Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 2013, 10, 334–346

EFFECT OF SMALL WATER RESERVOIR ON QUALITY AND USABLE VALUES OF SURFACE WATERS

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Summary. The aim of the paper was determining, on the basis of physicochemical indices, the ecological state and usable values of water inflowing into and flowing away from a small water reservoir, and establishing its effect on the surface quality waters.

The research was conducted in the „Nowy Zalew" reservoir in two measurement points situated on the water inflow to and outflow from the reservoir. Water samples were collected at monthly intervals from March to November, 2011.

Mean values of 9 indices (the temperature, pH, SO_4^{2-}, Cl^-, Mg^{2+}, H-NH_4^+, Mn^{2+}, Na^+ and K^+) were almost the same, four (total suspended solids, electrolytic conductivity, dissolved solids and Ca^{2+}) were slightly lower , whereas for N-NO_3^-, NO_3^- , $Fe^{2+/3+}$ and P_{total} clearly lower on the outflow. Moreover, aerobic conditions were more favourable on the outflow. Water in both measurement points revealed good ecological state (class II), however on the outflow this purity class was influenced by N-NO_3^- concentrations, whereas on the inflow also by oxygen concentrations. The inflow and outflow waters satisfied the requirements for waters in bathing resorts and those which are the natural habitat of cyprinid fish. Summing up, it may be stated that the water on the outflow reveals better physicochemical parameters than on the inflow, therefore owing to diverse processes occurring in it, the analyzed reservoir has been functioning as a biofilter, which advantageously affects the quality and usable values of surface waters.

Key words: water reservoir, ecological state, eutrophication

INTRODUCTION

Water cycling in hydrological catchments in terms of both quantity and quality is shaped by geomorphological, climatic and soil factors but also by the land use [Bogdał *et al*. 2010, Kanownik and Pijanowski 2011, Kondracki 2011]. Quality of surface waters is also considerably influenced by the kind and amount of pollutants supplied to rivers and their susceptibility to degradation and ability for self-purification [Murat-Błażejewska *et al*. 2004]. In any place or time water quality undergoes changes [Przybyła *et al*. 2011] caused by various intensity of water flow or character of individual seasons of the year [Ostrowski *et al*. 2005],

whereas in catchments with high population density, even due to specific humans' behaviour at various times of day [Rajda *et al*. 2004]. Also diversification of tributaries' chemical composition and irregular pollutant discharge from point pollution sources, as well as various intensity of surface runoff occurrence, influence the dynamics of water quality changes in main watercourses.

Available water resources of surface water in Poland are one of the smallest in Europe [Zieliński and Słota 1996], which per one inhabitant is only slightly better than in semi-desert Egypt. Water demand in Poland is growing constantly, therefore one of the ways to improve water balance of river catchments is its accumulation in small and big retention reservoirs. However, in order to be drinkable, fit for economic use, bathing or for life and development of aquatic fauna and flora, the water stored in retention reservoirs cannot be polluted with substances which present in excess worsen its usable values. Quality of surface water is also considerably influenced by the land use in the catchment area, agriculture (particularly fertilizers and chemicals used in agriculture), industries and sewerage systems in urbanized areas. These factors cause that the quality of stored water is unsatisfactory and because of the eutrophication processes and oxygen deficits will make reservoirs operation difficult and impossible their multifunctional use [Bogdał and Ostrowski 2008].

Changes of natural river hydrological regime occur during normal operation of the reservoir, including especially water levels, velocity and volume of flow above and below the reservoir [Ostrowski *et al*. 2005], but also changes of hydrogeological conditions of the areas adjoining the reservoir [Szafrański and Stefanek 2008] and terrestrial ecosystems in the riparian zones [Bonczar *et al*. 2005]. These changes cause that in retention reservoirs the processes affecting water quality are of slightly different character and intensity than in running waters.

The process of surface water eutrophication, including water accumulated in retention reservoirs, occurring under the influence of their excessive loading with biogenic compounds poses a global problem [Wang and Dei 2001]. This phenomenon is unfavourable both for natural, economic and health reason, since it limits potential use of water and may cause diseases and poisonings with toxins released by some algae or by products of formed excessive amount of organic matter. As demonstrated by previous research, in a vast majority of cases the main eutrophogenic factors are phosphorus and nitrogen from various sources, both natural and anthropogenic [Smith *et al*. 2001, Wang and Dei 2001, Cooper *et al*. 2002]. Phosphorus and nitrogen compounds may find their way to surface waters from point sources of pollution, e.g. urban sewage, municipal and industrial collection pipes [Mazurkiewicz-Boroń 2000], dispersed points of pollution (from built up areas, terrains without sewerage system or without sewage treatment plants), area source (from arable fields, meadows, forests and precipitations) and from linear sources connected with the use of communication infrastructure [Biernacka and Maciaszczyk 2005].

The paper aimed to determine, on the basis of analysed physicochemical indices, the ecological status and usable values of water inflowing to and flowing away from a small reservoir in Koniecpole, which allowed to assess its effect on the quality of surface waters.

MATERIAL AND METHODS

The investigated water reservoir, locally called „New lagoon" is situated in the area of Koniecpol city, among the Chrząstowska, Armii Krajowej and Klonowa streets. The city and district of Koniecpol are situated in the southern part of Poland and considering their administrative location, they belong to the Częstochowski county, which is a part of Śląskie province (Fig. 1). According to physical-geographical regionalization by Kondracki [2011], the area of the district under consideration is located on the Małopolska Upland, precisely in the Przedborska Upland macroregion, in the Włoszczowska Basin depression, which adjoins the Krakowsko-Częstochowska Upland. Geographically „New lagoon" is situated at 50°47'north latitude and 19°41' east longitude, while the coordinates of its geometrical centre, according to 1992 reference system are: X = 54509 and Y = 322953.

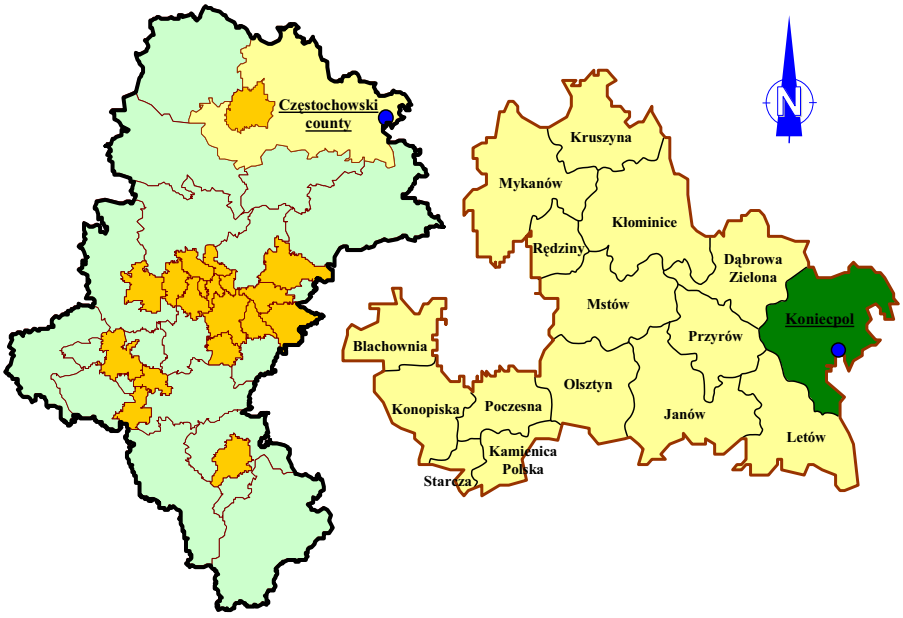

Fig. 1. Location of water reservoir against the background of Częstochowski county in Śląskie province

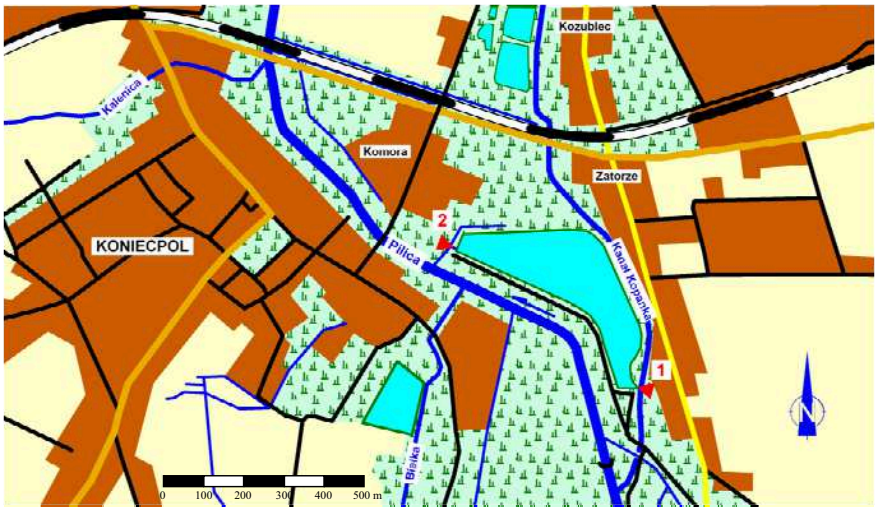

Fig. 2. Location of measurement-control points on the inflow to (1) and outflow (2) from the reservoir

Considering its natural localization, the reservoir is located in the Natura 2000 habitat protection zone, which was established in January 2011 as a site of community importance named „The Upper Pilica River Valley" No. PLH 260018.

„New lagoon" is a small side reservoir with water table area of 7.54 ha and capacity of 126 000 m^3, situated in the immediate vicinity of the right bend of the Pilica river (Fig. 2). Water intake and water supply is maintained using five-arch dam of reinforced concrete situated on the Pilica river and Kopanka or Młynówka channel. Damming, regulation of the water level and its drainage from the reservoir are possible owing to MN-4 outlet box with its submerged part (length L = 15 m), placed in the western part of the reservoir dam. Water from the „New lagoon" flows away by a short channel and then through the embankment culvert returns to the Pilica river.

In summertime, due to its urban location, the reservoir serves for leisure management. A guarded bathing place was created as well as hydrobikes' and kayaks' rental points and sites for „grill parties". After holiday season the reservoir is used by anglers. The area adjoining the reservoir from the north was temporarily sown with grass mixture, but effectively it will be designed for sports and recreation buildings which will provide recreational and holiday resort for Koniecpol city (Fig. 2).

Field and laboratory analyses were conducted in 2011. They comprised a random sampling of surface water once a month, in which measured or determined were values of 17 physicochemical indices. Additionally, nitrates were obtained from computation of nitrite nitrogen concentrations. Measurement-control points (Fig. 2) were situated on the water inflow (1) to and outflow from the reservoir (2), which allowed the initial assessment of the reservoir effect on

quality and usable values of water. All analyses were conducted using the equipment and test apparatus owned by the Department of Land Reclamation and Environment Development of the University of Agriculture in Kraków.

The temperature and dissolved oxygen were measured on site, at measurement-control points, by means of CO-411 oxygen meter, manufactured by Elmetron, equipped with thermal sensor. Moreover, the water pH was assessed using CP-104 pehameter and electrolytic conductivity, corrected to the temperature of 20°C, was measured using CC-101 conductometer. In water samples collected by means of bathometer made by Labart, the following indices were assessed in a laboratory using referential methods [Regulation… 2009]:

– dissolved solids and total suspended solids – by gravimetric methods,

– iron ($Fe^{2+/3+}$), manganese (Mn^{2+}), sodium (Na^{+}), potassium (K^{+}), magnesium (Mg^{2+}) and calcium (Ca^{2+}) – by means of atomic absorption spectrometry on UNICAM 969 apparatus,

– ammonium nitrogen ($N\text{-}NH_4^{+}$), nitrate nitrogen ($N\text{-}NO_3^{-}$), total phosphorus (P_{total}) and chlorides (Cl^{-}) – by means of flow analysis on FIAstar 5000 apparatus made by FOSS,

– sulphates (SO_4^{2-}) by gravimetric method by precipitation of sulphates using barium chloride.

For all analyzed indices basic descriptive statistics were determined, i.e. extreme values, arithmetic means and medians, which allowed to conduct physicochemical estimation of the ecological status of waters in compliance with the ministerial regulations [Regulation… 2008], their usability as habitat for salmonid and cyprinid fish [Regulation… 4 October 2002] and for bathing [Regulation… 16 October 2002] but also to estimate eutrophication hazard for surface waters [Regulation… 23 December 2002].

RESULTS

Arithmetic mean values and medians of the temperature and pH, both on the water inflow to (1) and outflow from (2) the „New lagoon" were almost identical. Also, concentrations of SO_4^{2-}, Cl^{-}, Mg^{2+}, $N\text{-}NH_4^{+}$, Mn^{2+}, Na^{+} and K^{+} were similar, irrespective of collection point. On the other hand, on average twice lower concentrations of $N\text{-}NO_3^{-}$, NO_3^{-} and $Fe^{2+/3+}$ and even five fold lower concentration of total phosphorus were registered on the outflow. The other analyzed quality indices, except dissolved oxygen, revealed on average 15% higher values in water flowing into the reservoir. Only dissolved oxygen concentrations were on average by about 11% higher on the outflow, but it only confirms that the „New lagoon" advantageously influences surface water quality (Tab. 1).

Values of 6 analyzed physicochemical water indices (the temperature, pH, total suspended solids, dissolved oxygen, $N\text{-}NH_4^{+}$, $N\text{-}NO_3^{-}$ and P_{total}) in all water samples collected on the outflow met the requirements for salmonid fish habitat.

In the inflowing water one of the quality indices did not meet the requirements for these fish habitat conditions, since according to the Regulation of the Minister of Environment in force [Regulation… 4 October 2002] dissolved oxygen concentrations met the requirements only in 87.5% of the samples, while all values should be higher than the required 7 mg $O_2 \cdot dm^{-3}$. On the other hand, in both measurement-control points concentrations of dissolved oxygen and the values of the other 5 quality indices met the requirements for inland waters which are the natural habitat for cyprinid fish (Tab. 1).

Water usability for bathing was assessed in compliance with the Regulation of the Minister of Health of 16 October 2002 on the requirements for water in watering places [Regulation… 16 October 2002]. On the basis of concentrations analysis and values of 6 analyzed indices (pH, total suspended solids, dissolved oxygen, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$ and P_{total}) it was stated that the physicochemical requirements for waters used for recreational purposes, i.e. for bathing and swimming were fulfilled in all samples of water inflowing to and flowing away from the „New lagoon" reservoir (Tab. 1).

The assessment of eutrophication hazard for waters inflowing to and flowing away from the reservoir was conducted following the guidelines of the Regulation of the Minister of Environment dated 23 December 2002 on the criteria determining waters sensitive to pollution with nitrogen compounds from agricultural sources [Regulation… 23 December 2002]. In both measurement-control points mean values of total phosphorus, nitrate nitrogen and nitrates (Tab. 1) did not exceed the permissible values, i.e. respectively 0.25 mg $P \cdot dm^{-3}$, 2.2 mg $N\text{–}NO_3 \cdot dm^{-3}$ and 10 mg $NO_3 \cdot dm^{-3}$.

However, it should be noticed that whereas phosphorus concentrations on the inflow and outflow were respectively even by 23 to 125 fold lower than the standard value, in case of nitrogen compounds the situation looked different. On average almost twice lower than permissible concentrations of $N\text{-}NO_3^-$ and NO_3^- were determined in water flowing away from the reservoir, whereas on the inflow values of these nitrogen compounds were very close (only by 6% lower) to the limit above which eutrophication occurs.

Ecological status of the waters was estimated on the basis of extreme values of 13 physicochemical indices, in compliance with the Regulation of the Minister of Environment of 20 August 2008 on the method of classification of the status of surface water bodies [Regulation… 20 August 2008].

Quality analysis revealed that thermal conditions in water on the inflow and outflow from the reservoir were advantageous and the temperature higher than permissible for class I, i.e. 22°C was not registered in any of the samples, however on one measurement date in point 2 water the temperature was only by 0.6°C lower than this threshold value. Maximum concentrations of other physical index, i.e. total suspended solids were in both measurement points several times lower than 25 mg $\cdot dm^{-3}$, i.e. the value permissible for water in class I.

Table 1. Descriptive statistics of analyzed quality indices of waters inflowing to (1) and flowing away (2) from the reservoir and assessment of their usable value

Water quality indicators		Maximum–Minimum / Average (Median)		Usefulness of surface water/water suitability						Eutrophication	
				as a natural environment for fish				for bathing and swimming			
				Salmonids		Cyprinids					
		1	2	1	2	1	2	1	2	1	2
Temperature	°C	6.5–19.3 / 13.9 (14.1)	7.4–21.4 / 13.8 (14.0)	yes	yes	yes	yes	–	–	–	–
pH	–	7.8–8.5 / 8.2 (8.3)	7.9–8.5 / 8.2 (8.3)	yes	yes	yes	yes	yes	yes	–	–
Total suspended solids	$mg \cdot dm^{-3}$	0.4–5.1 / 1.7 (1.3)	0.4–6.2 / 1.5 (0.6)	yes	yes	yes	yes	yes	yes	–	–
Dissolved oxygen	$mg \cdot dm^{-3}$	5.58–13.46 / 10.36 (10.32)	9.31–18.50 / 11.53 (10.86)	no	yes	yes	yes	yes	yes	–	–
Electrolytic conductivity	$\mu S \cdot cm^{-1}$	286–390 / 351 (355)	228–372 / 318 (334)	–	–	–	–	–	–	–	–
Dissolved solids	$mg \cdot dm^{-3}$	248–320 / 282 (289)	202–292 / 247 (248)	–	–	–	–	–	–	–	–
SO_4^{2-}	$mg \cdot dm^{-3}$	14.6–30.9 / 22.4 (22.5)	2.3–31.3 / 22.2 (25.0)	–	–	–	–	–	–	–	–

Cl^-	$mg \cdot dm^{-3}$	12.0–20.2 15.4 (14.2)	12.1–20.0 15.4 (13.8)	–	–	–	–	–	–	–	–
Ca^{2+}		60.1–81.7 73.8 (74.3)	51.4–82.1 64.9 (63.4)	–	–	–	–	–	–	–	–
Mg^{2+}		3.4–4.0 3.7 (3.7)	3.3–4.0 3.6 (3.7)	–	–	–	–	–	–	–	–
$N–NH_4^+$		Not recorded	Not recorded	yes	yes	yes	yes	yes	yes	–	–
$N–NO_3^-$		1.55–3.03 2.13 (1.95)	0.00–3.00 1.21 (1.00)	–	–	–	–	yes	yes	no	no
NO_3^-		6.86–13.42 9.44 (8.64)	0.00–13.28 5.37 (4.41)	–	–	–	–	–	–	no	no
P_{total}		0.000–0.029 0.011 (0.005)	0.000–0.016 0.002 (0.000)	yes	yes	yes	yes	yes	yes	no	no
$Fe^{2+/3+}$		0.10–0.60 0.28 (0.27)	0.00–0.27 0.15 (0.14)	–	–	–	–	–	–	–	–
Mn^{2+}		0.03–0.08 0.05 (0.06)	0.00–0.05 0.04 (0.04)	–	–	–	–	–	–	–	–
Na^+		3.5–5.4 4.4 (4.3)	3.4–5.8 4.5 (4.6)	–	–	–	–	–	–	–	–
K^+		1.8–2.5 2.1 (2.0)	2.0–3.0 2.3 (2.2)	–	–	–	–	–	–	–	–

Table 2. Assessment of ecological status of waters on the inflow to (1) and outflow from (2) the reservoir

Water quality indicators		Permissible value for water class according to the government ordinance of 2008		Maximum (or minimum*) values of indicators	
		class I	class II	Inflow(1)	Outflow (2)
Temperature	°C	≤ 22	≤ 24	19.3	21.4
Total suspended solids	$mg \cdot dm^{-3}$	≤ 25	≤ 50	5.1	6.2
pH	–	6.0–8.5	6.0–9.0	7.8*–8.5	7.9*–8.5
Dissolved oxygen	$mgO_2 \cdot dm^{-3}$	≥ 7	≥ 5	5.58*	9.31*
Electrolytic conductivity	$\mu S \cdot cm^{-1}$	≤ 1000	≤ 1500	390	372
Dissolved solids	$mg \cdot dm^{-3}$	≤ 500	≤ 800	320	292
SO_4^{2-}		≤ 150	≤ 250	30.9	31.3
Cl^-		≤ 200	≤ 300	20.2	20.0
Ca^{2+}		≤ 100	≤ 200	81.7	82.1
Mg^{2+}		≤ 50	≤ 100	4.0	4.0
$N–NH_4^+$		≤ 0.78	≤ 1.56	tr.	tr.
$N–NO_3^-$		≤ 2.2	≤ 5	3.03	3.00
P_{total}		≤ 0.2	≤ 0.4	0.029	0.016

– water quality class I, very good ecological status

– water quality class II, good ecological status

Values of pH were on a similar level, i.e. from 7.8 to 8.5 on the inflow to and outflow from the reservoir, which allowed to classify the water to very good ecological status. However, it is worth noticing that maximum values of this acidification index were on the boundary of classes I and II. Oxygen conditions only in point 2 allowed to classify water to class I, whereas on the inflow water met the requirements only of good ecological status. Maximum values of 6 salinity indices used for an assessment of water quality, i.e. electrolytic conductivity, dissolved solids, SO_4^{2-}, Cl^-, Ca^{2+} and Mg^{2+} were generally much lower than permissible values for waters in class I, independently of the sampling point.

In both measurement-control points concentrations of two biogenic substances, i.e. ammonium nitrogen and total phosphorus allowed to classify the waters to very good ecological status, whereas the maximum values of $N\text{-}NO_3^-$ met the requirements only for class II (Tab. 2).

CONCLUSION

Mean values of physicochemical features and chemical substance concentrations in water flowing away from the investigated reservoir were the same for 9 indices, slightly lower for four indices, whereas for $N\text{-}NO_3^-$ and NO_3^- , $Fe^{2+/3+}$ and P_{total} clearly lower than on the inflow. Moreover, oxygen conditions were more favourable on the outflow from the „New lagoon", therefore it may be stated that the analyzed reservoir positively influences physicochemical parameters of surface waters. The fact that, due to various processes occurring in reservoirs (e.g. sedimentation, nitrification, etc.) the amount of suspended solids and chemical substances diminishes, is an opinion often encountered in scientific literature, but in majority of reservoirs worsened oxygen conditions are registered, which is connected with decreased water flow velocity. In case of the outflow from the „New lagoon", oxygen situation was favourable, which may be connected with the fact that the reservoir is shallow and not stratified, therefore no oxygen deficits occurred by its bottom during the period of investigations. On the other hand, additional amounts of oxygen might have originated from the wavy motion of the water table, therefore from increased oxygen diffusion from the atmospheric air and from photosynthesis of aquatic vegetation covering the riparian zones of the analyzed reservoir.

In both measurement-control points waters had the same good ecological status (class II), however on the outflow a decrease in water class was influenced only by nitrate nitrogen concentrations, whereas on the inflow, apart from this biogenic index, also by oxygen conditions. In terms of utility, both water flowing to and flowing away from the reservoirs met the requirements for waters used in watering places and providing cyprinid fish habitat. However, in case of salmonid fish, advantageous conditions were only on the water outflow from the reservoir.

For the time being waters flowing away from the „New lagoon" are not threatened with eutrophication, whereas the reservoir itself may undergo this unfavourable phenomenon in the future, because even now concentrations of nitrate nitrogen and nitrates in water supplied to it from the Pilica river are approximating the value above which eutrophication occurs. Also hazard resulting from the change of meadow use of the adjoining area and its designation for recreational and holiday infrastructure for the city of Koniecpol should be taken into consideration. Considering the above, monitoring of these surface water should be conducted with reference to eutrophication hazard.

Summing up it may be stated that water on the outflow reveals better physicochemical parameters than on the inflow, so owing to various processes which occur in it, the analyzed reservoir currently performs the role of a biofilter, which beneficently influences the quality and usable values of surface waters.

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WPŁYW MAŁEGO ZBIORNIKA WODNEGO NA JAKOŚĆ I WALORY UŻYTKOWE WÓD POWIERZCHNIOWYCH

Streszczenie. Celem pracy było ustalenie na podstawie wskaźników fizykochemicznych stanu ekologicznego oraz walorów użytkowych wody dopływającej i odpływającej z małego zbiornika wodnego w Koniecpolu, co pozwoliło na ocenę jego wpływu na jakość wód powierzchniowych. Badany zbiornik „Nowy zalew” jest usytuowany w mieście Koniecpol w powiecie częstochowskim, woj. śląskiego. Jest to zbiornik boczny o powierzchni 7,54 ha oraz poj. 126 tys. m^3, zlokalizowany w bezpośrednim sąsiedztwie prawego zakola rzeki Pilicy.

Badania prowadzono w 2011 roku, co miesiąc, w dwóch punktach pomiarowo-kontrolnych usytuowanych na dopływie i odpływie wody ze zbiornika. W terenie i laboratorium oznaczano metodami referencyjnymi wartości i stężenia 18 wskaźników fizykochemicznych.

Na podstawie analizy wyników stwierdzono, że na odpływie średnie wartości i stężenia 9 wskaźników były takie same, 4 nieco mniejsze, a w przypadku $N\text{-}NO_3^-$, NO_3^- i $Fe^{2+/3+}$ i $P_{og.}$ wyraźnie mniejsze niż na dopływie. Ponadto warunki tlenowe były bardziej korzystne na odpływie. Wody w obu punktach miały dobry stan ekologiczny (klasa II), jednakże na odpływie wpływ na tę klasę miały stężenia $N\text{-}NO_3^-$, a na dopływie dodatkowo stężenia tlenu. Wody dopływające i odpływające spełniały wymagania stawiane wodom w kąpieliskach oraz będącym naturalnym środowisko życia ryb karpiowatych. Zbiornik obecnie nie jest zagrożony eutrofizacją, ale może jej ulec w przyszłości, ponieważ już teraz stężenia azotu azotanowego i azotanów w wodzie dopływającej są bliskie wartości krytycznej. Reasumując można stwierdzić, że woda na odpływie ma lepsze parametry fizykochemiczne niż na dopływie, a więc badany zbiornik poprzez różnorodne procesy w nim zachodzące pełni obecnie rolę biofiltru, który wpływa korzystnie na jakość i walory użytkowe wód powierzchniowych.

Słowa kluczowe: zbiornik wodny, stan ekologiczny, eutrofizacja