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UPPER VISTULA RIVER: RESPONSE OF AQUATIC COMMUNITIES TO POLLUTION AND IMPOUNDMENT I. PROBLEM, OUTLINE OF RESEARCH AND STUDY AREA

ABSTRACT: The main disturbancies in hydrological and chemical features of the Upper Vistula River were discussed as well as geological structure and soils of its drainage basin. Examined section of the river is 337 km long. Catchment area of 28 000 km^2 inhabited by 50 to 800 residents km^{-2}. Three main problems concerning the river were considered: salinity, pollution and water management. Between 89 and 95 km the river obtaines salty water from coal mines and down the 95 km of the river – huge load of pollution by the Przemsza River. The inflow supplying 91% of Vistulian flow at this point. This unusual proportion is caused by far transfer of drinking water from submontainous part of the Vistula or its tributaries. Polluted water comes back to the river by Przemsza River. Vistula had here too much of suspension, phosphorus, nitrite and ammonia, and sometimes zinc. Water quality between 90 and 170 km was useless for cyprinid fishes according to EC directive.

Vistula River and its affluents flow through holocenic river terraces – covered with alluvial and fluvioglacial deposits. In the region of Cracow there are small areas of upper Jurassic origin (marls and lime) and from the Cretaceous period. Holocenic terrace of the river is covered by alluvial soils. On the left bank, between the Przemsza and Nida rivers, there are large areas of loesses.

Investigations were carried out in the period between 3rd March 1997 and March 4th 1998. Also the present state of investigations of the Vistula River is discussed.

In 1997 in the period from 7th to 15th of July extreme and disastrous flood in the Vistula occurred. Flows, which usually in Cracow (on 165 km) provide 50 to 100 m^3 s^{-1}, grew up to 1430 m^3 s^{-1} and during the culmination of wave up to 2400 m^3 s^{-1}.

KEY WORDS: river, water pollution, drainage basin

1. INTRODUCTION

Hydrobiological investigations of the Upper Vistula (Figs 1, 2, 3) were carried out for over 120 years and had a rich literature. History of the Vistula investigations until 1986 was described in details by Dumnicka and Kownacki (1988a). Review of historic works shows deterioration of water quality below the Przemsza outlet in XIX-th. century and in the first half of XX-th century. It was connected with the development of industry, mostly in the Przemsza catchment. In 50's water of the Vistula was poisoned by raw

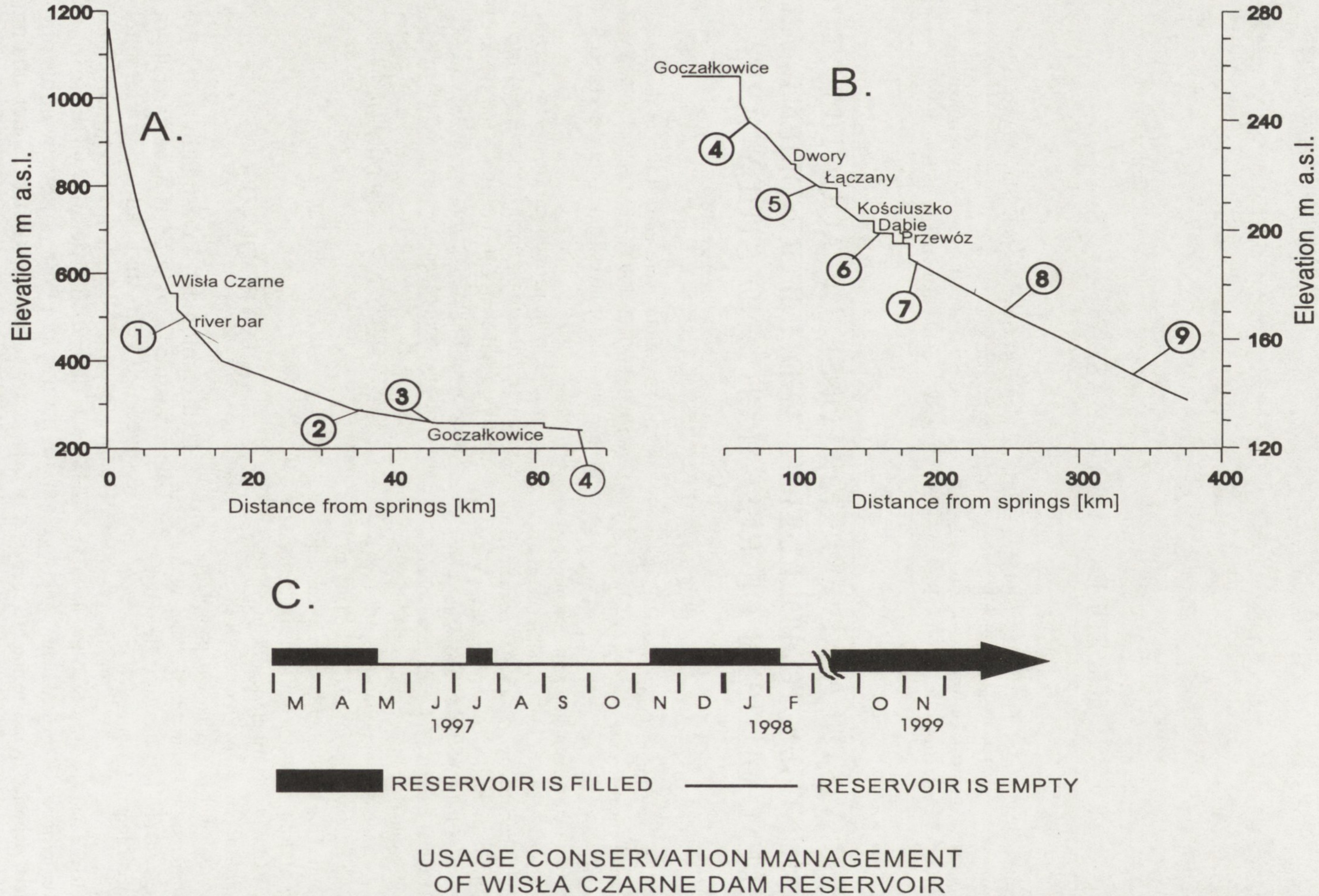

Fig. 1. Longitudinal profiles of the Vistula on water-level (measured on 9th of May 1998). A – the upper part from springs to the Goczałkowice dam, B – the lower part from the Goczałkowice dam reservoir to the end of Upper Vistula section (393.8 km of river course). The weirs are marked with their local names. 1 – 9 – sampling stations for this study. The scheme of water management in the Wisła Czarne dam reservoir in 1997/99 is given below (C). An arrow indicate that after repairing in November 1999 the reservoir is filled until these days.

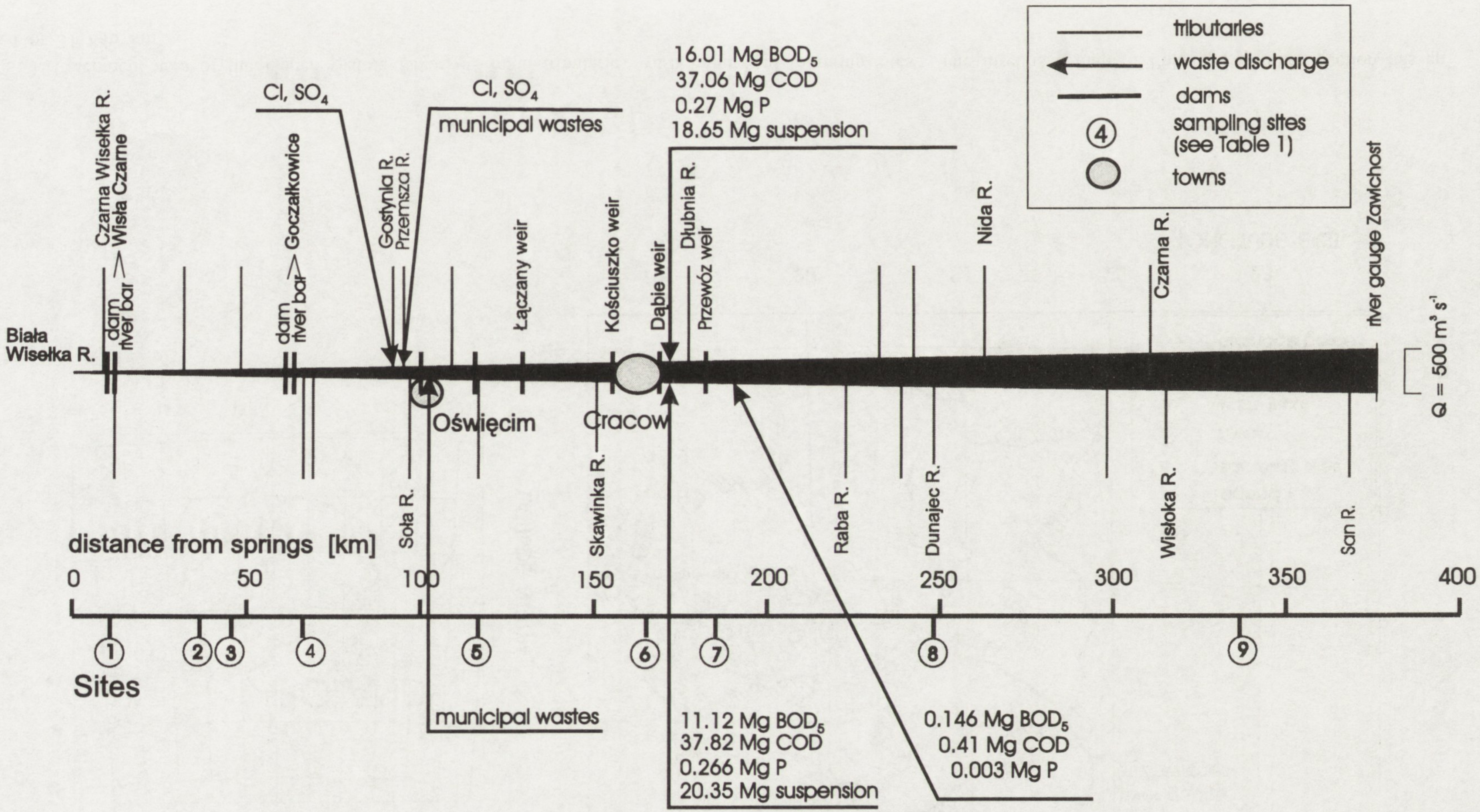

Fig. 2. Scheme of the Upper Vistula River along the increase of flow. Localisation of sampling sites, main tributaries, dams, towns are given with their respective local names as well as the values of daily load of pollution.

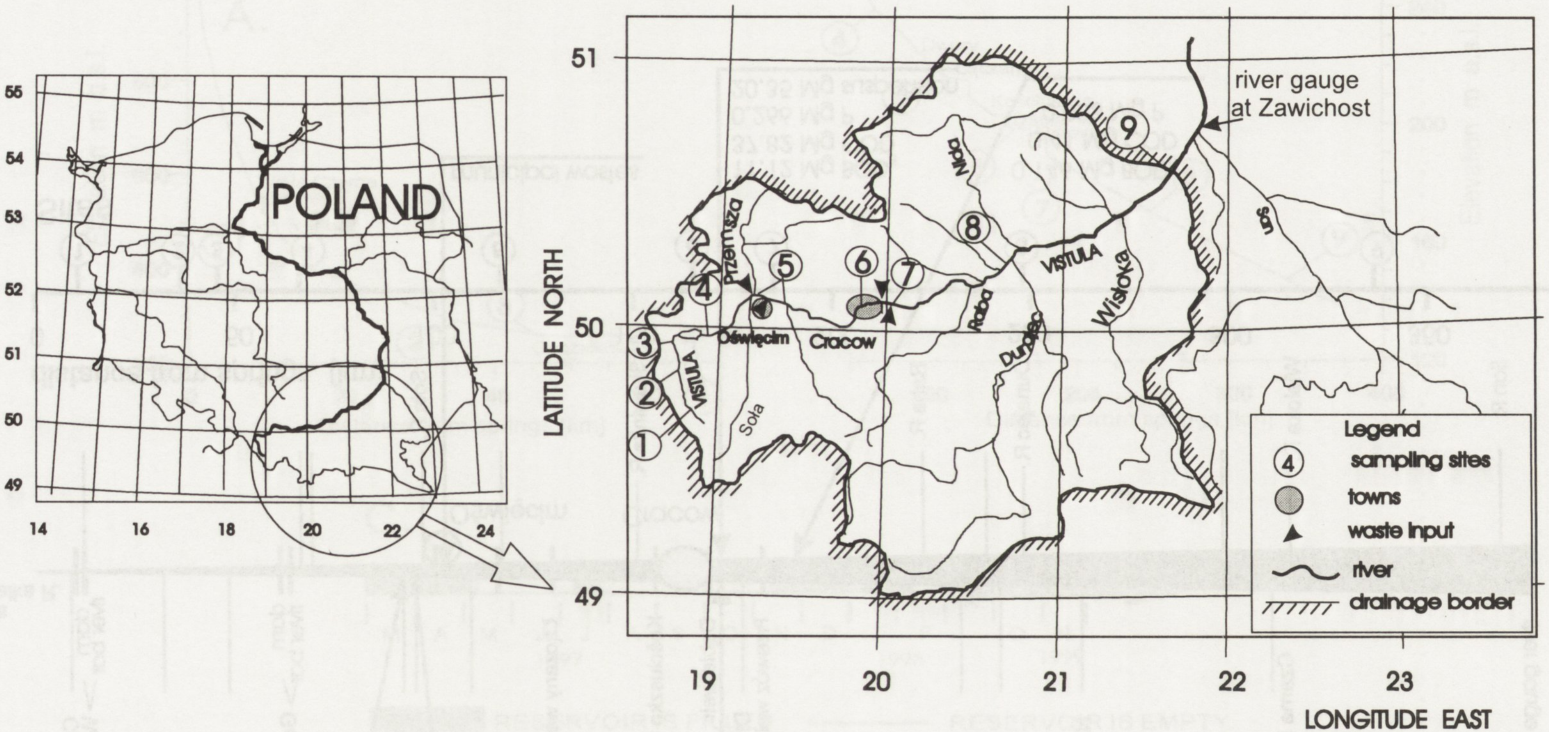

Fig. 3. Catchment area of the Upper Vistula River, its main tributaries waste input and sampling sites. The inset is a map of Poland. Examined section has an area of 31 846 km^2.

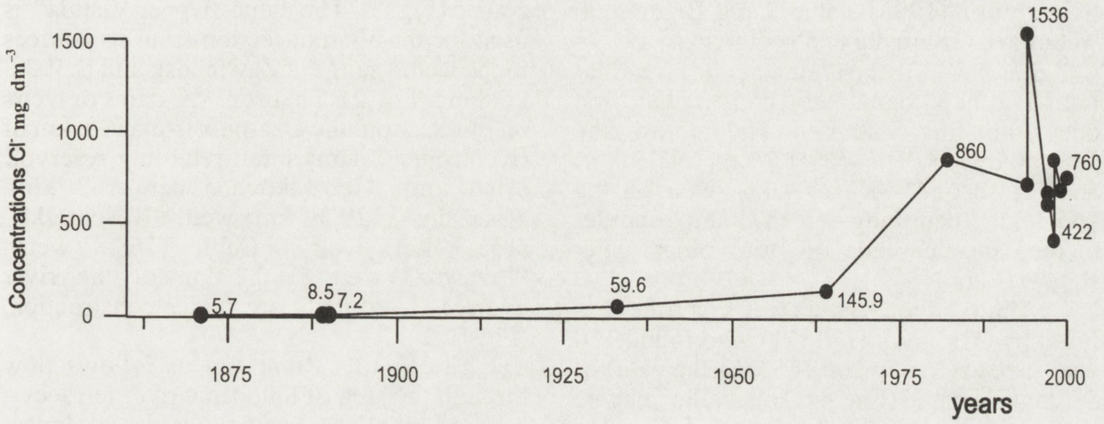

Fig. 4. Historical analyses of chlorides in Cracow on 165 km of the Vistula River course. Last 10 points are the mean values for a given year. Values according to Olszewski 1871, Bujwid 1912, Starmach 1938, Bombówna and Wróbel 1966, Kasza 1988, Krokowski *et al.* 1994, Wojtan *et al.* 2000, Kasza and Galas 2002, Turzański 1999, for 1998 Żurek, unpubl., Turzański and Wertz 2000, and for the year 2000 – State Inspectorate for Environmental Protection (unpubl.).

sewage rich in phenols from the chemical factory in Oświęcim (on 96 km). Mentioned town until these days did not have a waste purification plant. However, since 80's some water quality indices were improved, whereas other become worse. Phenol concentrations diminished from 0.3 mg dm^{-3}, in 60's to 0.005 presently. High amounts of coal particles present until 70's, vanished along with progress in technology in the coal mines and afterwards with liquidation of several mines in 90's. In these years paper factory discharging sulphite wastes through the Breń River was eliminated. Mean values of COD observed in Cracow (165 km) grew up from the range 35.4–78.4 in 1964 to 70.6–247 mg O_2 dm^{-3} in 1997/98. In 1999 purification plant in Cracow began to work. It has efficiency of 70 000 m^3 day^{-1}. In the first year, it purified biologically 9 669 000 m^3 of municipal wastes from Cracow, so, the amount of biologically treated wastes increased from 1% before 1998 to 12 %. The rest 41 % wastes is treated only mechanically and 47 % is discharged without treatment (Turzański and Wertz 2000). In 1998 the river obtained in the investigated sector, directly or through the tributaries 200 hm^3 of municipal wastes and 249 hm^3 of industrial wastes. The new waste purification plants in the drainage area began to work in 1996–1999. They are able to purify 88 300 m^3 daily (Turzański 1999). In the years 1982–83 the Vistula River was examined by hydrobiologists and hydrochemists starting from the Przemsza outlet to Cracow. Hydrochemistry was worked out by Kasza (1988), and lately by Wojtan *et al.* (2000). The trophic state of water was estimated with alga tests method by Bednarz (1988) showing high fertility of the water between 125 and 150 km. Starzecka (1988) investigated the bacterial decomposition of organic matter. She found increase in proteolytes bacteria biomass downstream. In this short sector Bednarz and Żurek (1988) found 210 taxa of algae and 83 taxa of planktonic animals. They noted brackish species in bioseston. Sessile algae were analysed by Kwandrans (1988), ciliata by Grabacka (1988), macroinvertebrates by Dumnicka and Kownacki (1988b). Detritivorous bentic animals were found at 128 km, whereas farther algivorous species were more numerous. Włodek and Skóra (1988) stated that increase in pollution has contributed to the recession from the Vistula above Cracow, not only of the most predatory fishes but also of some species of the cyprinid family. The problem of acidification on the first 10 km long section of the river (Czarna Vistula stream), and the effect of dolomitization on its bottom was examined by Wróbel (1995, 1998). Load of iodine and its concentrations were interesting for Ślizowski (1996), who stated in the Vistula on 79 km 337 μg J dm^{-3}, and on 91.9 km – 620 μg J dm^{-3}, whereas in Cracow (on 155.3 km) only 15–20 μg J dm^{-3}. The most of iodine was discharged by Gostynka stream on 89 km. In this stream 856 μg J dm^{-3} was noted. All the coal mines discharged 166 Mg iodine yearly. On 95 km Ślizowski (1996) stated 3 mg Br dm^{-3} in water and 18 mg kg^{-1} in sediments.

Since 90's, in the region of our investigations two new dams were constructed, first one on the first kilometre below the Goczałkowice dam (H=1.75 m, 61.2 km) and the second "Kościuszko" weir on the 155.3 km (damming 4.5 m). They supplemented the cascade of four older water stages, (Figs 1, 2).

Salinity of the Vistula was first time analysed by Olszewski (1871) who found 130 years ago in Cracow (on 165 km) the value of 5.7 mg Cl^- dm^{-3}, (Fig. 4). This value may be treated as the chloride background. Seventy years ago Starmach (1938) noted 272 mg Cl^- dm^{-3} below the Przemsza outflow (on 95 km). In 1989 to 1994 the mean daily load of chlorides above Cracow reached 5 600 tons daily (Krokowski *et al.* 1994). Data acquisition system installed in 1993 on Kościuszko weir (155 km) collected values of the concentrations from 50 to 2300 mg Cl^- dm^{-3}. Global production of salt in Poland was 2 925 000 tons, whereas "production" by draining of mines was 3 200 000 tons (Maciejewski 1994).

All papers presented in this volume address several aims. They include estimation of water quality of the Vistula 15 years after preceding investigations and evaluation of usefulness of different flora and fauna communities for classification and estimation of water quality. Authors applied a large gradient of water quality down the river to improve the biological coefficients of water pollution and also to estimate the structure of aquatic communities as a function of chemical features. All samplings and investigations were carried out simultaneously in one year cycle with 1 month ± 1 week sampling scheme. Only one site (No 5 on 115.6 km) was common with site 1 (on 122.7 km) in previous investigations in 1982/1983.

2. DESCRIPTION OF THE UPPER VISTULA DRAINAGE BASIN

2.1. GEOLOGY AND SOILS

Hydrobiological investigations of the Upper Vistula undertaken by the Institute of Freshwater Biology, refer to section of the Vistula between 10.9 km and 336.7 km of its course (Fig. 3). The name "Upper Vistula" is used for the Vistula section from its sources to the water-gauge at Zawichost, and is 393.8 km long (Fig. 2). There are six dams or weirs on this section: the Czarna Vistula (9.6 km of river course) dam; small retarding reservoir (10.6 km); Goczałkowice dam (62 km), "Łączany" (129.30 km) weir, "Kościuszko" (155.3 km) weir, Dąbie (168.8 weir), "Przewóz" weir (180.2 km of the river course). Two next are under construction, (Figs 1, 2).

The Vistula River and its inflows flow through the area of holocenic river terraces – covered by alluvial and fluvioglacial deposits. Deposits of the Vistula valley are defined as sea – Miocene. There are sands, loams with sandstones, gypsum and salts. In all valleys there are Quaternary alluvia, mostly sandy and clayey. In the region of Cracow there are small areas of the Upper Jurassic (marls and limes) and the Cretaceous origin. Holocenic river terrace is covered by mud soils. On the left bank between the Przemsza (95 km) and Nida (262.7 km) large areas of loesses are found .

The Upper Vistula River-basin on examined section has an area of about 31 846 km^2. Increase in this area depending on the length of the river can be calculated according to following equation:

$$S = 0.25 \pm 0.067 l^{2.01 \pm 0.047}, \quad r = 0.99 \qquad (1)$$

where: S – area of drainage basin in km^2, l – distance from sources in km.

Density of human population diversified: from 48–50 inhabitants km^{-2} to 800 km^{-2}. The largest population inhabits western and north-western parts of the river-basin. These terrains are urbanised and industrialised. Remaining areas of the river-basin are typically agricultural or forested with considerably lower population. Areas of partial catchment of the Przemsza River (left-bank inflow of the Vistula) and the Little Vistula (section from sources to the inlet of the Przemsza) have the greatest population density (Długosz 1991) (Fig. 3).

On the discussed area, mineral raw materials such as: pit-coal, zinc and lead ores, sulphur, salt exist and are exploited at present. Coal is mostly exploited in catchments of the Vistula till the outlet of the Przemsza and in the Przemsza catchment. (Figs 2, 4). In the Przemsza catchment there are also ores of zinc and lead. In the Raba River catchment there are the deposits of rock-salt being already considerably depleted. The catchment of the Nida (left-bank inflow of the Vistula, Fig. 3) is rich in gypsums. On right and left banks of the Vistula on 336 km there are large and still exploited sulphur deposits with subterranean melting out method. Two other opencasts are reclamated (Żurek 2000).

2.2. CONTAMINATION AND POLLUTION

Main sources of water pollution are municipal and industrial sewage discharged directly to the Vistula or its inflows. River obtains from Oświęcim town an inflow of domestic sewage and also deriving from the chemical industry. Cracow discharges down municipal sewage and other pollutants from metallurgic, power-, machine - and chemical – industry, all in <1% purified in biological process. Since 1999 this value grew up to 12% (Fig. 2, Table 1).

The highest value (ca. 80 $dm^3\ km^{-2}\ s^{-1}$) of areal runoff unit from the drainage basin was observed in the mountainous region, where catchment area is relatively small (31 km^2). Fluctuations are also much greater here than at lowland sites. Range of fluctuations diminishes together with the increase in the catchment area (Fig. 5). Catchments of all right side tributaries receive yearly precipitation between 800 and 1600 mm. In the river sector 90–220 km precipitations are lower 700–800 mm and diminish in north direction.

Temperature of water in the Vistula River ranged from 1 °C up to 22.4 °C and was typical of the conditions of this region. The water of the Vistula River was characterized by rather high oxygen content ranging between 9–15 mg $O_2\ dm^{-3}$ in the upper, 4–12 mg $O_2\ dm^{-3}$ in the middle, and 6–12 mg O_2 dm^{-3} in the lower course of the studied part of the river (Kasza and Galas 2002).

Six main anions outflowing from the catchment area are shown on Fig. 6. Two recurrence sequences of runoff coefficients from site 1 to 4 and from 5 to 9 are presented. They are similar with high coefficient decreasing along the river. These sequences concern phosphates, sulphates, chlorides, nitrite and ammonia but not nitrate. This last nitrogen form has a constant runoff coefficient from site 3a (the Goczałkowice dam reservoir) to site 9.

In Opatowiec (site 8), somewhat above the Dunajec River outlet, runoff coefficient has arisen to some extent. It concerned the sulphates, nitrates, calcium, magnesium and dry residue.

Runoff coefficients were calculated for calcium, magnesium and iron (Fig. 7). Their values show a similar pattern downstream the river as anions. Depending on type of drainage basin and its surface, these coefficients slightly varied between stations 1 to 3. After obtaining inflows from catchment basin rich in calcium and magnesium, this coefficient from site 5 to 9 is apparently higher. Similar fluctuations refer to iron, especially at low drainage basin area.

Decrease in high concentrations of nutrients since the Przemsza River outlet downstream is caused mainly by dilution due to relatively unpolluted inflows. Chemical composition of water for such parameters as calcium, magnesium or sulphate can be explained by the features of local drainage

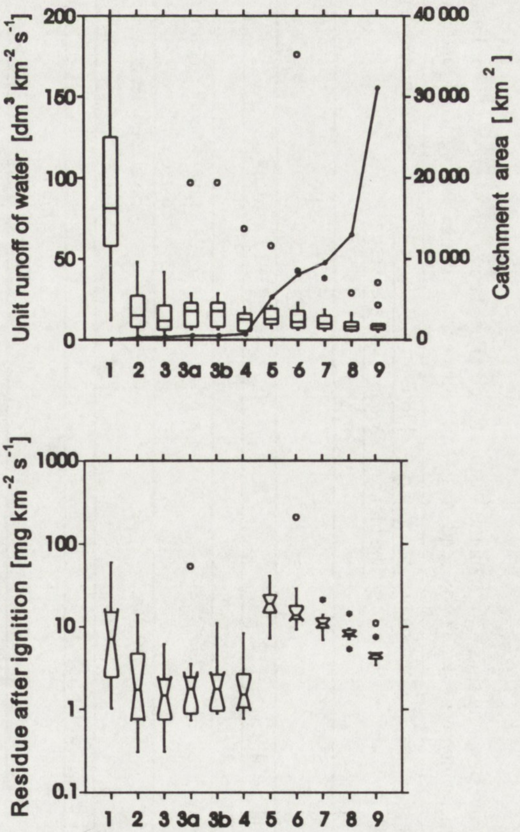

Fig. 5. Areal runoff unit of water and mineral solids. Values outside the inner fences are plotted with asterisks and values far outside the outer fences are plotted with empty circles. Solid line concerns the catchment area Sites see Table 1 and Figs 1, 2, 3. Site 3a was localised in the Goczałkowice dam reservoir near the gates, and site 3b – 50 m below the dam. These additional sites are only for chemical purposes.

Table 1. Most important points and sampling sites (1 – 9) on the Vistula River. *For dams values concern the ordinate of spillway (overflow). Length in kilometers of the river includes corrections of the Vistula's banks which were done to the end of 1997. Distance from springs. After Żurek and Kasza (2002)

	Distance [km]	m a.s.l.*	Catchment [km^2]	Flow [m^3s^{-1}] The highest	Flow Mean	Flow The lowest	Beds and deposits	Remarks
Wisła Czarne dam reservoir	9.6	554.2					clay	clear water, sometimes acid, damming 36.5 m, retention time 29 to 77 days
Site 1 (Wisła Czarne)	10.9	491.0	12.3	8.0	0.7	0.17	stones	clear water, gradient 11.1‰, current velocity 0.655 m s^{-1}
Wisła Czarne weir	11.4	489.0						retention time 20 minutes, damming 1.75 m
Site 2 (Skoczów town)	36.6	287.13	297.0	433	6.19	0.12	gravel , pebble, cobble and coarse sand	effluents from sewage treatment plant
Site 3 (Drogomyśl village)	45.7		312.3				gravel, pebble, coarse sand	effluents from ponds and purification plant at Skoczów town
Goczałkowice dam	61.2	256	523.1					3 km long earth dam, damming 12.60 m
(Goczałkowice dam reservoir)							mud	retention time ca. 150 days
Goczałkowice weir	62.2	243.75	523.6					damming 1.5 m
Site 4	66.2	239.78	738	288	9.52	0.47	coarse sand and sandy clay	outflow from dam reservoir, 5 km below the dam
Site 5 (Jankowice village)	117.6	217.0	5635.1				sand	mining waters providing by the Gostynia and the Przemsza trib. rich in Cl^{1-}, $SO_4^{\ 2-}$ suspension, $NO_3^{\ 1-}$, $PO_4^{\ 3-}$ as well as municipal wastes from Silesia. Not purificated wastes from Oświęcim town
Łączany overflow dam	129.3	209.78	6941.6				mud	damming 6.5 m
Kościuszko overflow dam	155.3	199.38	7523.6					warmed water from electric power station discharged by the Skawinka River, damming 4.5 m
Site 6 (Cracow)	167.8	195.2	7999.9	2260	95.5	23.4	sand in the channel, mud at the banks	Cl^-, $SO_4^{\ 2-}$, suspension, load of organic matter 74.88 Mg COD $year^{-1}$
Dąbie overflow dam	168.8	195.20	8101				mud at banks, sand in channel	damming 3.7 m.
Przewóz overflow dam	180.2	189.65	8333				mud at banks, sand in channel	damming 3.7 m.
Site 7 (Przylasek Rusiecki village)	185.20	189.0	8732				sand	site 2 km below the outflows of municipal wastes from Cracow
Site 8 (Opatowiec)	248.20		12 997	3130	210	62	mud, clay	slightly before connection with the Dunajec River. 25 km below inflow of clear water of large Raba River.
Site 9 (Machów village)	336.70	144.5	31 846	5260	309	71.2	sand in channel, mud at the banks, sandy islands	90 km below inflow of clear water from Dunajec River

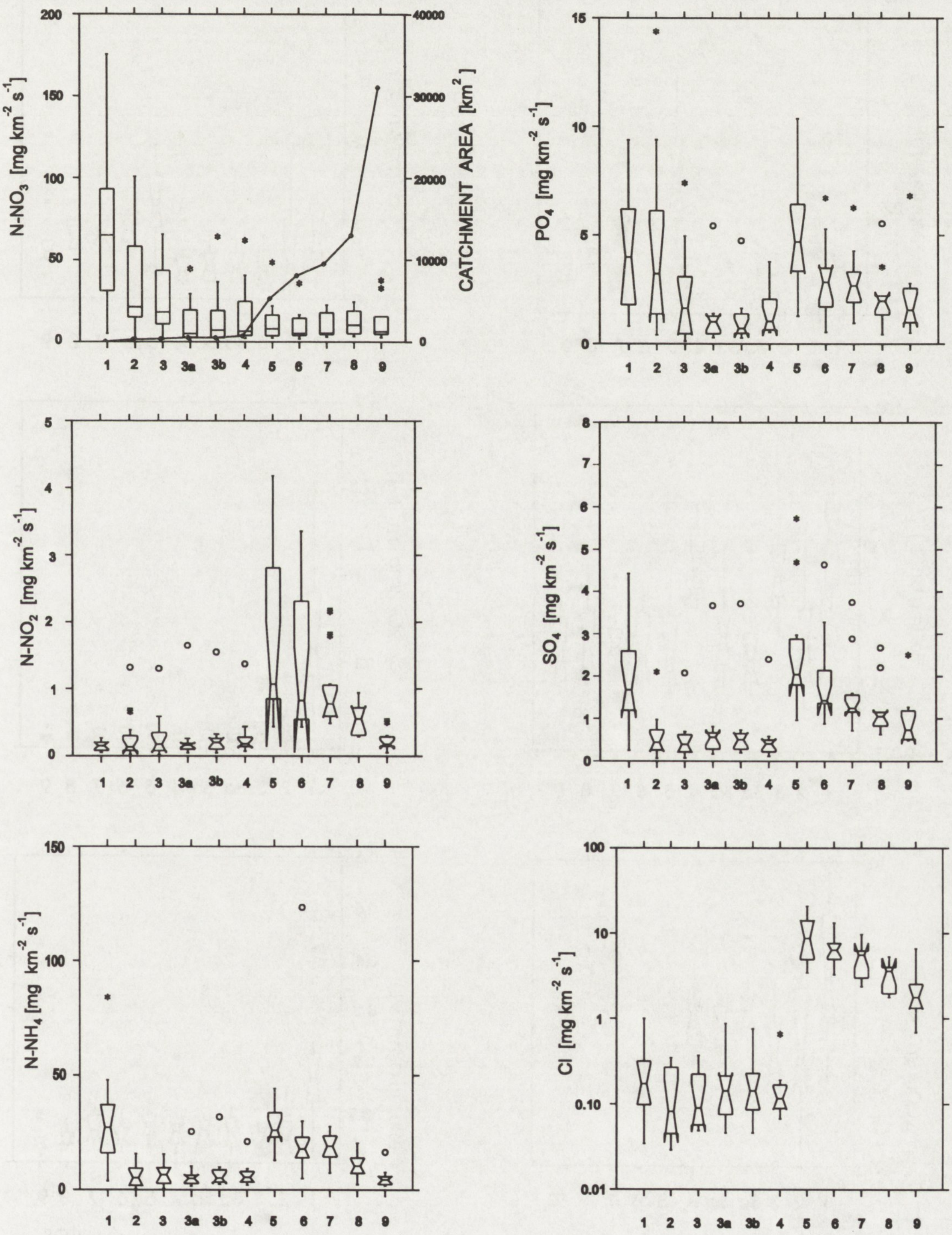

Fig. 6. Areal runoff of the main anions. Solid line on the first figure concerns the catchment area, sites and meaning of asterisks and empty circles as on Fig. 5.

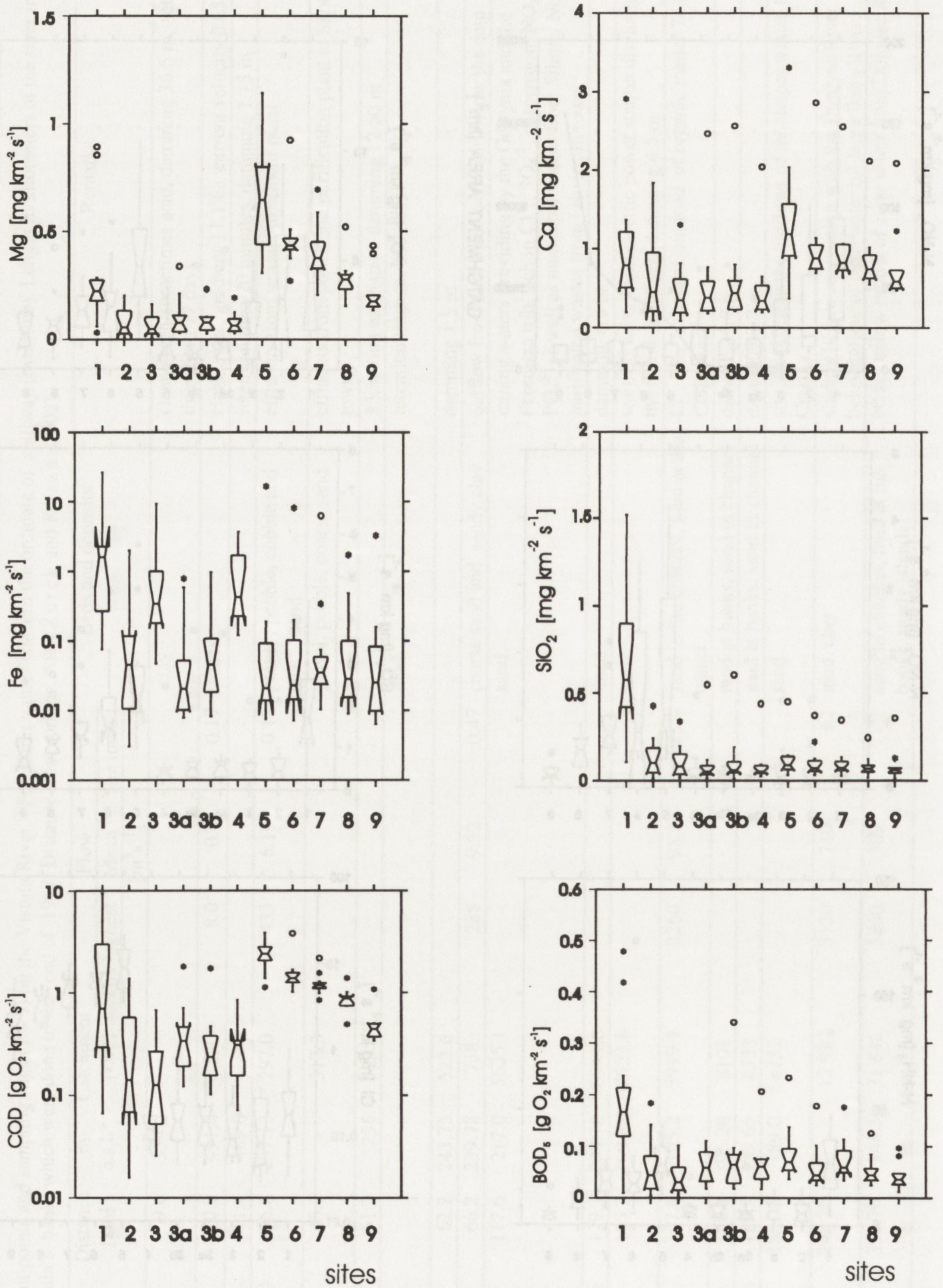

Fig. 7. Areal runoff of some cations, SiO_2, COD, BOD_5. Sites and meaning of asterisks and empty circles as on Fig. 5.

basin. The increase in Ca concentration at the last site (Kasza and Galas 2002) is caused by left side tributaries draining local catchment area of Jurassic origin rich in limestones and loesses.

As it was shown in particular papers (Bednarz 2002, Bucka 2002, Dumnicka 2002, Kasza and Galas 2002, Kasza and Wojtan 2002, Kwandrans 2002, Starzecka 2002, Starzecka and Bednarz 2002, Żurek 2002) water quality of the Upper Vistula River seems to be usually better downstream. This is an effect of both selfpurification and dilution of polluted water by much purer water of tributaries in which the loading of the river could be much higher. Some parts of organic matter of waste origin are transformed into CO_2, organic nitrogen into free nitrogen and other compounds are, e.g. precipitated and deposited on riverine terraces in the middle part of the river together with muds, sands etc.

It seems that statement of increasing or decreasing pollution level of the river should take into account also the loadings (Fig. 8). Chlorides can be a good marker of loadings. They are not included in living tissues of organisms in large amounts and not transformed, e.g. as nitrogen compounds. So, concentration of this marker diminished downstream the Vistula River from sites 5 to 9. Load of chlorides is constant on this sector.

$N\text{-}NO_3$ follows other pattern. Its concentrations and load rose downstream, from the Przemsza River outlet to site 9. Second important biogenic anion, phosphate showed a tendency to decline its concentration, whereas load after plateau between sites 5 and 8 increased at site 9.

Chemical oxygen demand (COD) also decreased downstream since site 5, whereas loads indicated tendency to increase (Fig. 8).

In the upper part of the Vistula River, the water was of bicarbonate-calcareous type and chloride-sodic type below inflow of the Gostynia and the Przemsza rivers.

The electrolytic conductivity of water fluctuated from 35.7 μS cm^{-1} at site 1 to 4298 μS cm^{-1} at site 5. In mountain part of the Vistula, where the river was exposed only to slight loadings of sewage, the sum of ammonia and nitrates contents was small (1 mg N dm^{-3}). At site 5 the amount of mineral nitrogen increased to 3 mg N dm^{-3}, due to pollution's inflow from the Silesia region and Oświęcim town, and was crucial there (amounting to 80% of mineral nitrogen). Below site 8, a more distinct decrease in nitrogen concentration was noted. Similar changes in phosphate concentrations as in the case of mineral nitrogen content were found.

At the onset course of the Vistula River to the Goczałkowice Reservoir, the content of organic compounds in the water (both easily degradable and refractory ones) was small. Starting from site 5 (Oświęcim), biochemical (BOD_5) and chemical oxygen demand (COD) and also oxidability and the loss after ignition, pointed to considerably higher amounts of organic compounds in the water. These high values were maintained along the further course of the river, however their value gradually decreased.

The contamination of the Vistula River by heavy metals was connected with the industrial waters and was of anthropogenic character. The concentrations of metals were variable with the maximal values: Pb – 50.0, Cu – 35.2, Zn – 564, Cd. – 8.36, Mn – 633 and Fe 7100 μg dm^{-3} of water. Taking into account high hardness, pH and amount of organic matter, concentrations of these heavy metals are not toxic for hydrobionts.

The water balance of the river has been disturbed. Some volumes of water are taken out from the Goczałkowice dam reservoir and transferred to Silesia. Similarly water from the right side tributary (Soła River) is also transferred to Silesia. This water strongly loaded with sewages comes back to the Vistula by Przemsza River. Participation of the inflow of Przemsza which fed the Vistula attains 91% (Punzet 1991).

3. EXTREMAL EVENTS

During our research period, i.e. from 3rd March 1996 to 4th March 1997, between 7–20 of July 1997, an impetuous flood in the Vistula took place. Flows, which usually in Cracow amount to 50–100 m^3 s^{-1} increased up to 1430 m^3 s^{-1} and during culmination, up to 2400 m^3 s^{-1}. Changes of flow in one year period of investigations are shown on Fig. 9. For making this drawing we used our data and that of Barczyk *et al.*, 1999. Volume of the flood in Cracow crossection had 894 × 10^6 m^3 (Barczyk *et al.* 1999). Concentration of suspension measured in the day of culmination gave value 1.5 kg of dry weight in m^3, (Mazurkiewicz and Żurek 1999). It al-

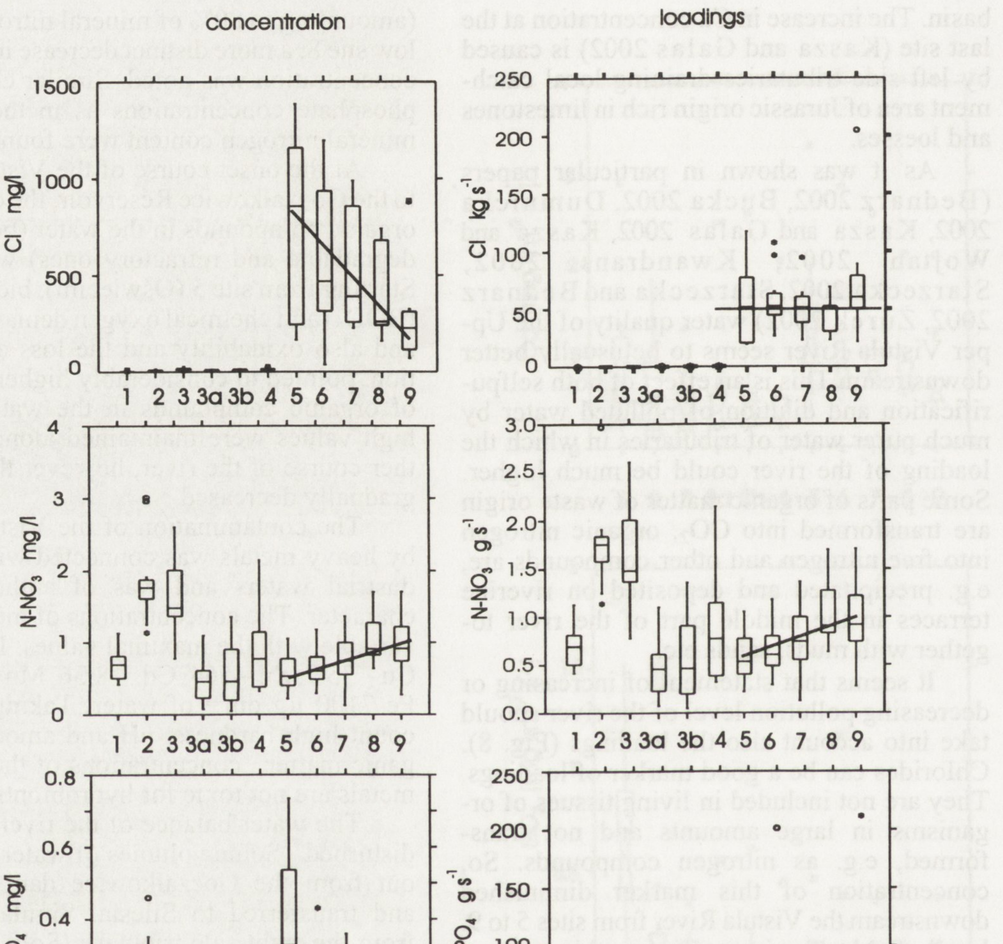

Fig. 8. Concentrations and loadings of some compounds along the river. Sites and meaning of asterisks and empty circles as on Fig. 5. Continuous line overleyed on boxes indicate the trends of changes.

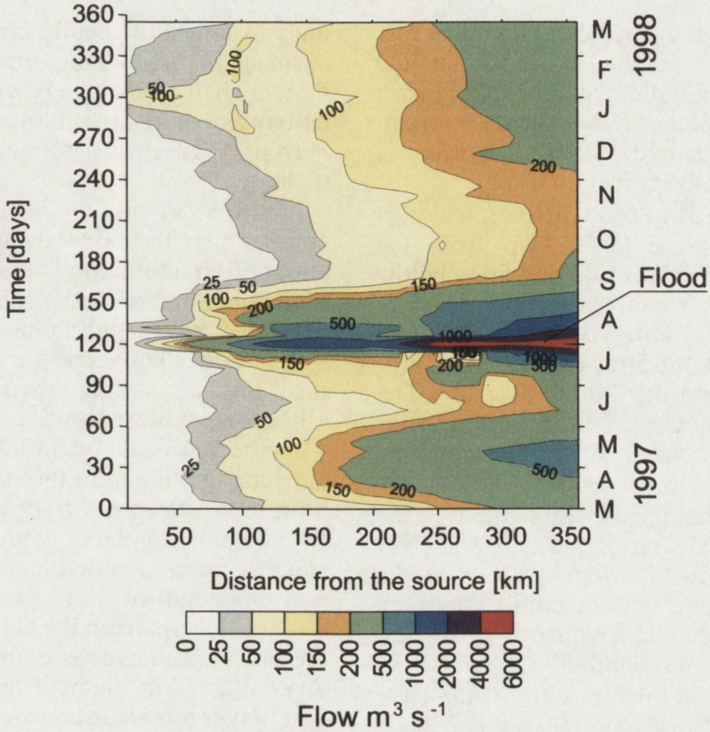

Fig. 9. Spatial temporary sketch of flows in Vistula. In July 1997 flood wave is visible.

low to estimate the dry mass of suspended fraction on 1 340 000 Mg.

The flood strongly but for a short time changed the structure of assemblages of fauna and algae.

4. DESCRIPTION OF SITES

In Table 1 the detailed location of examined sites is given. Scheme of location of sites and of more important inflows is presented on Figs 2 and 3.

Site 1. The Vistula River 1 km below the Wisła Czarne dam, 10. 9 km from springs of the Czarna Vistula (Black Vistula). Altitude about 500 m above sea level. Stream has a width of 5–10 m, depth 10–20 cm. Banks are grown with high trees shading bottom of the stream. Bottom is stony – diameter of stones 10–40 cm. Rapid current is equalized by dam reservoir situated above, usually to a value of 0.260 m^3 s^{-1}. At normal level of damming the retention time of waters in the reservoir is 29 days, whereas at flood level of damming it grows up to 77 days (Olszanowski 1995).

Age of waters, as a time needed to reach the x site from the springs, at site 1, below the dam fluctuates from 2 hours (at empty reservoir) up to 29–77 days, (when the reservoir is filled). Mentioned reservoir was being repaired and periodically emptied in the period of our investigations. Until March 12, 1997 reservoir was emptied due to the repairs of the dam. From 7 May to 7 July the reservoir was empty. As a result of flood between 7–23 of July, reservoir rapidly filled again and quickly became empty. It remained in this state until mid-November. Between mid-November and mid-February 1998, the reservoir was full (Fig. 1). Last emptyfying continue one and half year untill end of repair in November 1999. From this time the reservoir is filled. Between site 1 and 2, the stream possesses bars correction every 100 to 200 m.

Site 2. Vistula below Skoczów town, on 36.60 km of the river course. The whole section between sites 2 and 3 has bars correction every 200–500 m. Current is quick, bottom stony-gravel, stones of 2 –10 cm in diameter. Bottom niches are sunny, river bed notched 5–10 m below the valley, width 30–40 m, depth 15–50 cm. Banks grown with willows and other trees, which every few years are cut as a preventive measure against flood.

Site 3. Vistula in village Drogomyśl at road-bridge on 45.7 km of the river course.

Before inflow to the Goczałkowicki dam reservoir, the river is notched about 10 m below the bottom of the valley, steep banks grown with shrubs, which do not shade current, width of the river bed 30–40 m. Current is slow, bottom sandy-gravel.

Site 3a and 3b. For hydrochemical purposes samples were taken also from the Goczałkowice reservoir (3a) and 50 m below the bottom sluice from the reservoir (3b). The reservoir is 12 km long, 3–4 km wide with average depth about 5 m, capacity 150 million m^3, retention time 200 to 300 days.The dam was constructed in 1956 year on 61.2 km of the river course. Site 3b has concrete banks.

Site 4. Vistula 5 km below the Goczałkowice dam on 66.2 km of the river course, near railway bridge. Width of the river bed 20–30 m, bottom sandy gravel, in places clayey, steep banks, grown with trees, mostly with willows, depth 30–70 cm.

Site 5. Vistula on 115.6 km of the river course, near road-bridge in Jankowice village about 100 m above outlet of the river Skawa to the Vistula. Width of the river bed 50–100 m, quick current, bottom sandy, depth 50 to 200 cm. River incised about 3 m below floodplain. In a few metres distance from the rivers terrestrial embankment strengthened by stone-band was built. On this section intensive regulating works for improving shipping conditions are conducted.

Site 6. Vistula on 165.2 km of the river course in the zone of damming by "Dąbie" dam (on 168.8 km). This site was situated in the centre of Cracow, opposite to Wawel castle. Width of the river bed ca. 100 m, current moderately quick, bottom sandy, regulated with boulevards, depth 0–5 m. Flooded by damming terrace has silty-sandy bottom, grown in summer by *Potamogeton pectinatus*. From this site down the river, shortening of the river length due to clearance of some meanders was taken into account in a present study. Therefore from this site our measurements are in disagreement with still valid, official, but old ones.

Site 7. In village Przylasek Rusiecki, on 185.2 km of the river course, 5 km below the dam "Przewóz". The site remains under the influence of higher situated cascade buildings of the Vistula and of outflows of sewage from Cracow's – purification plant and from the Steel Factory in Nowa Huta. Width of the river bed ca. 50–80 m, current quick, transparency usually little ca. 30 cm, a lot of organic suspensions. River incised in floodplain ca. 5–6 m, banks are steep with the terrestrial embankment in ca. 100 m. distance from the current. Treeless terrace grown with meadow.

Site 8. Vistula on 248.2 km of the river course, near the ferry at Opatowiec village, about 50 m above the Dunajec outlet. Width of the river bed ca. 100 m, depth 2–3 m, banks regulated with band stone and with stone – spurs. Zones between spurs silted. River terrace low ca. 1–2 m above water level, usually grown with willows.

Site 9. Vistula on 336.7 km of its course, at Machów village in the vicinity of a road-bridge. Width of the river bed about 300 m. Right bank regulated with spurs and with stone – bands. Eroded bank with quick current has depth of more than 2 m. There are sandy shallows from the center of the river to the left bank. River is embanked by a earth levee situated in 300 m distance from the current. River terrace is a meadow, sporadically grown with osier.

5. SUMMARY

Investigations were carried out in the period between 3rd March 1997 and March 4th 1998 on the first 337 km sector of the Vistula River. All samples both for chemical and biological analyses were collected in the one month intervals. Localisation of the sampling sites is given on Figs 1, 2 and 3. At 9.6 and 62.2 km river has two dam reservoirs. 1 km below of each of them are small river bars. Between 95 km and Cracow is 4 overflow dams (Fig. 2). Drainage area at last site (9) has 31 846 km^2. Mean flow varied from 1 m^3 s^{-1} at site 1 on 10.9 km to 309 m^3 s^{-1} at site 9 on 336.7 km (Table 1). In the investigation period, in the days from 7th to 15th of July 1997 disastrous flood in the Vistula occurred. Flows, which usually in Cracow provide 50 to 100 m^3 s^{-1}, grew up to 1430 m^3 s^{-1} and during the culmination of wave up to 2400 m^3 s^{-1}, Fig. 9. Estimated dry mass of suspended fraction transported in the time of the flood at Cracow cros-section amounted 1 340 000 Mg.

Natural background of chlorides concentration 130 years ago in the Vistula amounted 5 to 6 mg Cl$^-$ l^{-1}. Since 70's chloride concentrations rapidly raised to about 1000 mg l^{-1} in Cracow profile, Fig.4. In the upper part of the Vistula River, the water was of bicarbonate-calcareous type and chloride-sodic type below inflow of the Gostynia and the Przemsza rivers. Chlorides and other pollutants are discharged by Gostynia and Przemsza rivers (on 89.3 and 95.1 km)

as well as by Oświęcim and Cracow towns (Fig. 2). Cracow discharges down municipal sewages and other pollutants from metallurgic, energy, machine and chemical industry, until 1999 in <1% purified in biological process. Since 1999 this value grew up to 12%.

Unit runoff from the drainage basin has the highest value (ca. 80 dm^3 km^{-2} s^{-1}) in the mountainous region, whereas at lowland sites diminished to 10–20 dm^3 km^{-2} s^{-1}. Range of fluctuations diminishes together with the increase in the catchment area (Fig. 5).

Unit runoff of six main anions outflowing from the catchment area is shown on Fig. 6. Two recurrence sequences of runoff coefficients from site 1 to 4 and from 5 to 9 are visible. These sequences concern phosphates, sulphates, chlorides, nitrite and ammonia but not nitrate. This last nitrogen form has a constant runoff coefficient from site 3a (the Goczałkowice dam reservoir) to site 9.

Runoff coefficients were calculated for calcium, magnesium, iron and other parameters (Fig. 7). Their values show a similar pattern downstream the river as anions.

In our opinion for estimating the progress in the selfpurification, important is estimation of both concentrations and loading of elements. Such comparison is presented on Fig. 8. Chlorides can be a good marker of loadings. They are not included in living tissues of organisms in large amounts and not transformed, e.g. as nitrogen compounds. So, concentration of this marker diminished downstream the Vistula River from sites 5 to 9 whereas the load remains constant. Decline of concentration there was not caused on selfpurification way but by dilution. Other examples are shown on this figure.

Detailed characteristics of sites, tributaries, soils and main geological formations was discussed (Table 1).

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