

A regulated river ecosystem in a polluted section of the Upper Vistula*

2. Hydrochemistry

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Abstract — Chemical investigations of the waters of the Vistula in the year 1982—1983 on a 25 km section in the region of the water stage at Łączany revealed strong pollution of the river. The water stage was not found to have any direct effect of improvement in the quality of the water. On a section about 20 km long below the stage the water purity slightly improved. When comparing the chemical composition of the waters of the Vistula in the years 1934, 1964—1965, and 1982—1983 a very distinct deterioration in quality can be seen to have occurred.

Key words: regulated river, pollution, hydrochemistry, loads of nutrients.

1. Introduction

The Institute of Freshwater Biology of the Polish Academy of Sciences in Cracow has been carrying out complex investigations on the effect of dam reservoirs and water stages on the biocenosis and water quality (Kasza 1986, Krzyżanek 1986). The present work is a constituent part of the above-mentioned research project whose subject is the River Vistula along a 25 km section in the region of the water stage at Łączany.

The physico-chemical properties of the waters of the Vistula along this section have already been described by a number of researches (Starmach 1938, Kotulski 1962, Bombówna, Wróbel 1966, Skoczeń 1982, Wróbel, Szczęśny 1983). The studies showed that the Upper Vistula is strongly polluted with wastes. The water is of the chloride-sodium type. Over a period of several years changes occurred in its chemical composition, unfavourably affecting its purity.

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Salinity of the water as well as the content of organic compounds greatly increased. In the opinion of Bombówna and Wróbel (1966) the Vistula along this section is one of the most polluted rivers in Poland.

The investigations carried out in the region of the water stage at Łączany in the period 1977—1979 and 1981—1982 (Schmager 1988) concerned evaluation of the effect of the water stage on the processes of self-purification. This evaluation was based on physico-chemical, oxygen, and biological criteria.

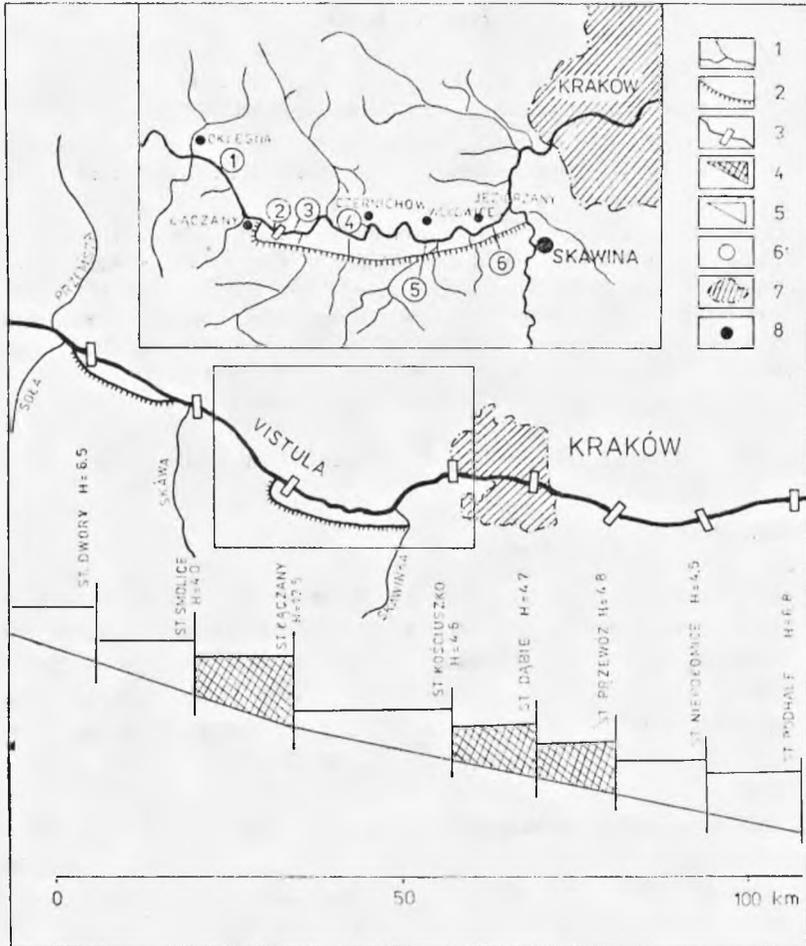


Fig. 1. — The Upper Vistula, showing cascade building and stations on the investigated river section. 1 — rivers; 2 — canal; 3 — water stages, dams; 4 — water stages built; 5 — water stages under construction and planned; 6 — stations; 7 — cities; 8 — towns and villages

The aim of the present study was to answer the question as to what degree a water stage on such a polluted river may affect the quality of its water.

The analytical part of the study was carried out by W. Huk, M.Sc., (from the Laboratory of Fish Diseases, Department of Veterinary Hygiene in Cracow) and T. Kysela, Eng., (from the Institute of Fresh-water Biology of the Polish Academy of Sciences).

2. Study area

The investigations covered a 25 km long section of the Vistula between the villages Okleśna and Jeziorzany (fig. 1). A detailed description of the area has been given by Dumnicka and Kownacki (1988).

3. Material and methods

Hydrochemical investigations in the region of the water stage in Łączany were carried out within a period of 1 year (from 15 Dec. 1982 to 13 Dec. 1983) at 6 stations (fig. 1). Samples were collected at monthly intervals. Throughout the investigated period 10 samples from each station were taken from the river bank using a Patalas sampler.

Water analyses were performed according to the methods described by Just and Hermanowicz (1964) and Golterman and Clymo (1969).

4. Results

The water reaching the stage (Station 1) is strongly polluted (Tables I, II). It is characterized by high values of BOD₅, oxidability, content of ammonium nitrogen, chlorides, and sulphates. The amount of total phosphorus is also very high.

Strong pollution of the river is also evidenced by poor oxydability of the water and a fairly small amount of nitrate nitrogen in comparison with the amount of ammonia nitrogen.

The water within the reservoir (Station 2) does not essentially differ in its composition from that flowing into it (Table I), being also strongly polluted with organic and mineral compounds. It is characterized by a high degree of salinity, while the oxygen content is low. Although the amount of organic matter (BOD₅, oxidability) diminishes, this decrease is negligible.

Water flowing from the dam at Station 3 has a somewhat changed chemical composition in comparison with Station 2 (Table I). The

Table I. Mean values and ranges of physico-chemical parameters of Vistula water at Stations 1-6 in the period 1982-1983

Factor	Stations					
	1	2	3	4	5	6
Temperature °C	$\frac{13.8}{4.5-21.5}$	$\frac{14.1}{3.9-24.0}$	$\frac{13.7}{4.5-19.2}$	$\frac{14.3}{4.1-22.5}$	$\frac{13.9}{4.0-21.5}$	$\frac{14.0}{4.1-21.2}$
pH	$\frac{7.2}{6.0-7.6}$	$\frac{7.2}{6.9-7.6}$	$\frac{7.2}{6.9-7.6}$	$\frac{7.2}{6.9-7.5}$	$\frac{7.2}{6.9-7.5}$	$\frac{7.2}{6.5-7.5}$
Alkalinity mval dm ⁻³	$\frac{3.2}{2.4-3.7}$	$\frac{3.3}{2.4-4.1}$	$\frac{3.2}{2.4-3.9}$	$\frac{3.2}{2.2-3.8}$	$\frac{3.3}{3.1-3.8}$	$\frac{3.2}{2.6-3.8}$
Total hardness °G	$\frac{26.1}{14.6-36.5}$	$\frac{25.2}{13.3-36.8}$	$\frac{24.9}{13.2-36.2}$	$\frac{25.0}{13.4-35.0}$	$\frac{25.6}{13.8-34.6}$	$\frac{26.1}{14.5-35.2}$
Oxidability mg O ₂ dm ⁻³	$\frac{19.0}{10.7-28.1}$	$\frac{16.0}{5.8-24.0}$	$\frac{15.7}{5.4-23.6}$	$\frac{15.0}{6.7-19.2}$	$\frac{15.6}{6.6-22.4}$	$\frac{15.9}{6.2-23.6}$
Dissolved oxygen mg O ₂ dm ⁻³	$\frac{4.2}{1.6-5.1}$	$\frac{4.6}{1.9-9.9}$	$\frac{8.6}{1.1-11.7}$	$\frac{8.9}{7.0-11.8}$	$\frac{9.2}{6.9-13.1}$	$\frac{8.4}{6.3-12.2}$
BOD ₅ mg O ₂ dm ⁻³	$\frac{20.0}{12.3-28.4}$	$\frac{16.3}{6.4-20.0}$	$\frac{21.5}{10.7-50.8}$	$\frac{14.4}{4.0-19.3}$	$\frac{14.2}{10.7-18.0}$	$\frac{15.5}{11.0-18.7}$
Calcium mg Ca dm ⁻³	$\frac{106.6}{66.2-142.6}$	$\frac{102.1}{61.9-139.7}$	$\frac{102.8}{65.7-142.6}$	$\frac{102.4}{63.3-141.1}$	$\frac{105.9}{65.4-141.1}$	$\frac{104.7}{57.2-139.7}$
Magnesium mg Mg dm ⁻³	$\frac{50.8}{22.1-71.8}$	$\frac{48.6}{19.9-74.8}$	$\frac{47.2}{17.3-70.5}$	$\frac{46.4}{19.5-66.2}$	$\frac{46.7}{20.4-64.5}$	$\frac{50.1}{22.1-67.9}$
Sodium mg Na dm ⁻³	$\frac{473.6}{200.0-710.0}$	$\frac{464.3}{171.2-710.0}$	$\frac{450.7}{102.4-710.0}$	$\frac{458.1}{165.0-700.0}$	$\frac{476.7}{110.0-690.0}$	$\frac{488.9}{190.0-690.0}$
Potassium mg K dm ⁻³	$\frac{21.0}{8.4-30.0}$	$\frac{20.6}{7.4-30.0}$	$\frac{20.4}{5.4-30.0}$	$\frac{20.1}{7.4-29.5}$	$\frac{21.0}{7.2-29.5}$	$\frac{21.3}{8.1-29.0}$
Iron mg Fe dm ⁻³	$\frac{1.0}{0.01-3.00}$	$\frac{0.8}{0.04-2.30}$	$\frac{1.4}{0.13-5.00}$	$\frac{1.1}{0.13-3.20}$	$\frac{1.3}{0.13-3.20}$	$\frac{1.2}{0.19-3.00}$
Ammonia nitrogen mg N-NH ₄ dm ⁻³	$\frac{3.27}{1.71-7.31}$	$\frac{3.67}{1.65-7.50}$	$\frac{3.75}{1.54-8.00}$	$\frac{3.53}{1.60-7.52}$	$\frac{3.60}{1.40-7.90}$	$\frac{3.18}{1.30-7.30}$
Nitrate nitrogen mg N-NO ₃ dm ⁻³	$\frac{0.51}{0.10-1.42}$	$\frac{0.52}{0.15-1.60}$	$\frac{0.59}{0.11-2.18}$	$\frac{0.59}{0.11-1.67}$	$\frac{0.59}{0.19-1.57}$	$\frac{0.62}{0.25-1.59}$
Nitrite nitrogen mg N-NO ₂ dm ⁻³	$\frac{0.14}{0.015-0.270}$	$\frac{0.13}{0.011-0.100}$	$\frac{0.13}{0.013-0.180}$	$\frac{0.15}{0.012-0.200}$	$\frac{0.18}{0.012-0.350}$	$\frac{0.20}{0.012-0.400}$
Phosphate mg P dm ⁻³	$\frac{0.16}{0.048-0.225}$	$\frac{0.17}{0.091-0.200}$	$\frac{0.16}{0.081-0.319}$	$\frac{0.16}{0.085-0.329}$	$\frac{0.14}{0.088-0.228}$	$\frac{0.14}{0.065-0.287}$
Total phosphorus mg P dm ⁻³	$\frac{1.14}{0.77-2.20}$	$\frac{1.32}{0.80-2.50}$	$\frac{9.15}{2.12-14.20}$	$\frac{2.49}{0.62-10.80}$	$\frac{1.30}{0.70-2.10}$	$\frac{1.37}{0.75-2.35}$
Chloride mg Cl dm ⁻³	$\frac{874.4}{369-1438}$	$\frac{824.7}{344-1402}$	$\frac{820.0}{242-1384}$	$\frac{807.8}{343-1172}$	$\frac{849.4}{362-1285}$	$\frac{860.7}{357-1285}$
Sulphate mg SO ₄ dm ⁻³	$\frac{230.3}{92.0-352.0}$	$\frac{238.6}{85.6-381.0}$	$\frac{225.6}{80.0-312.0}$	$\frac{239.2}{96.0-435.0}$	$\frac{246.0}{89.3-411.0}$	$\frac{223.1}{78.0-328.0}$
Silica mg SiO ₂ dm ⁻³	$\frac{9.5}{1.9-22.4}$	$\frac{9.5}{1.7-23.4}$	$\frac{10.1}{1.7-23.4}$	$\frac{7.9}{2.0-27.0}$	$\frac{6.8}{1.8-20.4}$	$\frac{9.8}{2.2-25.2}$
Dry residue mg dm ⁻³	$\frac{2174}{1100-3130}$	$\frac{2057}{835-3068}$	$\frac{2004}{598-2904}$	$\frac{2098}{908-2842}$	$\frac{1963}{864-2726}$	$\frac{1963}{836-2756}$

Table II. Comparison of the chemical composition of the Vistula water above Bielany in 1934 (after Starmach 1938), in 1964-1965 (acc. to Bombówna, Wróbel 1966), and above Jeziorzany (Station 6) in 1982-1983 (author's data)

Factor	1934	1964-1965	1982-1983
pH	7.4	7.5	7.2
Total hardness °G	10.2	13.4	26.1
Chloride mg Cl dm ⁻³	45.9	145.9	860.7
Sulphate mg SO ₄ dm ⁻³	24.5	122.3	223.1
Oxidability mg O ₂ dm ⁻³	6.2	20.1	15.9
Ammonia mg N dm ⁻³	0.33	2.14	3.18
Nitrate mg N dm ⁻³	1.14	0.41	0.62

amounts of oxygen and total phosphorus are considerably higher. The other indicated physico-chemical parameters do not show any great changes, only the content of organic compounds (oxidability) being slightly diminished.

The water of the Vistula collected from the successive sampling stations (Stations 4, 5, 6) changes considerably in its chemical composition. There is a pronounced decrease in the content of BOD₅ and of total phosphorus (Table I). Some favourable alterations towards improvement of the water purity may be noted: the ration of N—NH₄ to N—NO₃ decreases, the amount of dissolved oxygen increases, and the content of organic matter is maintained on a lower level than at Station 1.

The diel run-off of nitrogen compounds in the ammonia and nitrate forms and of total phosphorus at Station 6 was calculated (fig. 2). The diel load in the period April—October varied from 10 to 16 tons N 24 h⁻¹. During periods of higher water level there was a greater amount of nitrogen carried in the river. The proportion of nitrate nitrogen in the total amount of mineral nitrogen was also higher at the time. The diel loads of total phosphorus amounted to 2.7—7.9 tons P 24 h⁻¹.

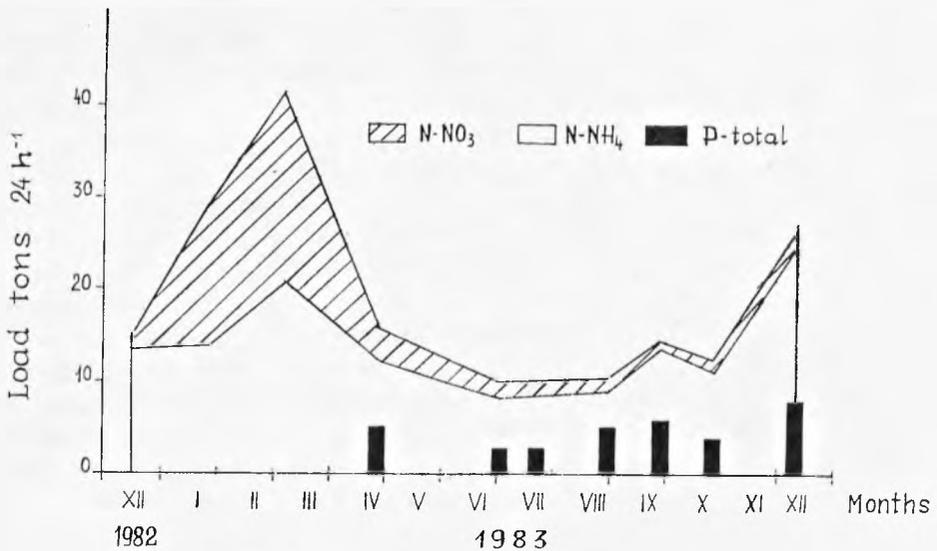


Fig. 2. Diel changes in the loads of mineral nitrogen and total phosphorus at Station 6 in the period 1982—1983

5. Discussion and conclusions

According to Wróbel and Szczesny (1983), any barrier across a river or stream leads to hydrological and, subsequently, physico-chemical and biological changes down river. The nature of these changes

depends among other things on the time of retention of the water in the reservoir. Its short retention at the stage in Łączany (16–20 h) does not bring about elimination of nutrients and salinity. The slowing of the current favours the sedimentation of organic matter in the reservoir and, according to Wróbel and Szczęsny (1983), also that of suspended matter. The fall of water from the stage and the subsequent increased current in the further course of the river brings about mechanical oxygenation of the water, this being responsible for a slight improvement in water purity at Stations 4–6. A change, though small, takes place in the ratio of $N-NH_4$ to $N-NO_3$, which is beneficial for the purity of the water. However, the process of improvement is very slow. This slow process of self-purification of the Vistula Bombówna and Wróbel (1966) explained as being due to the formation of new, not easily decaying organic compounds, similar to humus substances, in the course of mineralization of organic matter. Such compounds are found at a greater distance from the source of pollution, which indeed occurs in the case under consideration.

The polluted water of the Vistula assumes along the whole investigated section a subsaline character with the amount of chlorides and sulphates prevailing over that of carbonates and of sodium over calcium. Its electrolytic composition and the interrelation between the ions differ widely from the ionoequivalent composition given by Stangenberg (1958) for unpolluted rivers in Poland.

A comparison of the chemical composition of the Vistula water with the results of investigations carried out 49 years ago by Starmach (1938) and 19 years ago by Bombówna and Wróbel (1966) (Table II) gives a very unfavourable picture. It can be seen that during this period there took place essential changes in the chemical composition of the water. In the 1930's the pollution of the Vistula was slight. Since that time the salinity and the amount of sulphates have markedly increased and, to a lesser degree water hardness. During 19 years the content of chlorides has increased almost 6 times and that of sulphates and total hardness twice. The content of mineral nitrogen has increased only slightly. Such a high concentration of electrolytes in the water of the Vistula in 1983 was to some extent due to low water level. A comparison of the load of mineral nitrogen in the investigations by Bombówna and Wróbel (1966) with the present results shows that they have remained the same. Also the concentrations of mineral nitrogen in this period differ only slightly. Since the concentration and the load of mineral nitrogen in the water are the same, the main reason for the great increase in the salinity of the Vistula appears to be the progressive pollution with wastes.

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6. Polish summary

Ekosystem uregulowanego i zanieczyszczonego odcinka Górnej Wisły

2. Hydrochemia

W okresie jednego roku, 1982—1983, badano Wisłę na 25-kilometrowym odcinku od Okleśnej do Jeziorzan, na sześciu stanowiskach (ryc. 1). Stwierdzono silne zanieczyszczenie rzeki (tabela I). Na całym badanym odcinku Wisła posiadała wodę typu chlorkowo-sodowego.

Woda Wisły w samym zbiorniku nie różniła się zasadniczo swym składem od wody dopływającej. Jedynie zmniejszyła się w nim zawartość materii organicznej (tabela I). Krótki czas retencji nie wpłynął na eliminację składników pokarmowych i zasolenia. Na około 20-kilometrowym odcinku poniżej progu Wisła zaczyna nieznacznie poprawiać swą czystość.

Obliczono dobowy spływ związków azotu w formie amonowej i azotanowej oraz fosforu ogólnego (ryc. 2). Więcej azotu przepływało w Wisłę w okresie zwiększonych stanów wody.

Porównując skład chemiczny wody Wisły w latach 1934, 1964—1965 i 1982—1983 (tabela II), stwierdzono bardzo wyraźne pogorszenie jakości wody wiślanej. Wzrosło szczególnie zasolenie wody, nieco w mniejszym stopniu ilość siarczanów i twardość.

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