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The management of the catchment area of the Goczałkowice reservoir and its effect on the amount of nitrogen and phosphorus migration from it

Wpływ zagospodarowania zlewni zbiornika goczałkowickiego na wielkość migracji z niej azotu i fosforu*

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Abstract — Combining the run-off per unit of nitrogen or phosphorus from particular partial catchment areas of the tributaries of the Goczałkowice reservoir, or the mean content of these compounds in the waters of the rivers analysed, with the chosen elements of the catchment area management (percentage of arable land in the catchment area, percentage of green areas in the catchment area, percentage of woods in the catchment area, the content of N or P in human faeci, the content of N or P in mineral and organic fertilizers of animal origin) an attempt was made to show the degree of the influence of economic activity of man on the migration of biogenous compounds from the subsoil of the catchment area of the reservoir.

The Goczałkowice reservoir is the main water body of drinking water for the largest municipal-industrial agglomeration in Poland, i.e. the Upper Silesian Industrial District. Investigations carried out for three years on the properties of the waters of the reservoir (K a s z a 1979) have permitted to classify these waters, roughly, to the Ist purity class. However, periodical deterioration of the quality of the water designed for drinking purposes has been found to occur in the reservoir. Basing upon the changes in the chemical index content in the upper layer of the wa-

* Pracą wykonana w problemie węzłowym 10.2.

ter and in that close to the bottom of the reservoir, the waters in the Goczałkowice reservoir were classified periodically to the IInd and IIIrd purity class according to the standards of permissible concentrations (Governemental Act of 29th November 1975 — Rozp. Rady Min., D.U. 29. XI. 1975). 4 cases were reported of oxygen concentration below the standard values, i.e. 4 mg O_2/dm^3.

The cause of water quality deterioration in the reservoir at Goczałkowice lies in an excessive inflow of nitrogen and phosphorus compounds into it from the catchment area (Kasza 1977, 1979).

In general, natural componential elements of the water, such as the basement soil and vegetation, as well as external factors: climate and human activity have a great share in the formation of chemical properties of the water. Man's activities influence, among other things, the agricultural character of the management of the catchment area.

In connection with the intensification of agriculture the soils are enriched with bigger and bigger doses of fertilizers, containing the same compounds which cause water eutrophization. The physico-chemical properties of these components of fertilizers determine, among other factors, the extent of their migration into surface waters.

Nitrogen compounds are eluted from soils mainly in the form of nitrates since this form of nitrogen is not retained by the absorption soil complex (Bückman, Brady 1971). In a 10-year investigation programme on the chemical composition of the water of the River Veltava in Czechoslovakia and of the dam reservoir at Slapy, 25 per cent of the applied fertilizers were found to be eluted in form of nitrates (Prochazková et al. 1973). Vollenweider (1968) finds that the loss of nitrogen by elution from the soil can reach 10 to 50 per cent, whereas elution of phosphorus is rather low since only 5 per cent of phosphorus used in fertilizer (Sprenger 1968, Vollenweider 1968) can undergo elution and erosion. Soluble phosphates, used in fertilizers are bonded in the soils by physico-chemical processes and therefore its migration in the soils is very slow (Margowski, Bartoszewicz 1976, Pasternak 1965).

According to Halliday (1972) nutrient salts originating from such agricultural treatments as fertilization constitue rather a small percentage in comparison with the biogenous elements flowing into the waters with various pollutions. As regards the agricultural activity of man, the greatest participation in the eutrophication of waters have the inflows of waste waters from animal mass breeding and fatterring farms. Municipal sewage, however, the main source of soluble forms of phosphorus, and various industrial waste waters (Pasternak 1976) are considered the main cause of surface water eutrophization.

In view of the occurrence of periodical water pollution in the Goczałkowice reservoir and of the processes previously presented it seems per-

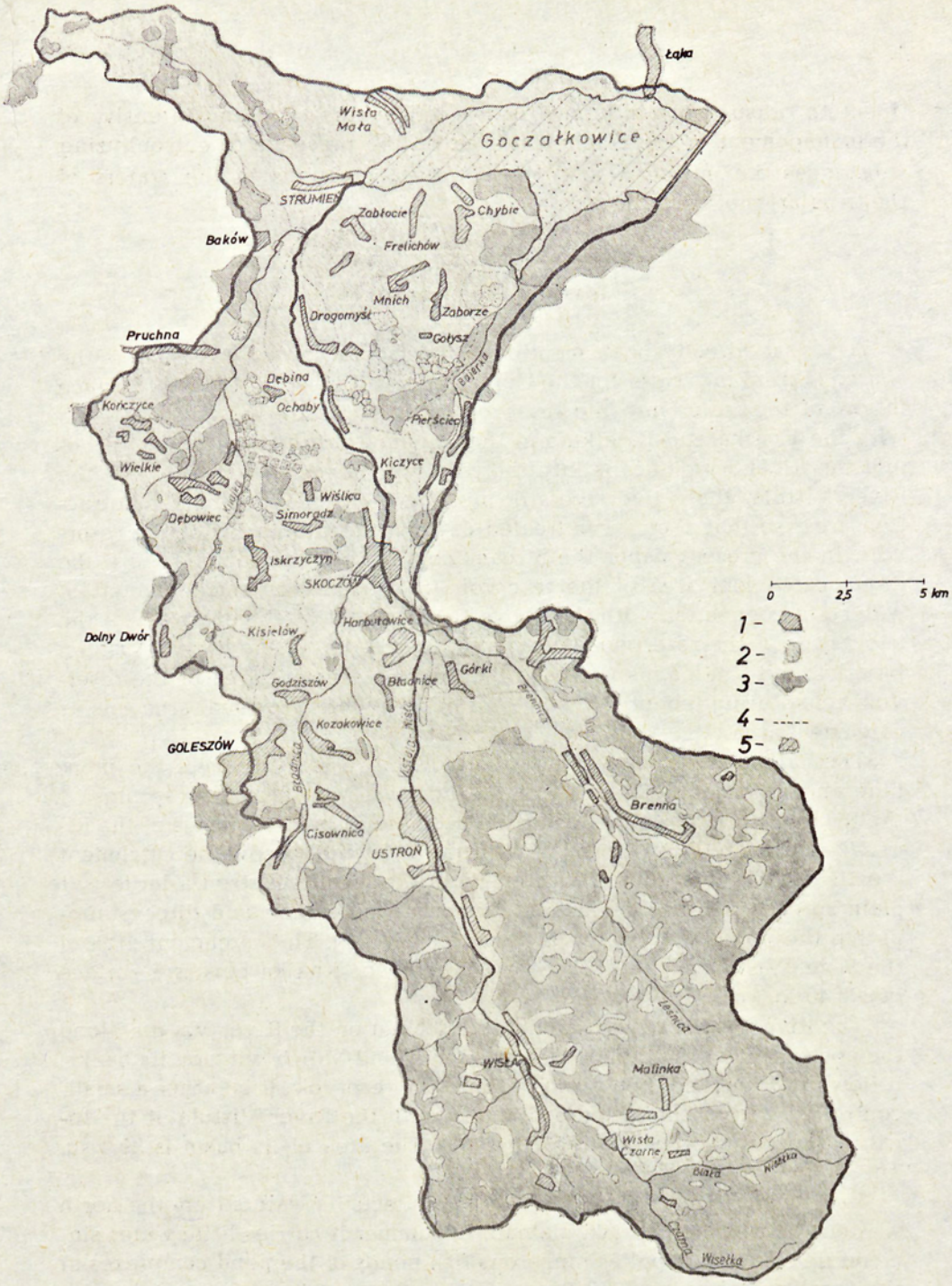

Fig. 1. Catchment area of the reservoir at Goczałkowice. 1 — towns and villages; 2 — waters; 3 — forests; 4 — limit of partial catchment areas; 5 — reservoir

Ryc. 1. Zlewnia zbiornika goczałkowickiego. 1 — miasta i osiedla; 2 — wody; 3 — lasy; 4 — granice zlewni cząstkowych; 5 — zbiornik

tinent to grasp, what influence is exerted by the type and intensity of the management of the catchment area on the presence of eutrophyzing substances, i.e. nitrogen and phosphorus compounds in the waters of the tributaries of the reservoir.

Investigation territory

As it has already been mentioned the Goczałkowice reservoir is the source of drinking water for the Upper Silesian Industrial District. Surface inflow of the water into the reservoir is provided by the rivers Vistula with the Knajka and Bajerka and the Stream Zbytkowski (fig. 1). Although the River Knajka falls into the reservoir in a common bed with the River Vistula, these two rivers do not merge until reaching the retraction area, so that they were treated as separate tributaries of the reservoir. In the present paper the Stream Zbytkowski was included into the direct catchment area of the reservoir (it carries very small amount of water). In connection with the above three partial catchment areas of the tributaries of the reservoir were distinguished, i.e. of the Rivers Vistula, Bajerka, and Knajka, as was also the direct catchment area of the reservoir constituting about 10 per cent of the total surface area of its catchment area.

The catchment area of the Goczałkowice reservoir covers the montane and submontane terrains of the Beskidy Mts. From the springs of the River Vistula up to the locality Ustroń and from the springs of the River Brennica up to the close vicinity of the town Skoczów the catchment area is of a mountainous character. From the locality Ustroń a large wet plain spreads rich in streams and numerous mill races, and ditches supplying the ponds with water (S t a r m a c h 1957). The catchment area of the River Vistula up to the mouth of the River Knajka covers a surface of 328.46 sq. km.

The River Bajerka flows along a vast plain on the River Vistula along the pond complexes at the localities Landek and Mnich lying on its banks. It flows 14.7 km, and then disgorges into the reservoir. It is rather a small, controlled stream connected artificially with the River Vistula at the locality Harbutowice (S o w a 1959, 1961). The area of its basin is 39.4 sq. km.

In its upper course the River Knajka collects its waters from the north western part of the Cieszyn plateau. In summer it carries little water since on its course it supplies numerous fish ponds of the pond complexes at the locality Dębowiec. The River Knajka flows across hilly terrains, intensively utilized for agricultural purposes with the exception of small wooded areas lying on the left bank of the river in its middle course. The surface area of the basin of the River Knajka is 81.30 sq. km.

Table I. Ground utilization structure in km^2 and in percentage in the catchment area of the reservoir at Goczałkowice

Tabela I. Struktura użytkowania gruntów w km^2 i w procentach w zlewni zbiornika goczałkowickiego

Catchment area Zlewnia Rivers - Rzeki	Total area Powierzchnia ogólna		Grounds - Użytki rolne										Forests Lasy		Others Pozostałe	
			total - ogółem		arable lands and orchards grunty orne i sady		meadows - łąki		pastures - pastwiska		ponds - stawy					
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Direct of the reservoir Bezpośrednia zbiornika	50.84	100.00	39.02	76.75	24.85	48.88	4.69	9.22	5.22	10.27	4.26	8.38	6.68	13.14	5.14	10.11
Vistula - Wisła	328.46	100.00	119.52	36.39	69.30	21.10	17.53	5.34	32.69	9.95	-	-	167.59	51.02	41.35	12.59
Knajka	81.30	100.00	60.30	74.17	39.33	48.38	5.82	7.15	11.68	14.37	3.47	4.27	9.73	11.97	11.27	13.86
Bajerka	39.40	100.00	13.43	34.09	8.14	20.66	2.37	6.02	2.36	5.99	0.56	1.42	17.40	44.16	8.57	21.75
Total - Całkowita	500.00	100.00	232.27	46.45	141.62	28.32	30.41	6.08	51.95	10.39	8.29	1.66	201.40	40.28	66.33	13.27

The structure of ground utilization is presented in Table I. Forests occur in the territory of the catchment area on large surfaces (fig. 1). They lie above all in the mountainous terrains covering about 90 per cent of their area. The plateau, on the other hand, is only slightly wooded. In that part the forests grow on steeper slopes and gorges, and are scattered among arable land in small bits over the whole plateau. In the low-land terrains arable land prevails. Forests cover larger areas only between localities Piersciec and Zabrzeg, concentrating in the region of the course of the River Bajerka and on the left bank of the River Knajka (P a s t e r n a k 1962).

The human population of the territory of the catchment area of the tributaries of the reservoir is above 75 thousand. It increases in the summer and winter seasons with the inflow of tourists and holiday-makers (c. 50 thousand too at the same time in the mountain region) (J a n u s z 1974).

Apart from the mountainous terrain the catchment area of the reservoir is densely populated. In the mountain valleys the villages are situated along the rivers and domestic and farm waste waters are discharged in the shortest way directly into the river or are collected in closed sedimentation tanks wherefrom they are carries away onto the neighbouring arable land.

In the upper sector of the catchment area there is lying the holiday resort Wisła, and the health resort Ustroń where radioactive, ferruginous waters and therapeutic mud are used for treatment purposes. In the upper sector of the valley of the River Brennica, Brenna, another holiday resort is situated, densely inhabited and visited in the summer season.

On a vast plain between the towns of Skoczów and Strumień there are various villages and settlements. Their domestic sewage is discharged directly into numerous ditches and flows. In the localities situated higher up intensive agricultural cultivation prevails, while in the lower ones, on the other hand, meadows and fish ponds dominate.

In animal husbandry cattle and pig breeding prevail. The number of these animals varies from 66.4 to 95.9 and 53.3 to 101.3 specimens/100 ha of arable land respectively. Apart from it, sheep and horses are also bred. Mineral fertilization is not intensive. Nevertheless, in 1975 additional fertilizers were used in the average amount of 115.1 NPK kg/ha of arable land, where the ratio N : P : K was 1.3 : 0.8 : 1.2. The use of fertilizers in the analysed region varied within the range 73.0 to 140.0 NPK kg/ha.

In the crops structure, corn and fodder crops constitute about 49 per cent and 25 per cent respectively (G o r g o s z 1973).

In an analysis of the partial catchment areas of the particular tributaries of the Goczałkowice reservoir it should be stressed that these terrains are mainly influenced by tourism and forest economy, whereas in the other part of the catchment area, mostly by agriculture.

The territory of the catchment area of the River Knajka is most intensively utilized for agriculture. Apart from the horse stud at the locality Pruchna there are great pig farms on industrial scale. The number of cattle is also higher than the average for the whole catchment area of the Goczałkowice reservoir. A wet inundation terrace on which some complexes of artificial fish ponds are grouped between the localities Dolny Dwór and Dębowiec is a characteristic feature of the catchment area of the River Knajka. The River Knajka dewaters a vast complex of ponds at the foot of the elevation of the terrace between the towns Wiślica and Dębina.

The catchment area of the River Bajerka in its upper part includes arable land. Similarly as in the catchment area of the Vistula, in this region too, the main branch of agricultural production is cattle and pigs breeding. The other territories of the catchment area are covered with woods. The River Bajerka which flows along the pond complexes at the locality Mnich, covering the area of 56.5 ha, carries away their waters into the reservoir at Goczałkowice.

The direct catchment area of the reservoir is similar as to the character of the management and soil utilization structure to that of the catchment area of the River Knajka (Table I) since 75 per cent of the soils of these two catchment areas are arable land. On the right bank of the river there is also a plain rich in streams, with numerous mill-races and ditches which water the ponds since fish economy is run on an area of 426 ha.

Methods

The amount of the surface run-off of mineral nitrogen and phosphorus was obtained from the works carried out in the years 1973 to 1975 (Kasza 1979). The materials concerning the management of the catchment area were obtained mainly from the local administration of the particular communities lying inside the catchment area of the reservoir.

To calculate the components of animal manure and of human excrements in the whole territory of the catchment area recalculation coefficients elaborated by Müller (1955, quoted after Vollenweider 1968) were applied.

Since the stock of animals given by the local authorities listed only physical specimens without considering the structure of the herd and its displacements, recalculation coefficients were applied with regard to N and P for cattle and pigs, 0.75 and 0.33 respectively, in order to obtain more reliable data.

It was assumed for calculations that a man excretes per day 10.8 g N and 2.18 g P (Vollenweider 1968). Since the territories of the

catchment area of the River Knajka is most intensively utilized for agri-making traffic, 50 thousand holiday-makers (J a n u s z 1974) staying there for a period of 150 days in a year were added.

Investigations results and discussion

Taking into regard the sizes of particular catchment areas of the investigated rivers, the run-off of biogenous substances per unit, established for the mean annual cycle was presented in Table II. The partial catchment areas of the reservoir at Goczałkowice can be included, as concerns the „export" of phosphorus, to mezotrophic areas (V o l l e n w e i d e r 1968). On the other hand, the run-off of mineral nitrogen with the waters of the Rivers Bajerka and Knajka are within the limits adopted for oligotrophic catchment areas.

Table II. The annual mean run-off of nutrient compounds from the catchment area of the investigated rivers

Tabela II. Średnioroczny spływ substancji pokarmowych ze zlewni badanych rzek

Matter - Substancja	Rivers - Rzeki		
	Vistula Wisła	Bajerka	Knajka
Mineral nitrogen Azot mineralny - N g/m^2 . year rok	1.173	0.484	0.182
Total phosphorus Fosfor ogólny - P g/m^2 . year rok	0.031	0.032	0.022
Phosphates Fosforany - $P-PO_4$ g/m^2 . year rok	0.012	0.009	0.011

The content of nitrogen and phosphorus in human and animal faeci and in the mineral fertilizers applied in this territory for agricultural purposes is illustrated in Table III. The data in that table confirm the fact that the catchment area of the River Knajka is most intensively utilized for agricultural economy since the production of nitrogen and phosphorus contained in organic manure of animal origin and the doses of mineral fertilizers are markedly higher there than in the direct catchment areas of the Rivers Vistula and Bajerka.

Combining the run-off per unit of nitrogen and phosphorus from particular catchment areas or the mean content of these compounds in the waters of the analysed rivers with the chosen elements of the catchment area management equation sets were set forth, to show the degree of the influence of the economical activity of men on the migration of biogenous compounds. A multiple regression equation of the following type was applied:

Table III. Approximate doses and potential production of nitrogen and phosphorus in g/m^2 in the catchment area of the investigated rivers

Tabela III. Przybliżone dawki i potencjalna produkcja azotu i fosforu w g/m^2 w zlewni badanych rzek

Catchment area of the rivers Zlewnia rzek	Mineral fertilizers Nawozy mineralne		Organic fertilizers Nawozy organiczne		Human feeci Fekalia ludzkie		Total load Całkowity ładunek	
	N	P	N	P	N	P	N	P
Vistula Wisła	2.074	0.557	1.961	0.260	0.689	0.164	4.724	0.981
Bajerka	1.930	0.518	2.170	0.292	0.692	0.140	4.792	0.950
Knajka	4.539	1.218	3.995	0.522	0.517	0.104	9.051	1.844

$$y = ax_1 + + bx_2 + cx_3 + dx_4 + ex_5 \quad (1)$$

where:

y — N, P run-off per unit in $g/m^2 \cdot$ year or concentration in mg/dcm^3,
x_1 — per cent of arable land in the catchment area,
x_2 — per cent of green areas in the catchment area,
x_3 — per cent of woods in the catchment area,
x_4 — content of N and P in faeces ($g/m^2 \cdot$ year),
x_5 — content of N and P in mineral fertilizers and organic manure,
a, b, c, d, e — regression coefficients.

The applied method did not show the expected regularity, i.e. the relation $y = f(x_1 \ldots x_2)$ since the multiple correlation coefficients and regression coefficients, with the exception of c — per cent of woods, proved insignificant.

A marked influence of the woods on the concentration of mineral nitrogen, nitrates, and phosphates, and total phosphorus in the waters was recorded, as shown in fig. 2. It should be added that the abscissa shows the percentage of grounds in the catchment area, woods ecluded. Also in the regression equations given in these illustrations the independent variable x assumes the percentage value of the area free of wooded terrains.

It was, thus, found that a greater participation of woods in the catchment areas of the investigated rivers causes a higher concentration of mineral forms of nitrogen in their waters. To say it in other words — smaller amounts of nitrates and other forms of mineral nitrogen run-off with the waters flowing down from green areas, arable land, and grounds situated in the vicinity of farm buildings and towns than from woodland.

The above observation is apparently inconsistent with the investigation results published by some authors who, not only in lysimetric investigations (Hedlin 1971) and in ground waters analysis (Margowski, Bartoszewicz 1976) but also by the method of comparing the waters of the rivers flowing across territories of a typical agricultural character with the waters of streams crossing territories with markes

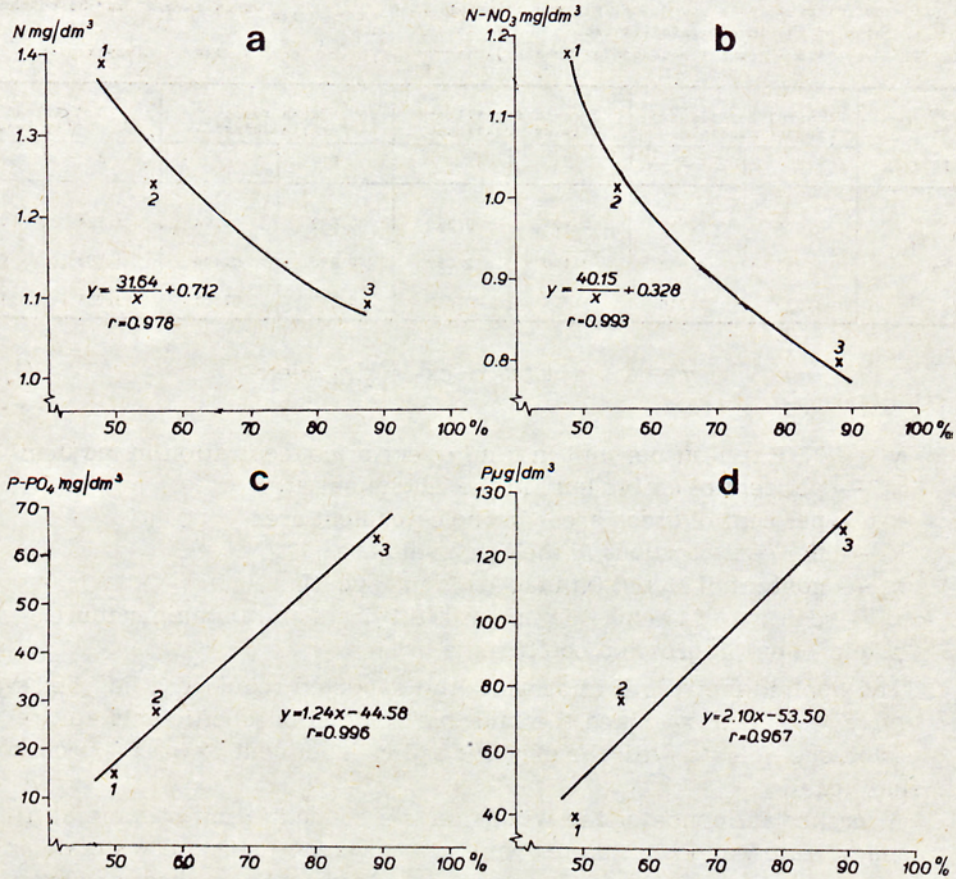

Fig. 2. Dependence of the concentration of: a — mineral nitrogen; b — nitrates; c — phosphates; d — total phosphorus in the tributaries of the reservoir at Goczałkowice on the catchment area utilization structure (woodless terrains). Rivers: 1 — Vistula; 2 — Bajerka; 3 — Knajka

Ryc. 2. Zależność stężeń: a — azotu mineralnego; b — azotanów; c — fosforanów; d — fosforu ogólnego w dopływach zbiornika goczałkowickiego od struktury użytkowania zlewni (obszar bez lasów). Rzeki: 1 — Wisła; 2 — Bajerka; 3 — Knajka

prevalence of woods (J a a g 1972), find that the highest amounts of nitrogen content are eluted by the waters flowing down from arable land.

There are, however, data in literature based upon lysimetric investigations (H ö l l 1963) which point to a high content of nitrates in the waters flowing out from woods. H ö l l found that the content of nitrates in the waters flowing down oak and birch woods reaches 550 NO_3 mg/dm³, whereas the mean content of nitrates in the waters flowing down from pine woods was, according to that author, 80.7 NO_3 mg/dm³. The quoted data are a few score to several hundred times higher than the

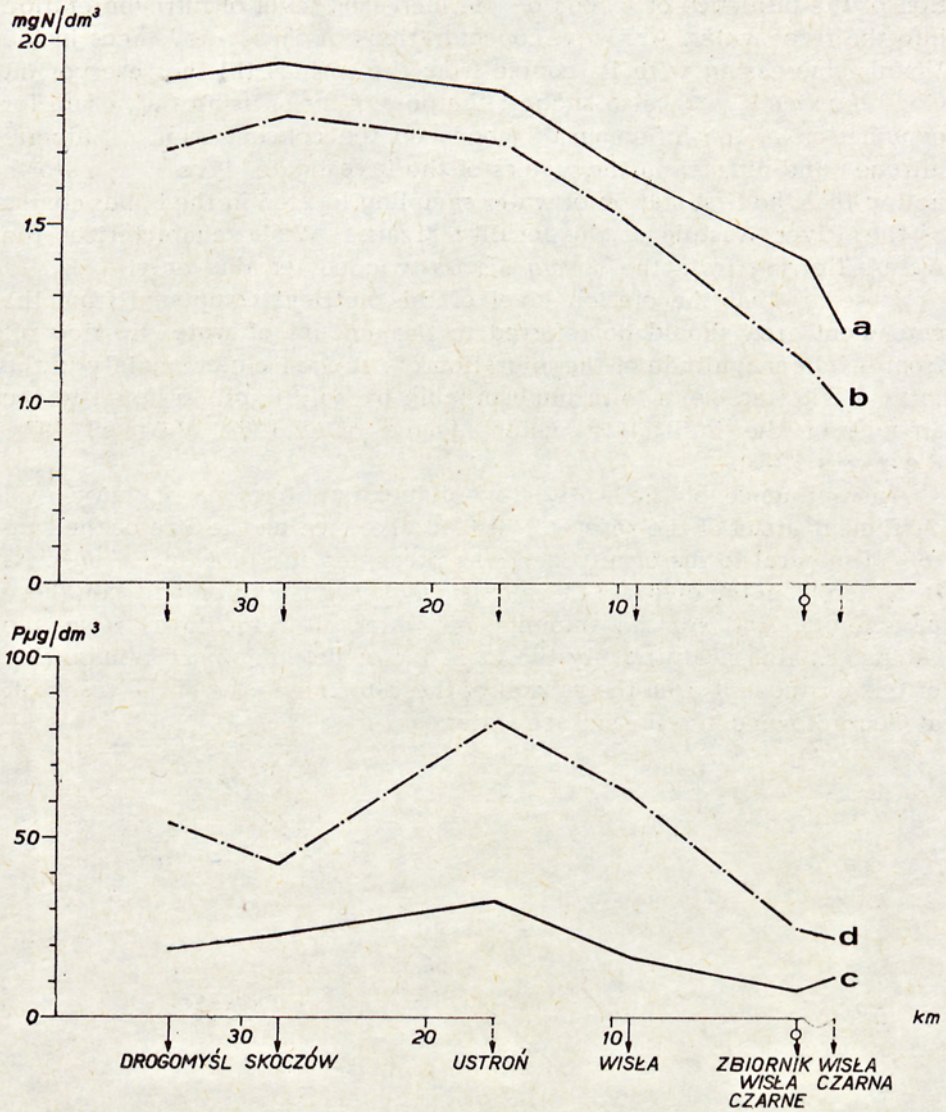

Fig. 3. Mean concentration of: a — mineral nitrogen; b — nitrates; c — phosphates; d — total phosphorus for 1976—1977 along the course of the River Vistula up to the reservoir at Goczałkowice

Ryc. 3. Średnie stężenie: a — azotu mineralnego; b — azotanów; c — fosforanów; d — fosforu ogólnego z lat 1976—1977 z biegiem Wisły po zbiornik goczałkowicki

concentrations of nitrates in the Rivers Vistula (0.40 to 9.96 NO_3 mg/dm³), Bajerka (0.58 to 16.25 NO_3 mg/dm³), and in the Knajka (0.58 to 17.84 NO_3 mg/dm³); hence these data could not be used directly for the elucida-

tion of the influence of woods on the increased level of nitrogen elution into the river water. Anyway, concentrations of these substances in the Vistula, increasing with its course from the springs till the reservoir at Goczałkowice (fig. 3), also suggest the possibility of using these data for explanation of the influence of woods on the concentration of mineral nitrogen and nitrates in the waters of the investigated rivers. It is worth noting that the first station of water sampling located in the upper course of the River Vistula at the locality Czarna Wisła characterizes the waters flowing from the spring across wooded terrains only.

It seems that the elution level of this nutrient compound from the catchment area should be referred to the amount of water flowing off from it. The magnitude of the migration of nitrogen eluted, mainly in the form of nitrates, i.e. a form unabsorbable by soil, is proportional to the amount of the infiltrating water (Jung et al. 1969, Vömel 1974, Reeves 1975).

The influence of the water flow-off per unit from particular partial catchment areas of the reservoir at Goczałkowice on the size of the run-off of mineral forms of nitrogen was presented in fig. 4 (in l/s/km²). As it is seen from the diagram there exists a close correlation between these parameters. And so, the amounts of water flowing down from the catchment area are probably the main factor determining the migration of this component from the subsoil of the catchment area of the reservoir at Goczałkowice into the surface water.

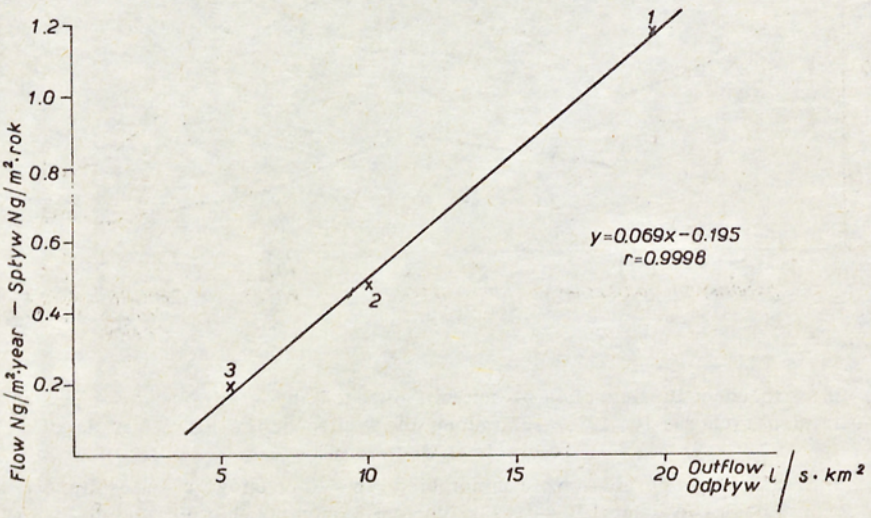

Fig. 4. Mineral nitrogen run-off from the catchment area of the tributaries of the reservoir at Goczałkowice in dependence of the annual mean of water flow-off

Ryc. 4. Spływ azotu mineralnego ze zlewni dopływów zbiornika goczałkowickiego w zależności od średniorocznego odpływu wody

As it results from the considerations on the influence of the management of the catchment area on the level of nitrogen elution, there is no correlation between the intensity of soil fertilization in the catchment area with mineral fertilizers and concentration of that component in the flowing-off waters. The results of the investigations this subject are controversial. Some researches (Prohazková et al. 1973) have found a great correlation to exist between the content of nitrates and total nitrogen in the water of the reservoir; whereas Tomlison (after Halliday 1972) who in the years 1953 to 1967 in 17 rivers in England investigated the relations between the content of nitrates and the amount of the applied nitrogen fertilizers did not find any correlation between these relation independent of a controlled marked increase in the doses of nitrogen fertilizers. Finally he came to the conclusion that the major part of nitrogen present in the water originated from large, soil resources of that component, while the nutrient salts originating from agricultural treatments in form of fertilization constituted a small per cent of it.

When balancing the run-off of nitrogen from the catchment area, reference should be also made to the binding of N_2 from the atmosphere, denitrification, and a number of factors influencing the elution level of this element, and not considered in the investigation method. These include: the day on which fertilizers are sown, mechanical soil composition, the amount and distribution of rainfalls in the catchment area, etc. (Halliday 1972, Jung 1972, Margowski, Bartoszewicz 1976).

In considering the question of phosphorus elution from the soils, a negative influence of forests on the concentration value of the phosphates and total phosphorus in flowing waters has been found (fig. 2c, d). In other words, the more wooded areas there are in the territory of the catchment area, the poorer in that component are the waters of the streams which flow across the wooded terrains. The above observation confirms the results recorded by other authors (Taylor et al. 1971, Jaag 1972, Kilmer 1972, Ventz 1972, Dillon, Kirchner 1975).

It has been simultaneously shown that more phosphorus compounds migrate into flowing waters from agriculturally utilized soils, from grounds located in the vicinity of farm buildings than from wooded terrains.

The analysis of the influence of phosphorus fertilization of the territory of the catchment area on the magnitude of its elution showed lack of any correlation between these parameters. Besides, this is corroborated by the results of a number of authors (Kilmer 1972, Kolenbrander 1972, Margowski, Bartoszewicz 1976). Kilmer finds that phosphorus fertilization seems not to be correlated to the increase in phosphorus content in inland waters. But, according to him it contri-

butes to the improvement of the pollution state of waters, since it stimulates the growth of plants, and thus reduces erosion. Harmeson and Larson — after Olson (1972) quote that since 1962 the phosphate concentration has remained unchanged in the River Kaskaskia, though the amounts of phosphate fertilizers applied in its catchment area have increased 3 times. There arises the question where increased phosphate and total phosphorus content comes from in the main tributary of the reservoir at Goczałkowice, the Vistula (fig. 3) growing with its course.

Among other authors Taylor (1967) and Nelson (1971) after Klingebiel (1972) find that phosphorus is eluted from soils at a very small degree, except of sandy soils. The losses of that component are caused mainly by erosion, since the phosphorus brought into the soil with mineral fertilizers is already after some hours transformed into a hardly soluble form of iron, aluminium, and calcium compounds.

Adopting the opinion of a number of authors after Vollenweider (1968) and Jaag (1972) who find that generally municipal sewage is the main source of phosphorus, the quantitative differences in the content of that component in the investigated rivers should be associated with the population density in their catchment areas.

The number of population living in that part of the catchment area of the Rivers Vistula, Bajerka, and Knajka are 174.9; 175.8; and 131.2 heads/sq. km respectively.

It was indeed shown in these investigations that the annual run-off of total phosphorus from the particular partial catchment areas of the tributaries of the reservoir is correlated with the population density. This correlation can be expressed with the equation of the type:

$$y = 0.216\,x - 6.4 \qquad (2)$$

where:

y — run-off per unit of total P mg/m² · year,

x — number of inhabitants/sq. km.

A high correlation coefficient, for this equation $r = 0.998$, proves a high run-off of phosphorus from the territories of the partial catchment areas with the density of their population and, in this connection, with the potential possibilities of municipal sewage production.

The proof presented in the equation No. 2 which indicates to the relation between total phosphorus present in the waters of the investigated rivers and domestic sewage permits to determine the percentage participation of municipal pollutions in the total inflow of phosphorus into the reservoir at Goczałkowice. These calculations were carried out according to the diagram in the collective publication (Jaag 1972) on 10 Swiss lakes. In that diagram Jaag presented the close correlation between the population density and percentage participation of phosphorus of waste water origin in the total inflow of that compound. The percentage

participation of polluting phosphorus read from that diagram would constitute in the total run-off of that element from the catchment area of the investigated rivers (at an average population density) for the Rivers Vistula, Bajerka, and Knajka 79 per cent, 80 per cent and 75 per cent respectively. Since J a a g assumed that a man excretes daily 3 g P and for the purpose of this paper the value 2.18 P g/day was adopted, hence the obtained data should be by about 27 per cent lower, i.e. the percentage amounts of phosphorus originating from the municipal sewage would be in the Rivers Vistula, Bajerka, and Knajka 57.7 per cent, 58.4 per cent, and 54.7 per cent respectively.

Summing up the above considerations it can be said that about 55 to 58 per cent of phosphorus flowing into the reservoir at Goczałkowice originates from municipal sewage. The other part of the content is phosphorus found in the ground waters and that eroded from the soil of the catchment area.

Assuming that losses of phosphorus introduced into the catchment area with fertilizers of animal and mineral origin equal 1 to 1.4 per cent (J a a g 1972), the annual run-off of phosphorus through these channels would be 8.16 to 11.42 P kg/sq. km. Since the mean run-off of total phosphorus obtained from three-year investigations equals 31.2 P kg/sg. km · year, the participation of phosphorus eluted from soils due to erosion in the general balance would constitute 26 to 37 per cent.

STRESZCZENIE

Scharakteryzowano zagospodarowanie i rodzaj użytkowania gleb zlewni dopływów zbiornika goczałkowickiego, tj. Wisły, Bajerki i Knajki. Ogólnie biorąc, zlewnia Wisły jest mniej wykorzystywana rolniczo niż zlewnie pozostałych potoków zasilających zbiornik. Zlewnia rzeki Knajki natomiast jest najbardziej użytkowana rolniczo.

Uwzględniono i oszacowano składniki nawozowe mineralne oraz wydalane przez zwierzęta hodowlane i ludzi zarówno mieszkających stale na terenie zlewni, jak i też przebywających tam czasowo na urlopie. Rezultaty badań poddano analizie matematycznej.

Łącząc spływ jednostkowy azotu lub fosforu z poszczególnych zlewni, względnie średnią zawartość tych składników w wodach analizowanych rzek z wybranymi elementami zagospodarowania zlewni (procent gruntów ornych w zlewni; procent użytków zielonych w zlewni; procent lasów w zlewni; ilość N lub P w fekaliach; ilość N lub P w nawozach mineralnych i organicznych pochodzenia zwierzęcego) utworzono układy równań, za pomocą których starano się wykazać stopień wpływu działalności gospodarczej człowieka na migrację biogennych składników. Zastosowano równanie regresji wielorakiej.

Zastosowana metoda wykazała wyraźny wpływ lasów na stężenie azotu mineralnego, azotanów oraz fosforanów i fosforu ogólnego w wodach. Obrazują to ryc. 2a i 2b, 3a i 3b.

Po dalszej analizie wielkości spływu mineralnych form azotu z gleb zlewni zbiornika goczałkowickiego stwierdzono, że o poziomie migracji tego składnika z podłoża prawdopodobnie decyduje ilość odpływającej wody.

Rozważając zagadnienie wymywania fosforu z gleb, stwierdzono ujemny wpływ lasów na wartość stężenia fosforanów i fosforu ogólnego w wodach płynących. Równocześnie wykazano, że z gleb wykorzystywanych rolniczo oraz z gruntów położonych w sąsiedztwie zabudowań gospodarskich przechodzi do wód płynących więcej związków fosforu niż z rejonów leśnych.

Analiza spływu jednostkowego fosforu ze zlewni cząstkowych dopływów zbiornika wykazała ścisłą korelację pomiędzy gęstością zaludnienia a spływem fosforu z obszarów zlewni Wisły, Bajerki i Knajki. Na podstawie tej zależności i wykresu pracy Jaaga (1972) wyliczono, że ok. 55—58% fosforu dopływającego do zbiornika goczałkowickiego pochodzi ze ścieków komunalnych.

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