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Production and destruction processes in the selected lotic and lenitic zones of the Upper Vistula: Effect of water stages on changes in water quality

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Abstract – Two water stages, the Wisła-Czarne (characterised by a fairly good quality of water) and "Kościuszko" (with polluted water) were investigated. Analysis of the chemical composition of water flowing in and out of them showed no significant changes in its quality below the dams. It was found that some traits of the water were slightly improved, e.g. the indices of organic matter content and the concentration of biogenic compounds or mineral substances. However, in relation to the quality of the inflow small differences were determined in the parameters, which were taken into consideration. No worsening of water quality was found below the two dams.

Key words: water stages, pollution, organic matter, salinity.

1. Introduction

The complex engineering project for the Vistula stipulates that a navigable artery should be constructed in its upper course. A few water stages have already been built, damming the water of the Upper Vistula (Łączany, "Kościuszko", Dąbie, Przewóz). The barring of a river results in hydrological and then physico-chemical and biological changes below the damming constructions (Ward and Stanford 1979, Wróbel and Szczęsny 1983). The changes are diverse and may lead to positive, negative, simultaneously positive and negative, or sometimes no significant effects of the damming on the quality of the waters (Woyciechowska and Dojlido 1982, Dumnicka et al. 1988, Giziński et al. 1989, Kentzer and Giziński 1995).

On the basis of investigations carried out on the Łączany water stage some authors postulate that the cascade engineering on the River Vistula will effect worsening of water quality and suppression of the biocoenosis particularly active in the self-purification of the river (Schmager 1988). It may also retard the self-purification processes and extend the polluted zone of the river (Kownacki 1988). Since the time of the quoted studies new cascade reservoirs have been built on the Vistula, necessitating the verification of the conclusions quoted above. The

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new working hypothesis is that the metabolism of all organisms colonizing a unit section of the river is higher in the lotic than in the lenitic zone. The refutation or confirmation of the above hypothesis may answer the question whether the cascade engineering on the Vistula intensifies or retards the self-purification processes of the river.

The aim of complex hydrobiological studies carried out on two water stages was to answer the question posed above. The present paper is a part of the studies, in which an attempt was made to solve the problem using chemical methods. An attempt was made to characterize the direction of changes in the physico-chemical parameters of the river waters below the two bars.

2. Study area

The Wisła-Czarne water stage (49°36' N, 18°66' E) was built on the 11.4 km of the Vistula course, at an altitude of 489 m. This water stage is located several hundred metres below the Wisła-Czarne Reservoir. On the days of investigation the water retention time in the Wisła-Czarne water stage varied from 0.2 to 10 hours. The water stage "Kosciuszko" (50°03' N, 19°48' E) was constructed on the 153 km of the Vistula course, at an altitude of 200.4 m. Above the dam at a distance of about 25 km lies the Łączany water stage. On the days of sampling the water retention time ranged from 6 to 20 minutes in a 100-m sector of the river course. The years of the study (1998 and 1999) were in a series of wet years.

3. Materials and methods

At each water stage three stations were appointed: 1 – on the river above the impounded reach, 2 – on middle part of the impounded reach, 3 – on the river below the dam. Samples for analyses were collected from May 1998 to April 1999, eight series of the investigation having been carried out. In 1998 the sampling dates were 6 May, 8 June, 7 July, 4 August, 1 September, 30 September, and 18 November. In 1999 the sampling day was 20 April. Analyses were carried out according to methods given by Hermanowicz et al. (1976).

The comparison of water parameters at the stations will provide information on the effect of the water stages on the self-purification processes in the River Vistula. Therefore, calculations were made to determine the mean concentrations of elements at the sampling stations. The significance of differences was determined using Student's t-test ($p=0.05$). The comparison between Stations 1 and 2 characterized the changes in concentration of studied compounds in the upper part of the impounded reach, between Stations 2 and 3 the changes in the lower part of the impounded reach, and between Stations 1 and 3 the changes in the physico-chemical parameters within the impounded reach. The same test was conducted for differences in the load of the investigated compounds between Stations 1 and 3.

4. Results

The two water stages differed in the quality of waters flowing into the dams (Table I). The River Vistula above the Wisła Czarne carried fairly pure waters. The

Table I. Ranges of selected physico-chemical parameters of the Vistula water before inflow to the Wisła-Czarne Reservoir and "Kościuszko" water stage from May 1998 to April 1999.

Parameters		Wisła-Czarne Reservoir		"Kościuszko" water stage	
		Min.	Max.	Min.	Max.
Conductivity	$\mu S\ cm^{-1}$	62.7	113	804	4968
Cl	$mg\ L^{-1}$	1.0	3.5	86	865
Dissolved oxygen	$mg\ L^{-1}$	9.1	13.8	7.2	11.7
Oxidability	$mg\ O_2\ L^{-1}$	1.2	3.7	4.6	12.5
BOD_5	$mg\ O_2\ L^{-1}$	0.7	3.4	3.5	6.7
COD	$mg\ O_2\ L^{-1}$	2.8	13.2	79.5	252.4
NH_4	$mg\ N\ L^{-1}$	0.22	0.47	0.49	1.74
NO_3	$mg\ N\ L^{-1}$	0.04	0.91	0.27	1.44
$N_{Kjeld.}$	$mg\ N\ L^{-1}$	0.88	2.49	1.91	3.87
PO_4	$\mu g\ P\ L^{-1}$	4	72	97	230
$P_{tot.}$	$\mu g\ P\ L^{-1}$	17	81		

content of organic matter determined by COD varied from 2.8 to 13.2 mg $O_2\ L^{-1}$, the concentration of phosphates not exceeding 72 µg P L^{-1}. The Vistula waters feeding the "Kościuszko" water stage were polluted with organic compounds (COD: 79.5–252.4 mg $O_2\ L^{-1}$), rich in nutrients (especially phosphates: 97–230 µg P L^{-1}), and saline (chloride content: 86–865 mg L^{-1}).

Analysis of changes in the concentration showed that neither the Wisła-Czarne (Table II) nor "Kosciuszko" water stages (Table III) caused statistically significant changes in the investigated water parameters. An improvement in some quality traits of the Vistula water was recorded, e.g. in the indices of organic matter content, concentration of nutrients, and mineral compounds. However, decreases in the content of the above-mentioned compounds in relation to that in waters of the inflow were too small to justify conclusions concerning the favourable effect of the river bars. Nevertheless, no deterioration of water quality below the two dams was determined.

Analysis of changes in the load of chemical compounds of water flowing into and out of the stages showed no significant impact of these constructions on the retention and elimination of the investigated substances from the water (Tables IV–V). A similar observation concerned their concentration. The comparison of loads of organic compounds, nutrients, and components of the ionic composition brought into a water stage showed their partial retention (the Wisła Czarne: retention of 6% for COD, 32% for N_{min}, and 36% for N_{Kjeld}; the "Kościuszko" water stage: 25%, 15%, and 20%, respectively, and PO_4 21%), although it was statistically non significant.

Table II. Mean values of some physico-chemical parameters in the Wisła-Czarne Reservoir from May 1998 to April 1999: 1 – river before entrance into the impounded reach, 2 – middle part of the impounded reach, 3 – river below the dam.

Parameters		Stations		
		1	2	3
Conductivity	µS cm^{-1}	85.7 ±17.1	83.6 ±16.0	85.6 ±16.7
Chlorides	mg Cl L^{-1}	2.0 ±1.2	1.7 ±0.9	1.6 ±0.9
Sulphates	mg SO_4 L^{-1}	19.2 ±3.5	26.7 ±22.2	17.0 ±4.3
Calcium	mg L^{-1}	10.4 ±2.1	10.6 ±2.4	10.1 ±2.2
Magnesium	mg L^{-1}	2.4 ±0.8	2.4 ±0.6	2.4 ±0.7
Nitrate nitrogen	mg N L^{-1}	0.55 ±0.26	0.48 ±0.18	0.48 ±0.18
Ammonia nitrogen	mg N L^{-1}	0.31 ±0.09	0.33 ±0.18	0.28 ±0.05
Total N_{min}	mg N L^{-1}	0.87 ±0.30	0.82 ±0.30	0.77 ±0.20
N_{Kjeld}	mg N L^{-1}	1.47 ±0.54	1.43 ±0.92	1.17 ±0.43
Phosphate phosphorus	µg P L^{-1}	17 ±22	17 ±19	17 ±25
Total phosphorus	µg P L^{-1}	44 ±23	39 ±15	39 ±20
Dissolved oxygen	mg L^{-1}	10.55 ±1.56	10.55 ±1.42	10.13 ±1.36
Oxidability	mg O_2 L^{-1}	2.51 ±0.84	2.62 ±1.06	2.51 ±0.75
BOD_5	mg O_2 L^{-1}	1.71 ±0.81	1.36 ±0.23	1.24 ±0.49
COD	mg O_2 L^{-1}	8.30 ±2.96	7.38 ±2.19	7.03 ±2.67
Turbidity	mg SiO_2 L^{-1}	4.04 ±2.91	4.28 ±2.98	4.28 ±3.03
Dry residue	mg L^{-1}	74.5 ±12.2	79.7 ±15.2	78.4 ±12.0
Residue after ignition	mg L^{-1}	52.2 ±18.0	57.9 ±17.2	53.2 ±16.2

Table III. Mean values of some physico-chemical parameters in the "Kosciuszko" water stage from May 1998 to April 1999: 1 – river before entrance into the impounded reach, 2 – middle part of the impounded reach, 3 – river below the dam.

Parameters		Stations		
		1	2	3
Conductivity	µS cm^{-1}	2794 ±1406	2539 ±1534	2515 ±1273
Chlorides	mg Cl L^{-1}	453.9 ±281.8	410.9 ±290.8	400.3 ±241.1
Sulphates	mg SO_4 L^{-1}	147.9 ±47.3	129.6 ±65.4	131.9 ±56.8
Calcium	mg L^{-1}	91.8 ±33.5	86.5 ±37.2	87.2 ±31.4
Magnesium	mg L^{-1}	41.9 ±26.6	41.7 ±24.6	41.5 ±20.7
Nitrate nitrogen	mg N L^{-1}	0.65 ±0.38	0.72 ±0.42	0.66 ±0.36
Ammonia nitrogen	mg N L^{-1}	1.15 ±0.53	0.91 ±0.39	1.03 ±0.42
Total $N_{min.}$	mg N L^{-1}	1.96 ±0.58	1.77 ±0.54	1.84 ±0.60
N_{Kjeld}	mg N L^{-1}	2.67 ±0.67	2.64 ±0.81	2.39 ±0.51
Phosphate phosphorus	µg P L^{-1}	165 ±49	136 ±42	120 ±48
Dissolved oxygen	mg L^{-1}	8.65 ±1.44	8.41 ±1.54	8.40 ±1.50
Oxidability	mg O_2 L^{-1}	7.19 ±2.60	6.99 ±3.51	5.85 ±1.29
BOD_5	mg O_2 L^{-1}	5.04 ±1.08	5.16 ±1.61	4.74 ±1.50
COD	mg O_2 L^{-1}	160.4 ±59.3	129.2 ±46.8	134.0 ±46.4
Turbidity	mg SiO_2 L^{-1}	24.1 ±30.1	8.4 ±54.7	25.2 ±13.2
Dry residue	mg L^{-1}	1829 ±876	1659 ±923	1646 ±741
Residue after ignition	mg L^{-1}	1538 ±745	1396 ±781	1478 ±741

Table IV. Mean loads of some chemical compounds in the Wisła-Czarne Reservoir from May 1998 to April 1999: 1 – river before entrance into the impounded reach, 3 – river below the dam

Parameters		Stations	
		1	3
Chlorides	g Cl s^{-1}	1.9 ±2.3	1.9 ±2.4
Sulphates	g SO_4 s^{-1}	23.3 ±35.9	21.7 ±34.3
Calcium	g Ca s^{-1}	11.2 ±14.6	11.1 ±15.0
Magnesium	g Mg s^{-1}	2.5 ±3.4	2.6 ±3.4
Nitrate nitrogen	g N s^{-1}	0.74 ±1.11	0.48 ±0.18
Ammonia nitrogen	g N s^{-1}	0.39 ±0.54	0.28 ±0.05
Total N_{min}	g N s^{-1}	1.13 ±1.64	0.77 ±0.20
N_{Kjeld}	g N s^{-1}	1.84 ±2.74	1.17 ±0.43
Phosphate phosphorus	g P s^{-1}	0.02 ±0.02	0.02 ±0.01
Total phosphorus	g P s^{-1}	0.04 ±0.05	0.06 ±0.05
Oxidability	g O_2 s^{-1}	3.7 ±5.4	3.6 ±5.3
BOD_5	g O_2 s^{-1}	1.7 ±2.2	1.4 ±1.8
COD	g O_2 s^{-1}	10.3 ±14.4	9.7 ±13.8
Dry residue	g s^{-1}	92.9 ±129.5	100.4 ±141.9
Residue after ignition	g s^{-1}	71.7 ±101.7	66.4 ±99.4

Table V. Mean loads of some chemical compounds in the "Kościuszko" water stage from May 1998 to April 1999: 1 – river before entrance into the impounded reach, 3 – river below the dam.

Parameters		Stations	
		1	3
Chlorides	kg Cl s^{-1}	58.6 ±69.8	44.2 ±34.3
Sulphates	kg SO_4 s^{-1}	21.3 ±24.7	16.7 ±15.8
Calcium	kg Ca s^{-1}	13.6 ±16.9	11.9 ±12.3
Magnesium	kg Mg s^{-1}	5.9 ±8.0	5.2 ±5.1
Nitrate nitrogen	kg N s^{-1}	129.1 ±181.4	130.8 ±183.8
Ammonia nitrogen	kg N s^{-1}	203.1 ±255.0	150.3 ±168.4
Total N_{min}	kg N s^{-1}	349.0 ±491.4	296.5 ±355.3
$N_{Kjeld.}$	kg N s^{-1}	440.8 ±454.4	350.6 ±296.2
Phosphate phosphorus	kg P s^{-1}	24.2 ±27.5	19.1 ±19.6
Oxidability	kg O_2 s^{-1}	1.2 ±1.3	0.9 ±1.0
BOD_5	kg O_2 s^{-1}	0.7 ±0.7	0.7 ±0.7
COD	kg O_2 s^{-1}	23.1 ±27.5	17.4 ±15.5
Dry residue	kg s^{-1}	251.2 ±301.1	196.4 ±170.3
Residue after ignition	kg s^{-1}	211.3 ±255.0	115.4 ±176.5

5. Discussion

The character and magnitude of the physico-chemical and biological changes below the damming constructions depend on a complex of factors, above all on the capacity of the reservoir and size of the river (time of water retention). It also depends on the quality of the inflowing waters (Wróbel and Szczęsny 1983). Analysis of changes in the water quality in 72 of the world dam reservoirs took into consideration the degree of pollution of inflowing in waters, showing diverse trends in these changes (Woyciechowska and Dojlido 1982, Kajak 1995). In 50% of reservoirs fed with pure water no changes were recorded, the same observation being made in 70% of reservoirs supplied with moderately polluted water and in 35% of those with a polluted water supply. In the present work no significant changes in water quality determined in the water stage supplied both with fairly pure and with polluted waters are in agreement with the above mentioned data. The investigation conducted in the Włocławek Reservoir, constructed on the Vistula and fed with polluted waters, showed that below this reservoir the water quality was improved with respect to suspension and total phosphorus (Kentzer and Giziński 1995). The ratios of various forms of nitrogen and phosphorus were also changed. The concentration of phosphate phosphorus and of all forms of mineral nitrogen, as well as the share of phosphorus and mineral nitrogen in total N and P, increased.

The magnitude of retention of substances brought in to the two investigated water stages was fairly low (20–30%). In reservoirs constructed on rivers the retention of substances is extremely variable (Żytkowicz et al. 1990, Kentzner and Giziński 1995). It is usually higher in reservoirs with a longer time of water retention (Straskraba et al. 1995). The results of analyses carried out in the above quoted 72 reservoirs show that in general no changes in water quality occur in reservoirs with a strong water flow (Woyciechowska and Dojlido 1982). In other words, the retention of some substances in them is low. The two investigated water stages characterized by the short time of water flow corroborated the above observation.

The results of the present study did not prove distinct changes in the content of organic substances, expressed by such indices as BOD_5, oxygen consumption, or COD. Neither an improvement nor deterioration of oxygenic conditions were determined. In general, in the reservoirs of the world analysed by Woyciechowska and Dojlido (1982) the oxygenation of pure waters did not change, while it was reduced in polluted ones. In the Włocławek Reservoir a decrease in oxygen content to the value of 2.7 mg L^{-1} was recorded in summer (Kentzer and Giziński 1995). The absence of changes found in the "Kościuszko" water stage (fed with polluted waters) might have resulted from a very short time of water retention.

With respect to the prognoses quoted in the "Introduction" (Kownacki 1988, Schmager 1988), the present study does not answer the question of whether the cascade engineering on the Vistula will deteriorate or improve the quality of its water. However, the suggestions of Kajak (1995) should be taken into consideration. According to that author the cascade of reservoirs built on rivers with rich phosphorus resources can favour water blooms. In single reservoirs of short water retention period the phytoplankton does not manage to develop abundantly while a cascade presents for the phytoplankton something like one long reservoir with a respectively long retention period. The long retention time permits the propagation of the phytoplankton and the intensification of its development down the cascade.

In recapitulating the discussion on the effects of the Wisła-Czarne and "Kościuszko" water stages on the water quality of the Vistula, one more fact should be taken into account: the present investigation was conducted in wet years. Therefore, the recorded data showing lack of the impact of damming on the chemical composition of the water below the dams are valid with respect to the years characterized by abundant precipitation and great water discharges into the river. In dry years stronger effects of hydrotechnical constructions on the river on changes in water quality will undoubtedly be observed.

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