it along with the waters of river Por.

Key words: dam reservoir, pre-dam reservoir, water retention, eutrophication

INTRODUCTION

Water is a natural resource that determines the life on Earth and plays many important functions within the natural environment and national economies. On agricultural areas, it determines the crop yields, affects the biological diversity, is necessary for maintaining the natural values and shaping the ecological balance. Sustainable development of a state is associated, among others, with rational management of water resources, both in the quantitative and qualitative aspects [Mioduszewski 1999, Ryszkowski *et al.* 2003]. A comprehensive approach to water protection is governed by the framework of the Water Directive (2000/60/EC), the main goal of which is to achieve good status of surface and underground waters in all EU member countries by 2015. In Poland, water protection gets more and more important, because renewable surface water resources amount to about 1600 m³ per inhabitant (or only 1100 m³ during dry

periods), while in Europe – about 4600 m³ [Inspection... 2003]. Moreover, water resources in Poland are often characterised by inappropriate quality and considerable variability within a year [Mioduszeński 1996]. Therefore, in many branches, water deficit reduces the opportunity of economic development and enforces rational water management and more thorough analysis of all threats to water quality. Disordered wastewater management and agricultural activity are among the principal reasons for poor surface water quality. Contamination of anthropogenic origin, occurring in surface waters, makes the quality of these waters much worse, which contributes to their eutrophication [Rajda *et al.* 1992, Solarski and Solarski 1994].

One of the methods for enhancing the available water resources, as well as reducing the flow rate variations in flows, is water retention in dam reservoirs, the characteristic feature of which is the possibility of free disposal of water resources [Kowalewski 2003, Mioduszeński 1996, 1999]. However, dam retention reservoirs are the area where pollutants carried by supplying flows accumulate, and mudding and worsening of retained water can sometimes occur during their exploitation, to such an extent that their usable features can be lost [Kostecki 2003]. In order to improve the quality of waters retained in dam reservoirs, the pre-dam reservoirs are built, situated upstream from the primary reservoirs. Their function is to keep the contaminants transported by a river. An example of such a solution can be the largest reservoir in the Lublin region – „Nielisz”.

The objective of the study presented here was to analyse the influence of the pre-dam reservoir on the quality of waters supplying the main reservoir.

MATERIALS AND METHODS

The water reservoir „Nielisz” is situated in central section of river Wieprz. The damming section of the reservoir is situated on the 235th kilometre of the river course in the axis of the regional road No. 48168 Nielisz–Gruszka. The reservoir is within the communes of Nielisz and Sułów, district of Zamość, province of Lublin. Total area of the reservoir at normal water surface level (NPP) of 197.50 m above sea level is 888 ha. Regulation of the flow rate of river Wieprz below the dam is the primary purpose of the Water Reservoir „Nielisz”. The regulation consists in decreasing the flood flow rates during snow cover melting and spring-summer heavy rainfalls, and increasing the flow rates in the river during drought and low precipitation periods (most often in summer). Besides these general aims, the reservoir is also used to produce electric energy (about 1800 MWh·year⁻¹), for recreation, and for amateur angling. The reservoir consists of two parts divided with a dam. The main reservoir (water surface area 709 ha at NPP, mean depth 2.8 m and total capacity of 18.30 mln m³) is situated in the valley of river Wieprz. Its catchment area is 1236.2 km². The pre-dam reservoir, with 179 ha area at NPP, mean depth of 0.7 m, and total capacity of 1.18 mln m³, is situated in the valley of river Por. The damming section is situ-

ated on 1.685 km of its course, while the catchment area amounts to 590.3 km² [Twardowski 2008, Tyszewski *et al.* 2008].

The construction of the pre-dam reservoir resulted from the need to protect the main reservoir against the sink exposure in the case of lower water levels and against pollution carried along with waters of river Por [Pawłat *et al.* 1994, Twardowski 2008, Tyszewski *et al.* 2008]. It is worth mentioning that river Por flows parallel to the northern edge of Roztocze up to the estuary of its right tributary – stream Gorajec [Kondracki 2002]. Both streams drain the Western Roztocze area that, due to the presence of soils developed from loess, diverse relief, and agricultural activity, is threatened with water erosion, which is confirmed by a dense network of existing ravines [Józefaciuk and Józefaciuk 1992]. Survey made by Świeca [1994] revealed that mean amount of rock debris in the water of river Por was 31.0 mg·dm⁻³ in 1989–1992, with extreme values from 0.2 to 976.5 mg·dm⁻³. Whereas, lower oscillations (0.4–22.4 mg·dm⁻³) and three times lower mean turbidity (9.4 mg·dm⁻³) were observed in the water of river Wieprz at that time, as well as levels of other analysed macroelements and biogenic substances.

Studies aimed at evaluating the efficiency of the pre-dam reservoir and its influence on the quality of the water of river Por supplying the main reservoir, were carried out from June 2008 till March 2009. Water samples were collected at quarterly intervals at the inflow and outflow from the reservoir. The following water quality indices were determined in collected samples by means of commonly used procedures:

- acidity – potentiometry using multi-parameter measuring device Multi 340i – SET (WTW),
- specific electric conductivity – conductometry using multi-parameter measuring device Multi 340i – SET (WTW),
- total suspension – direct gravimetry using paper filters and scales,
- dissolved oxygen – oxygen-meter Oxi 538 (WTW),
- BOD₅ – dilution method,
- total nitrogen – spectrophotometer PCspectro (AQUALYTIC) after sample oxidation in thermo-reactor at 100°C),
- ammonia – photometer MPM 2010 (WTW),
- nitrates – photometer LF 205 (Slandi),
- nitrites – photometer MPM 2010 (WTW),
- phosphates – photometer MPM 2010 (WTW),
- potassium – photometer LF 205 (Slandi),
- sulphates – photometer LF 205 (Slandi),
- chlorides – photometer LF 205 (Slandi).

RESULTS

Achieved study results are presented in Table I. They reveal that the concentrations of analysed parameters of waters flowing into the reservoir and flowing out of it were characterised by apparently seasonal variability.

Table I. Selected parameters of water quality measurements

Quality index	Unit	Measurement date							
		VI 2008		IX 2008		XII 2008		III 2009	
		inflow	outflow	inflow	outflow	inflow	outflow	inflow	outflow
Acidity	pH	8.0	8.1	7.8	7.7	7.6	7.2	8.1	8.0
Electrical conductivity	$\mu\text{S}/\text{cm}$	502	476	473	444	504	511	466	538
Suspension	$\text{mg}\cdot\text{dm}^{-3}$	73	23	28	4	31	3	14	2
Oxygen	$\text{mg O}_2\cdot\text{dm}^{-3}$	9.13	8.27	8.98	9.03	11.05	11.16	10.51	10.57
BOD ₅	$\text{mg O}_2\cdot\text{dm}^{-3}$	2.32	1.48	4.28	4.53	4.90	4.88	5.24	6.16
Total nitrogen	$\text{mg N}\cdot\text{dm}^{-3}$	2.2	1.4	2.0	1.8	2.0	1.8	2.3	1.5
Ammonia	$\text{mg NH}_4\cdot\text{dm}^{-3}$	0.54	0.32	0.61	0.50	0.49	0.22	0.07	0.03
Nitrates	$\text{mg NO}_3\cdot\text{dm}^{-3}$	3.6	1.2	2.1	1.1	5.1	4.5	4.2	3.1
Nitrites	$\text{mg NO}_2\cdot\text{dm}^{-3}$	0.05	0.05	0.06	0.07	0.07	0.04	0.05	0.03
Phosphates	$\text{mg PO}_4\cdot\text{dm}^{-3}$	0.78	0.35	0.71	0.26	0.51	0.30	0.45	0.24
Potassium	$\text{mg K}\cdot\text{dm}^{-3}$	2.4	2.0	2.5	2.9	3.6	3.3	4.9	3.1
Sulphates	$\text{mg SO}_4\cdot\text{dm}^{-3}$	15.5	<10	<10	<10	15.5	10.0	14.5	<10
Chlorides	$\text{mg Cl}\cdot\text{dm}^{-3}$	6.3	5.3	4.0	4.0	5.8	5.9	17.2	9.5

The concentration of total suspended solids (TSS) flowing into the reservoir ranged from 14 to 73 $\text{mg}\cdot\text{dm}^{-3}$. The lowest values were recorded in March, while the highest in June. In the spring-summer season, the TSS inflow was at the level of about 30 $\text{mg}\cdot\text{dm}^{-3}$, whereas its concentration at the outflow was from 3 to 10 times lower. After the passage of the water through the pre-dam reservoir, a 78% reduction of the TSS level (average for the period of the study) was observed.

Biogens concentrations flowing into the reservoir also varied in time. In March and June, total nitrogen level at the inflow oscillated around 2.2–2.3 $\text{mg N}\cdot\text{dm}^{-3}$. Slightly lower concentration (2.0 $\text{mg N}\cdot\text{dm}^{-3}$) was recorded in September and December. Values of total nitrogen levels below the pre-dam reservoir were within the range from 1.4 to 1.8 $\text{mg N}\cdot\text{dm}^{-3}$, which indicates nitrogen amount reduction when flowing through the reservoir. The highest reduction (about 36%) of the item quantity was observed in March and June, while only 10% lower concentrations of total nitrogen were recorded in September and December. Mean reduction of total nitrogen levels at the outflow decreased by 24% during the study period.

The highest ammonia concentrations at the inflow and outflow were recorded in September 2008, amounting to $0.61 \text{ mg NH}_4\cdot\text{dm}^{-3}$ and $0.50 \text{ mg NH}_4\cdot\text{dm}^{-3}$, respectively, whereas the lowest – in March 2009 – $0.07 \text{ mg NH}_4\cdot\text{dm}^{-3}$ and $0.03 \text{ mg NH}_4\cdot\text{dm}^{-3}$, respectively. In September, ammonia quantity was reduced in the reservoir water by only 18%, while in other periods ammonia concentration decreased by 41% to 58%, with a mean decrease of 37% during the survey period.

The highest content of nitrates (5.1 and $4.2 \text{ mg NO}_3\cdot\text{dm}^{-3}$) at the outflow, along with their highest reduction within the reservoir (from 12 to 27%), was recorded in the autumn-winter season. Almost twice as low nitrate concentration at the inflow occurred in the spring-summer season, when nitrates were more efficiently removed in the reservoir, their concentrations decreasing by 48% to 67% in relation to the inflow concentration. On average, 34% reduction of nitrate level was recorded at the outflow.

Low nitrite concentration at the inflow to the reservoir (from 0.05 to $0.07 \text{ mg NO}_2\cdot\text{dm}^{-3}$) was observed throughout the survey period. In June and September, the level at the outflow also remained unchanged, while in December and March, a nitrite amount reduction was observed (by 17%).

The concentration of phosphates at the inflow was at rather high levels: the lowest ($0.45 \text{ mg PO}_4\cdot\text{dm}^{-3}$) was recorded in March, whereas the highest ($0.78 \text{ mg PO}_4\cdot\text{dm}^{-3}$) in June. The values of phosphates concentrations below the pre-dam reservoir ranged from 0.24 to $0.35 \text{ mg PO}_4\cdot\text{dm}^{-3}$, which indicated a reduction of phosphate amounts due to flowing through the reservoir. On average, phosphate levels at the outflow decreased by 47%; however, in spring and summer, the reduction reached even up to 55 and 63%.

Potassium, the highest concentrations of which at the inflow were observed in autumn and winter (3.6 and $4.9 \text{ mg K}\cdot\text{dm}^{-3}$), was reduced by 15% on average after water flowing through the reservoir. In September 2008, potassium concentration higher by 16% was recorded at the outflow in reference to the inflow. The water salinity indices (chlorides and sulphates) were also unchanged at low levels with a gradual decrease below the reservoir.

The lowest measured value of BOD₅ index ($2.32 \text{ mg O}_2\cdot\text{dm}^{-3}$) was recorded in June 2008 at the inflow, with further decrease at the outflow by 36%, which indicates water quality improvement. In September and December, BOD₅ value for waters at the inflow increased respectively to 4.28 and $4.90 \text{ mg O}_2\cdot\text{dm}^{-3}$; no apparent changes of the indicator were recorded at the outflow. In March 2009, waters supplying the pre-dam reservoir were characterised by the highest BOD₅ level for the whole survey period ($5.24 \text{ mg O}_2\cdot\text{dm}^{-3}$), while its increase to $6.16 \text{ mg O}_2\cdot\text{dm}^{-3}$ was observed at the outflow. For the whole experimental period, BOD₅ value increased by 2%.

Both at the inflow and outflow of the reservoir, studied waters were characterised by good aeration conditions. The content of dissolved oxygen ranged from 8.27 to $11.16 \text{ mg O}_2\cdot\text{dm}^{-3}$. The lowest indices of water aeration were re-

corded in the spring and summer season, while the highest in autumn-winter. In June 2008, over 9% decrease of dissolved oxygen concentration was found at the outflow, whereas in other cases no apparent changes were observed. On average, the indicator decreased by 2% within the studied period.

The acidity of waters determined at the inflow to the reservoir oscillated from pH 7.6 to pH 8.1, while from pH 7.2 to pH 8.1 at the outflow, which implies their slightly alkaline character. In the winter-spring season, studied waters had slightly higher alkaline character than in summer and autumn. Mean pH value at the outflow from the reservoir increased by 2%.

Also electrical conductivity increased by 1%, on average. In the autumn-winter season, studied waters at the outflow were characterised by 8% increase, whereas in spring and summer time – 6% decrease of electrolytic conductivity values as compared to waters flowing into the reservoir.

DISCUSSION

Delivery of chemicals through flows supplying the reservoirs are considered as the main pollution source of dam reservoirs [Kostecki 2003, Czamara and Grześków 2008], while agriculture is responsible for major eutrophication of aquatic environments due to the deposition of biogens in waters originating from fields and farms [Rajda *et al.* 1992]. Performed survey indicates that the waters of river Por are contaminated with biogens. In rural areas, ammonia penetrates surface waters most often from ammonification of organic nitrogen substances or inorganic salts (fertilisers). Its concentration depends on the level of water contamination due to nitrogen compounds and their seasonal transformations. Nitrogen compounds reduction and oxidation processes cause the appearance of nitrites in water that, due to biochemical factors, are converted to ammonia or nitrates being the nutrient for aquatic organisms during the vegetation period [Gomółka and Szaynok 1997]. Elimination of contamination sources is not always possible, thus in order to precipitate the pollutants, so-called pre-dam reservoirs are built, which in some cases can improve water quality in the main reservoirs [Benndorf *et al.* 1975, Czamara and Wiatkowski 2002, Czamara and Grześków 2008]. Research conducted by Czamara and Grześków [2008] revealed that the reduction of biogens load in the preliminary reservoir could amount to 65%, while that of nitrites – even 80%.

The results of performed survey revealed apparent, seasonal reduction of a majority of water quality indicators at the outflow. The level of total suspended solids decreased the most (78%) within the study period, phosphates concentration decreased by 47%, ammonia by 37%, nitrates by 34%, total nitrogen by 24%, nitrites by 17%, and potassium by 15%. BOD₅ value increased by 2%, while electrical conductivity and acidity by 1%. The slight increase in conductivity (1%) at the outflow from the preliminary reservoir, despite a marked decrease of the analysed ions conducting current, may be due to changes of other

unmarked indicators of water quality. The largest reduction of pollutant concentrations in the pre-dam reservoir on stream Por occurred during the period of intensive growth of macrophytes, which was also confirmed by the results of a study by Czamara and Wiatkowski [2002] and by Czamara and Grześków [2008]. Biogens flowing into the reservoirs are nutrients for developing aquatic plants floating on the surface or growing on the bottom and shores of a reservoir. The example may be the osier that can uptake about 1 g nitrogen and 2 g phosphorus per 1 square meter of a water reservoir annually [Fleischer and Stribe 1991, Petersen *et al.* 1992].

Analysis of the results of the conducted survey univocally indicates that the analysed pre-dam reservoir contributes to significant improvement of quality of the water flowing into the main reservoir. The efficiency of the reservoir work is high. However, it is not able to eliminate all contaminants flowing into it along with the waters of river Por.

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WPLYW ZBIORNIKA WSTĘPNEGO NA JAKOŚĆ WÓD POWIERZCHNIOWYCH ZASILAJĄCYCH ZBIORNIK WODNY „NIELISZ”

Streszczenie. W pracy przedstawiono badania dotyczące wpływu zbiornika wstępnego na jakość wód zasilających zbiornik główny. Próby wód pobierano w odstępach kwartalnych na dopływie i odpływie ze zbiornika. Analiza wyników badań jednoznacznie wskazuje, że badany zbiornik wstępny przyczynia się do znaczącej poprawy jakości wody dopływającej do zbiornika głównego. Największą redukcję stężeń zanieczyszczeń w zbiorniku wstępnym na rzece Por stwierdzono w okresie intensywnego wzrostu makrofity. Skuteczność pracy zbiornika jest duża. Nie może on jednak wyeliminować wszystkich zanieczyszczeń dopływających wraz z wodami rzeki Por.

Słowa kluczowe: zbiornik zaporowy, zbiornik wstępny, retencja wodna, eutrofizacja