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CHANGES OF WATER QUALITY IN SMALL RESERVOIRS IN AGRICULTURAL LANDSCAPE OF NORTHERN PODLASIE

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Summary. The hydrological regime in reservoirs is one of the factors used in control of water quality. Inflow of nutrients, water retention time and other agricultural activity within a catchment influence the intensity of eutrophication. Observed dissimilarities permit reservoirs to be assigned to two groups: PFR (with periodical stream inflow) and SFR (with permanent river inflow). Organic nitrogen forms depend on processes inside reservoirs with periodic flow. Dominating in reservoirs of the SFR type mineral nitrogen form is bound with the migration from basins with surface runoff. Slow exchange of water during vegetation season is favourable to development of the phytoplankton, which limits clarity of water in PFR reservoirs. Labile phosphorus forms (SRP, SOP) were connected to spring runoff. Important participation of dissolved organic carbon in the TOC was observed throughout the year in all reservoirs. The PFR reservoirs very intensively change water quality: produced organic compounds and reduced mineral nutrient load. SFR reservoirs have the hydrochemical character of rivers which were created on.

Key words: dam, reservoir, nutrients

INTRODUCTION

Dam reservoir water quality is connected with catchment condition: the quality and the quantity of water reaching the reservoir, drainage area and human activity. Morphological features of the reservoir are very important in water quality management [Mander and Järvet 1998, Wetzel 2001]. Drainage area management is one of the main factors influencing the concentration of dissolved organic carbon (DOC) and major biogens in water [Hessen 1999, Górniak and Zieliński 2000, Friedl and Wüest 2002]. Dam reservoirs are the transitory element in the migration of nutrients and organic matter from the drainage area, especially in the higher order of rivers. Chemical and biological processes which occur intensively in reservoirs are non-typical for river ecosystems where they were created.

Increase of water resources in dam reservoirs is significant through the construction of structures permitting their optimal management. An attempt was made at determining the hydrological regime that would limit the negative consequences of river water retention in reservoirs.

Projects of water resources retention in dam reservoirs existed in the first years of the 20th century in the Northern Podlasie (NE Poland), and some new dam reservoirs have recently been constructed. The new reservoirs were created in agricultural landscape, on small periodic or stable streams with different water retention time. The main aim of the study was to observe the influence of surface runoff on the water quality in small dam reservoirs with different hydrological regimes in agricultural landscape and the character of water changes in reservoirs with stable and periodical flow.

STUDY AREA, MATERIAL AND METHODS

The new Zarzeczany Reservoir (ZR), Jasionówka Reservoir (JR) and Sitawka Reservoir (SR) were created in 2000, and the Korycin Reservoir (KR) in 2002, in the Podlaskie Province (Poland) (Tab. 1). ZR and JR exist as a result of waters damming from melioration systems, with spring (snow melting) water inflow to the reservoirs. Water quantity increased in spring is being transferred from the reservoirs through overflow wells. SR and KR were created on the same river, Kumiała, and they are distant from each other about 25 km. They are characterised by stable flow. The reservoirs have different water regimes and morphological parameters (Tab. 1).

Table 1. Characteristics of the investigated reservoirs
Tabela 1. Charakterystyka analizowanych zbiorników

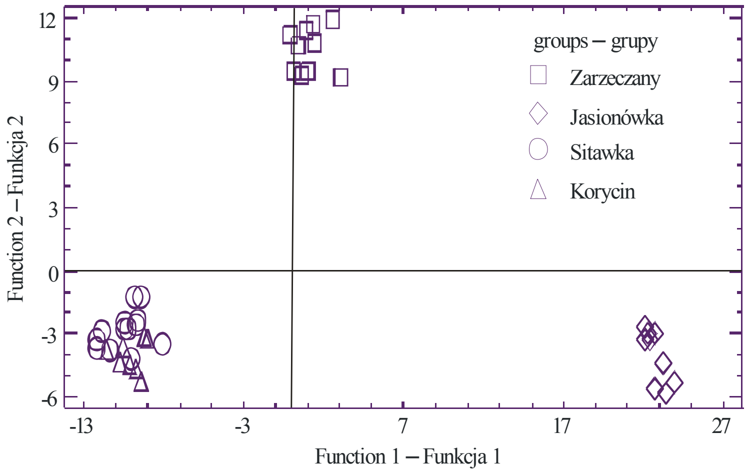
Reservoirs	PFR		SFR	
Zbiorniki	Zarzeczany	Jasionówka	Sitawka	Korycin
Reservoir location Lokalizacja zbiornika	N 53°06' E 23°41'	N 53°23' E 23°02'	N 53°27' E 23°14'	N 53°23' E 23°06'
Sampling period – Termin pobierania próbek	2001-2003	2002-2003	2001-2003	2003
Reservoir area – Powierzchnia zbiornika (ha)	11.0	4.5	6.5	6.0
Reservoir capacity – Pojemność zbiornika (x 1000 m^3)	77.0	67.0	87.2	80.0
Catchment area – Powierzchnia zlewni (km^2)	10.1	6.8	101.0	216.4
Forest in catchment – Powierzchnia lasu (%)	43	21	44	24
Basin – Zlewnia	Supraśl Narew	Brzozówka Biebrza Narew	Kumiała Brzozówka Biebrza Narew	Kumiała Brzozówka Biebrza Narew

Water samples for chemical analyses were collected at three-week intervals from March to October in the years 2001-2003 (Tab. 1). Water chemistry analyses were made in samples as an integrated sample (5 litres) from the whole pool of water (from depths of 0 m, 1 and 2 m at one test-station). The temperature, pH, water conductivity (EC) and dissolved oxygen (DO) were measured in the field using Hydrolab DataSonde 4. The chemical analyses of the water were determined using standard spectrophotometric methods [Hermanowicz *et al.* 1999]. Dissolved organic carbon (DOC) concentrations were carried out using the Shimadzu Carbon Analyser TOC 5050A. Particulate organic carbon (POC) was measured using the calorimetric chromic method [Bowman 1998]. Dissolved inorganic carbon (DIC) was calculated using HCO_3 concentration. Quality of dissolved organic matter in water was assessed by SUVA index (Specific UV Absorbance), SUVA = $\text{Absorbancy}_{260} \times 1000/\text{DOC}$ [Zieliński *et al.* 2004]. Chlorophyll *a* concentration in water was determined using spectrophotometric method with boiling 90% ethanol extraction [Jacobsen and Rai 1990]. Soluble reactive phosphorus (SRP), dissolved phosphorus (DP) and total phosphorus (TP) determinations were conducted using molibdate method with ascorbic acid. TP and DP – after previous mineralisation using UV radiation with concentrated H_2SO_4 and 30% H_2O_2. SRP and DP samples were filtered through

GF/C filter 0.45 μm before analytical procedures [Chróst 2001]. Soluble organic phosphorus SOP = DP – SRP, Particulate phosphorus PP = TP – DP. Total inorganic nitrogen (TIN) was calculated as a sum of N-NOx (nitrites + nitrates) and N-NH_4. Total organic nitrogen (TON) was determined using Kjeldahl method after removal of ammonia nitrogen.

RESULTS AND DISCUSSION

Applying statistical analyses (Fig. 1) to the estimation of the degree of hydrochemical diversity of the reservoirs permitted the assertion of substantial differences between the hydrological regime of their functioning.



Discriminant function Funkcja dyskryminacyjna	Relative Percentage Względność procentowa	Canonical Correlation Korelacja kanoniczna	Chi-Square Chi-kwadrat	DF	P-Value Poziom istotności
1	81.11	0.997	272.4	66	0.000
2	17.47	0.988	135.6	42	0.000
3	1.42	0.877	38.2	20	0.008

Fig. 1. Discriminant analysis of independent variables: pH, temp, EC, SEC, ColourPt, DO, Ca, Mg, K, Na, Cl, SO_4, Fe, Si, TP, TIN, TON, chla, DIC, DOC, POC, SUVA in the 4 investigated reservoirs; number of complete cases: 40

Rys. 1. Analiza dyskryminacyjna zmiennych niezależnych: pH, temp, EC, SEC, ColourPt, DO, Ca, Mg, K, Na, Cl, SO_4, Fe, Si, TP, TIN, TON, chla, DIC, DOC, POC, SUVA w 4 badanych zbiornikach, liczba kompletnych przypadków: 40

Reservoirs Sitawka and Korycin retain the hydrochemical character of the river which were created on. Reservoirs with sporadic flow show clear separateness. The Zarzeczany reservoir is extracted from the group of agricultural catchment reservoirs, caused by high percentage of waterlogged peat meadows in the catchment. Presented dissimilarities permit the reservoirs to be assigned to two groups: PFR (with periodical stream inflow to reservoirs) and SFR (permanent/stable flow reservoirs). SFR reservoirs have lower water pH and higher water conductivity then PFR reservoirs (Tab. 2). The main pool of nitrogen reaching water ecosystems is organic and mineral of topsoil origin [Boyd 1996, Hessen 1999, Braskerud 2002]. Organic forms of nitrogen are dominant in nitrogen pool and depend on biogeochemical processes in the reservoirs. Concentration of mineral N forms was higher than N in organic compounds in SFR types than in PFR (Tab. 2).

Table 2. Hydrochemical characteristics of the analysed reservoirs water in vegetation seasons during the years 2001-2003
Tabela 2. Hydrochemiczna charakterystyka wody analizowanych zbiorników w trakcie sezonów wegetacyjnych lat 2001-2003

Parameters Parametry	PFR				SFR			
	1. Zarzeczany n = 29		2. Jasionówka n = 18		3. Sitawka n = 29		4. Korycin n = 13	
	x	s	x	s	x	s	x	s
pH	8.07	0.52	8.07	0.26	7.79	0.35	7.80	0.31
EC (μS cm^{-1})	358	26.4	298	52.7	522	46.8	532	66.7
SEC (m)	0.99	0.37	1.44	0.50	1.22	0.56	1.31	0.53
CPt (mgPt dm^{-3})	65.3	20.4	26.3	17.6	50.2	14.2	39.2	26.1
DO (%)	91.0	22.3	104	22.9	102	24.9	106	24.6
SRP (μgP dm^{-3})	17.7	10.4	20.2	9.89	23.1	13.2	46.6	33.6
SOP (μgP dm^{-3})	73.9	59.8	118	72.7	83.2	75.2	204	164
PP (μgP dm^{-3})	54.3	56.7	49.9	26.2	63.6	32.2	71.1	61.9
TP (μgP dm^{-3})	146	119	188	89.9	170	95.9	322	249
TIN (mgN dm^{-3})	0.39	0.37	0.25	0.08	0.79	0.74	1.04	1.01
TON (mgN dm^{-3})	2.23	0.23	2.17	1.31	1.99	0.54	1.52	0.59
DIC (mgC dm^{-3})	46.9	4.61	35.7	10.6	68.1	3.91	66.5	5.25
DOC (mgC dm^{-3})	21.3	2.27	10.7	5.66	13.2	3.09	11.4	5.38
POC (mgC dm^{-3})	3.09	1.27	2.35	0.84	3.02	0.70	2.90	0.79
SUVA (Abs_{260} mgC dm^{-3})	16.3	1.02	15.0	7.20	20.7	4.83	22.0	7.54
chlorophyll *a* (μg dm^{-3})	16.7	7.93	4.12	2.39	22.2	15.7	9.13	9.04

n – sample dimension – liczba prób, x – average – średnia, s – standard deviation — odchylenie standardowe

Slow exchange of water during vegetation season is favourable to the development of higher phytoplankton volumes in PFR water bodies and decreased water transparency (Secchi disk visibility) (Tab. 2). Inflow of biogens and other agricultural activity in the drainage area and water retention time influence primary production intensity [Perkins and Underwood 2000], increased chlorophyll a concentration, and water transparency reduction. Higher water DOC concentrations in ZR were observed as a result of the drainage area character. In the analysed reservoirs with long water retention time the major part of organic carbon is created by autochthonous phytoplankton production. Considerable part of the external pool of organic carbon inflow into the reservoirs is the suspended form. Higher POC concentrations are able to enrich autochthonous production by runoff from agricultural areas (Fig. 2B). SUVA values noted in the analysed reservoirs are 50% smaller than those observed in the majority of waters in Podlasie [Górniak and Zieliński 2000, Zieliński *et al.* 2004]. Values of this parameter are confirmed by bigger determination in reservoirs supplied with water from agricultural drainage areas constantly (SFR), approaching values for forest drainage areas. Observed spring concentrations raised labile biogenic compounds in all the reservoirs (Fig. 2). Available for plant forms of phosphorus (SRP, SOP) were connected to spring runoff caused development of the phytoplankton (Fig. 2A). Available forms of phosphorus are significant factors of the eutrophication of water [Boyd 1996]. It occurs during the year in reservoirs with periodic flow within constant phosphorus resources consumption. The particular phosphorus maximum values were observed in the summer. In PFR reservoirs in annual dynamics, summer is the period when processes of production are occurring the most intensively. However, in outflow reservoirs the biggest concentrations are bound with the intensity of the flow: SRP in the autumn and PP in spring. Small reservoirs are able to retain particular phosphorus forms [Hessen 1999, Friedl and Wüest 2002]. The long time of water retention and the sporadic flow are not the reason of the vegetation seasonal recycling of phosphorus in the investigated PFR reservoirs.

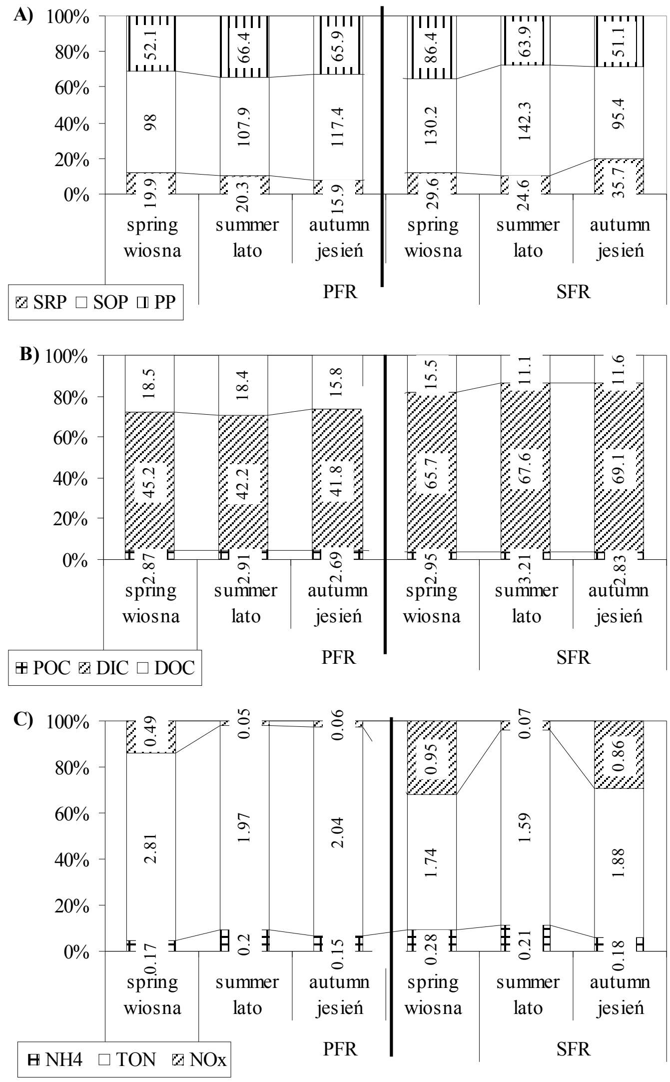


Fig. 2. Seasonal changes of biogenic compounds in the reservoirs with periodical (PFR) and stable (SFR) flow in the years 2001-2003

Rys. 2. Sezonowa dynamika biogenów w zbiornikach o okresowym (PFR) i stałym (SFR) przepływie w latach 2001-2003

Higher concentrations of dissolved inorganic carbon (DIC) are connected with surface runoff and intensified migration from the drainage area (Fig. 2B). Formation of inorganic forms of carbon in the processes of photolysis is not so important as in colour polyhumic waters typical of forest drainage areas [Bertilsson and Tranvik 2000]. This form was spread over almost the whole pool of organic carbon in the newly constructed reservoirs. Heikkinen [1990], Górniak and Zieliński [2000] observed a spring increase in DOC concentrations in the moderate zone in rivers, without autumnal concentration increase as reported earlier. An important share of dissolved organic carbon in the TOC pool was observed throughout the year, so low participation of POC was observed in the pool of organic carbon in numerous examinations (especially in small drainage areas) [Parks and Baker 1997]. The quantity of nutrients reaching reservoirs in the form of mineral-organic compounds is limiting the processes of primary production in these ecosystems [Wetzel 2001]. In seasonal variability of DOC in SFR reservoirs, increased concentrations of dissolved organic carbon were observed in the spring-summer period (Fig. 2B), probably as the effect of load from the drainage area together with products exported from the catchment after reduction of snow cover and with original production [Wetzel 2001]. In the first period of reservoir functioning the dynamics of biogenic elements were determined by the chemical activity of flooded soil [Koerselman *et al*. 1993]. The importance of nitrogen forms (except ammonia ions) is marked by the highest concentrations in spring when they reach the reservoirs together with spring surface runoff from agricultural areas (Fig. 2C). $N\text{-}NH_4$ reaches maximum values of concentration in the summer, when it is responsible for intensifying ammonification processes (Fig. 2C). It results from richness of the drainage area in nutrients that are brought into the reservoirs in the form of mineral-organic complexes [Górniak *et al*. 2002].

CONCLUSIONS

1. Our investigation shows than in Northern Poland nitrogen and phosphorus water denudation from agricultural catchment to water bodies is activated by winter or spring weather conditions and it is impossible to reduce, but management of dammed water is more important than basin character.

2. An influence of cold period surface runoff on water quality in small dam reservoirs was observed.

3. Organic nitrogen forms concentration depends on processes within the reservoirs. Mineral nitrogen forms, dominant in reservoirs of the SFR type, are bound with migration from the drainage area with surface runoff.

4. In the analysed reservoirs with long water retention time a major part of organic carbon is probably of internal origin DOC (autochthonous production). Values of SUVA are confirmed by bigger determination in reservoirs constantly supplied with water from agricultural drainage areas (SFR), approaching the values for forest catchments.

5. The PFR reservoirs are subject to very intensive changes in water quality through produced organic compounds and reduced mineral nutrient load. The SFR reservoirs have the hydrochemical character of the river which they were created on.

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DYNAMIKA JAKOŚCI WODY MAŁYCH ZBIORNIKÓW W KRAJOBRAZIE ROLNICZYM PÓŁNOCNEGO PODLASIA

Streszczenie. Jedną z metod kontroli jakości wody jest modyfikowanie reżimu hydrologicznego w zbiornikach retencyjnych. Stały dopływ biogenów, zwiększony czas retencji wody oraz działalność rolnicza w obrębie zlewni prowadzą do przyspieszonej eutrofizacji wód. Wśród badanych zbiorników można wydzielić dwie grupy: PFR (zbiorniki przepływowe okresowo) i SFR (zbiorniki o stałym przepływie). Organiczne formy azotu, dominujące w zbiornikach PFR powstają przede wszystkim w procesach wewnątrzzbiornikowych. Dominujące w zbiornikach SFR mineralne formy azotu związane są z migracją ze zlewni przede wszystkim w okresie pozawegetacyjnym. Zmniejszone tempo wymiany wody w trakcie sezonu wegetacyjnego sprzyja intensywnemu rozwojowi fitoplanktonu, ograniczającego przejrzystość wody w zbiornikach typu PFR. Występowanie labilnych form fosforu (SRP, SOP) było ściśle związane ze zwiększonym wiosennym spływem powierzchniowym. Zanotowano stale wysoki w ciągu roku udział DOC w puli węgla organicznego we wszystkich analizowanych zbiornikach. Zbiorniki typu PFR bardzo intensywnie zmieniają jakość retencjonowanej wody: generują powstawanie związków organicznych i redukują ładunek mineralnych form biogenów. Zbiorniki typu SFR mają hydrochemiczny charakter; rzeki, na których zostały utworzone odgrywają większą rolę tranzytową niż retencyjną w stosunku do większości biogenów.

Słowa kluczowe: zbiornik, retencja, biogeny