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The effect of flooding on the chemical composition of waters in the catchment basin of the River Skawinka (southern Poland)

Krystyna Stachowicz

Institute for Physical Planning and Municipal Economy,
ul. Salwatorska 14, 30-109 Kraków, Poland

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Abstract — In periods of flooding the chemical composition of the waters of the River Skawinka is determined by the supply of eroded material from the catchment basin. Liquid wastes bring in a relatively small load of pollution. In the partial catchments of the drainage basin the land use influences the course of the spring meltwaters and the relief of the region determines the participation of these waters in the annual outflow balance.

Key words: streams, chemistry, high water level, melt, land use, concentrations, loads.

1. Introduction

In mountainous and submontane regions in periods of thaw as well as extensive precipitation and heavy rainfall, the processes of mechanical and chemical erosion (denudation) lead to the transport of soil material from the catchment area to the surface waters. The extent of the export of suspension and of nutrients depends on natural and anthropogenic factors in the catchment basin, i.e. the configuration of the land, subsoil, climatic conditions, soil and vegetation cover, the level of fertilization, and the character of soil cultivation (Gerlach 1976, Omernick 1976, Frere et al. 1977, Wetzel, Manny 1977, Bliven et al. 1979, Ryding, Forsberg 1979, Froehlich, Słupik 1980, Kudeyarov, Bashkin 1980, Florczyk 1982, Froehlich 1982, Pawlik-Dobrowolski 1983, Stachowicz 1986a, b).

In most catchment basins of Polish rivers in periods of flooding the

chemical composition of the waters is affected not only by natural leaching of the environment and agricultural activities but also by the inflow of sewage from point pollution.

The study by Stachowicz (1988) described the chemical composition of waters in the catchment basin of the River Skawinka in periods of low water level, during which one may best assess the effect of point (PP) and diffuse pollution (DP). The present work is a continuation of those investigations. Its aim was to determine the main natural and anthropogenic factors responsible for non-point pollution (NPP) in this catchment basin, as well as to estimate the proportion of sewage from PP in the total load of pollution occurring in periods of flooding.

2. Study area

The catchment area of the River Skawinka is characterized by considerable differentation of the relief. The steepest slopes occur in the southern (Beskid Mts) part of the river basin. The determinate part

Table I. Comparative characteristics of the catchment basins of the Włosanka and Mogiłka streams

Parameter	Catchment basin of the stream	
	Włosanka	Mogiłka
Area (ha)	823	1216
Altitude (m)	218—376	213—333
Maximum absolute height (m)	376	332
Changes of level (m)	158	120
Fall in terrain (% of area):		
27%	6.10	0.53
18—27%	10.18	11.43
10—18%	54.35	46.79
5—10%	17.19	26.18
5%	12.18	16.07
Subsoil	formations of the Carpathian Flysch	
Type of soil	loess, in the stream valleys dust and dusty clay	
Fertilization (kg NPK ha^{-1}):		
mineral	142	205
organic	400	437
Mean annual precipitation (mm)	796	
Land use (ha):		
agricultural	596	1109
arable	427 = 52%	840 = 69%
pasture	145 = 17%	233 = 19%
orchards	24 = 3%	36 = 3%
forests	227 = 28%	107 = 9%

of the catchment, situated within the Wieliczka Plateau, represents a typical submontane relief. The falls in terrain rarely exceed 200 m.

The processes of water surface erosion of the soil occurring in the catchment basin are very intense. Non-point pollution is, above all, the result of the washing off of soil material following atmospheric precipitation or thaw. The dense network of field tracks contributes also to the amount of soil material carried away from the slopes (Froehlich, Słupik 1980). In the northern part of the Skawinka catchment, in typical agricultural use, there occur dusty loessic covers (Komornicki 1980), very vulnerable to the action of water surface erosion. The land use of the basin also favours the occurrence of NPP since 23% of the thea is forest and as much as 53% arable.

Detailed investigations on the effect of NPP on the quality of surface waters were carried out in 2 partial catchment basins drained by the Włosanka and Mogiłka streams. These basins are situated in the lower, northern part of the Sktwinka catchment area. Comparative characteristics of the natural and anthropogenic factors in the two basins are given in Table I. A very significant common feature was the general occurrence of strong surface erosion of the soil (4th grade of erosion intensity — Puchała, unpubl. data).

3. Material and methods

Investigations of the chemical composition of water in the period of spring melt in 1988 covered the whole area of the Skawinka catchment basin when the flood wave was falling. The sampling stations and the range of analyses were the same as in the investigations conducted in the periods of low water level (Stachowicz 1988). Only the content of heavy metals and ether extract were not determined.

The effect of the meltwaters on the chemical composition of the water was analysed in two selected partial catchment basins free from PP. The sampling stations were located in the mouth sections of the Włosanka and Mogiłka streams. The investigations were carried out in the period from 28 February to 4 March 1985. The thaw sensu stricto took place from 1 to 4 March, and the analysis made on 28 February was regarded as background material for comparing the water quality before the beginning of the melt and in the period of its duration. The samples were collected twice a day. The analysis included the following parameters: pH, $N\text{-}NH_4$, $N\text{-}NO_3$, $N_{org.}$, PO_4, $P_{tot.}$, K, Ca, total suspension. The volume of flow was calculated on the basis of hydrometric measurements carried out in the overflow streambeds.

Investigations of the chemical composition of the water of the Skawinka were conducted in various hydrological conditions at the Station

in Radziszów (6.2 km of the river course) in the years 1982—1986, 1987—1988. 39 water samples were collected — 9 in periods of low water level, 15 during high water level, and 15 during medium water level. On the sampling days the flow values were obtained from the Institute of Meteorology and Water Economy as well as the data referring to the mean frequency of occurrence of some defined water flows in the River Skawinka at the cross-section at Radziszów and the mean time of their duration (multiannual data). The analyses included all parameters determined in the investigations of the Włosanka and Mogiłka streams and also oxidability, BOD_5, SO_4, Cl, Na, Mg, $Fe_{tot.}$, MHn, soluble parts, and electrolytic conductivity. The physico-chemical determinations were made according to the methods described by Hermanowicz et al. (1976).

The results of analyses of the chemical composition of the Skawinka waters in various hydrological conditions were subjected to regression and correlation analysis, the calculations being performed analogously to those of a previous study by the author (1986a).

In order to determine the amount of chemical components transported from the Skawinka catchment basin during the period of flooding the results of analyses of the waters of the drainage area from t period of low water level (22 February 1983) were utilized. The meteorological conditions at the time completely eliminated the inflow of NPP from the catchment basin. While the chemical composition of the waters, owing to the hydrological conditions ($Q = 1.25\ m^3\ s^{-1}$), was formed under the influence of ground waters and wastes from PP.

4. Results

4.1. Chemical composition of waters in the Skawinka drainage basin during periods of flooding

Table II lists the concentration values of selected parameters of water quality registered during thaw flooding at 6 stations along the course of the River Skawinka and 4 stations along the course of the Cedron stream. The flow of water in the Skawinka measured at Radziszów cross-section was high, amounting to $11.4\ m^3\ s^{-1}$.

As the area of the Skawinka catchment basin taken into consideration increased, the tendency was observed towards an increase in turbidity, colour, and concentration of the suspension, $P_{tot.}$, $Fe_{tot.}$ and the cations (Ca^{++}, Mg^{++}) and anions (SO_4^{--}, Cl^-), as well as in the hardness and alkalinity of the water (Table II). This regularity was somewhat disturbed at Station 2 (below the sewage inflow from Sułkowice) and

Table II. Chemical composition of water in the River Skawinka (1—6) and the Cedron stream (10—13) during the spring melt. Sampling stations as in Stachowicz (1988)

Station	Area of the catchment basin km^2	Hardness mval dm^{-3}	Alkalinity mval dm^{-3}	Suspension mg dm^{-3}	Soluble parts mg dm^{-3}	Ca^{++} mg dm^{-3}	Mg^{++} mg dm^{-3}	SO_4^{--} mg dm^{-3}	Cl^- mg dm^{-3}	$N\text{-}NO_3$ mg dm^{-3}	$P_{tot.}$ mg dm^{-3}	$Fe_{tot.}$ mg dm^{-3}
1	9.0	2.3	1.0	25	167	30	3.9	34.6	15.6	6.24	0.09	0.19
2	56.6	2.4	0.8	32	225	32	7.8	47.1	18.4	4.88	0.19	0.46
3	81.2	2.8	1.3	39	214	44	5.2	49.8	17.4	6.24	0.19	0.37
4	198	3.0	1.3	85	215	38	11.7	53.3	24.1	5.20	0.26	1.12
5	296	3.6	1.6	101	237	46	11.7	52.5	21.6	4.90	0.34	1.06
6	320	3.4	1.5	98	230	46	11.7	50.4	26.6	5.16	0.34	1.12
10	—	4.2	2.7	30	248	62	20.8	47.0	21.3	5.56	0.10	0.27
11	—	4.4	2.6	70	246	64	11.7	53.9	24.8	4.80	0.28	0.58
12	—	7.2	2.2	77	282	60	13.0	51.4	22.7	4.78	0.19	0.74
13	—	5.2	2.1	108	266	58	10.4	57.0	23.4	4.20	0.49	0.98

at Station 5 (below the Cedron confluence), where increased concentrations of Cl^-, $P_{tot.}$, suspension, and soluble parts were observed.

In the case of the Cedron, which collects large amounts of wastes from point and diffuse pollution, the tendency towards an increase in the concentration of chemical components of the water at successive stations from the spring section (Station 10) to the stream mouth (Station 13) was only slightly visible. It was manifested only by the suspension and $Fe_{tot.}$, while Ca^{++}, Mg^{++}, and alkalinity showed a decrease in values with as more of the catchment basin was considered. The inflow of wastes from PP, concentrated in the region of Kalwaria Zebrzydowska, was reflected in increased concentrations of SO_4^{--}, Cl^-, and $P_{tot.}$ at Station 11. Both in the River Skawinka and the Cedron stream very high concentrations of $N\text{-}NO_3$ (4.20—6.24 mg dm^{-3}) were observed in the period of thaw flooding.

A comparison of the chemical composition of the waters in the Skawinka drainage area in the period of low water level and in that of

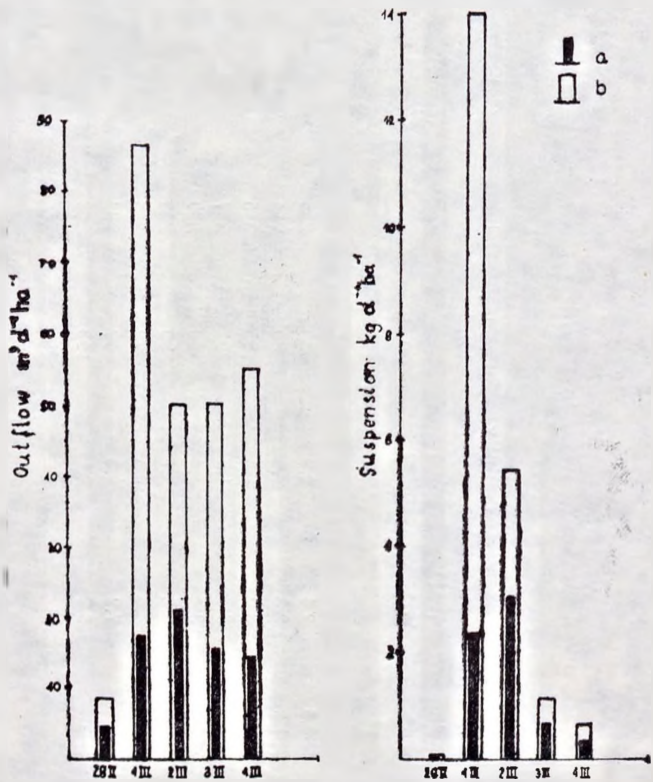

Fig. 1. Periods of spring melt. Comparison of the volume of the runoff and suspension loads in the waters of the Włosanka (a) and Mogiłka (b) streams

spring melt showed that in the latter period the increase in turbidity and suspension was very high (25-fold), while the concentrations of $N\text{-}NO_3$ and $Fe_{tot.}$ increased several times. In turn, the indices illustrating the inflow of domestic and farm wastes — detergents, $N\text{-}NH_4$, PO_4, and phenolic compounds — showed a decrease in their concentrations. A small drop in the values was recorded for Ca^{++}, Mg^{++}, soluble parts, and alkalinity. Concentrations of other indices remained unchanged.

It was calculated, moreover, that the wastes flowing into the waters of the Skawinka drainage area in the period of thaw flooding carry a relatively small load of pollution. The main part of pollution observed at this time is due to the bringing in soil material from the catchment basin. The loads of suspension, $N\text{-}NO_3$, and $Fe_{tot.}$ during low water levels amounted only to 1—3% of the values observed during thaw flooding, whereas the loads of BOD_5 and oxidability reached 10%. The smallest changes in values were shown by the loads of phenolic compounds, detergents, and $N\text{-}NH_4$. During low water levels their values were 22—30% of the loads determined in the period of thaw.

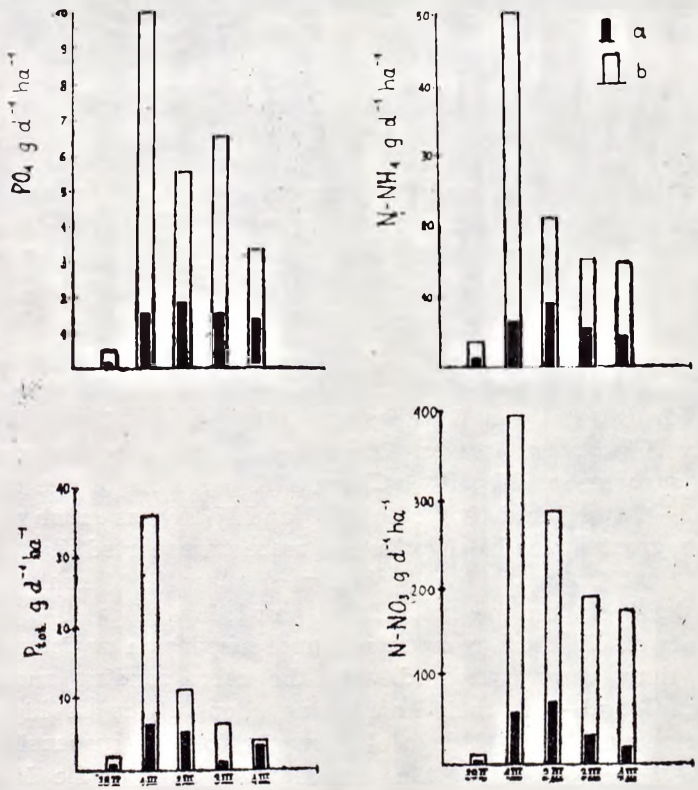

Fig. 2. Periods of spring melt. Comparison of the loads of PO_4, $P_{tot.}$, $N\text{-}NH_4$, and $N\text{-}NO_3$ in the waters of the Włosanka (a) and Mogiłka (b) streams

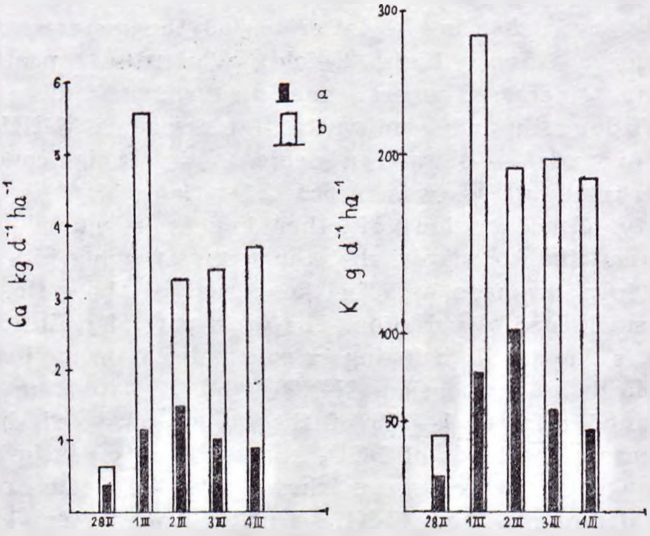

Fig. 3. Periods of spring melt. Comparison of the loads of Ca and K in the waters of the Włosanka (a) and Mogiłka (b) streams

4.2. Chemical composition of the waters of the Włosanka and Mogiłka streams during the spring melt

Figures 1, 2, and 3 show the values of elementary runoff and the loads of chemical components and suspension in the waters of the Włosanka and Mogiłka streams on the successive days of thaw. A comparative analysis of the data revealed a much greater runoff of dissolved material and suspension in the Mogiłka stream, whose catchment basin was chiefly in typical agricultural use, unlike the farming and forest character of that of the Włosanka. In the latter the proportion of forests was 3 times greater and the level of mineral fertilization 30% lower. It was found that in the Mogiłka stream the outflow of suspension, PO_4, $P_{tot.}$, Ca, and K per 1 ha of the catchment basin was 3—4 times and that of $N\text{-}NH_4$ and $N\text{-}NO_3$ as much as 6 times higher. The greatest loads of pollution were transported from the Mogiłka catchment basin on the first day of thaw (1 March), and from the Włosanka basin on the second and third days (figs 1—3).

The loads of chemical components and suspension registered in the periods of thaw were compared with the corresponding annual ones. It has been found that their share was about twice as high in the Włosanka stream. During 4 days of thaw the load of suspension in this stream amounted to 44% of the annual load, and in the Mogiłka to 23%. The highest outflow was reported for $N\text{-}NO_3$, amounting to 84% of the annual load in the Włosanka and 39% in the Mogiłka. The outflow

of $P_{tot.}$ and PO_4 was 25 and 31% (Włosanka stream) and 22 and 15% (Mogiłka stream). During the spring melt the loads of $N\text{-}NH_4$, $N_{org.}$, K, Ca constituted 20—30% and 11—17% of the annual loads for the Włosanka and Mogiłka streams, respectively.

4.3. Changes in the chemical composition of the Skawinka waters with increasing flow

Regression and correlation analyses showed that there exists a functional dependence between the flow volume of water in the Skawinka and the values of suspension, oxidability, BOD_5, $N\text{-}NO_3$, $P_{tot.}$, Ca.

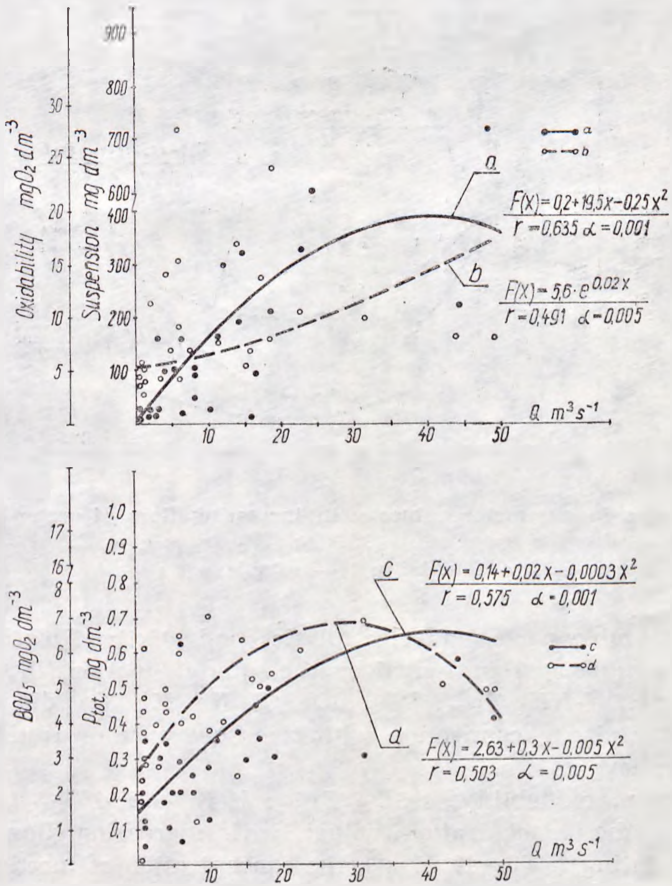

Fig. 4. Changes in parameter values with increasing flow of water in the Skawinka at the Radziszów station: a — suspension; b — oxidability; c — $P_{tot.}$; d — BOD_5

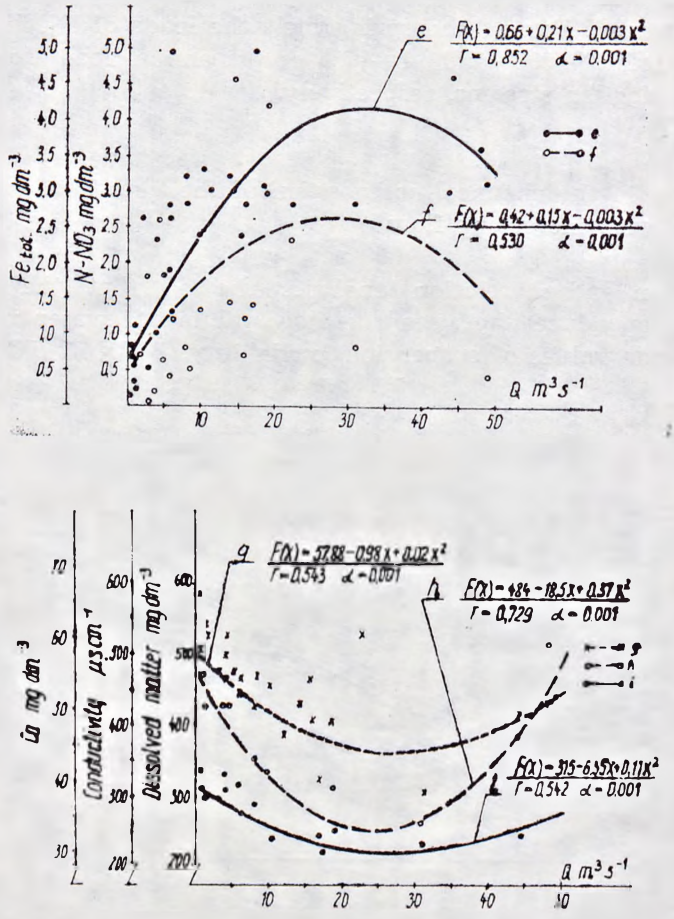

Fig. 5. Changes in parameter values with increasing flow of water in the Skawinka at the Radziszów station: e — $N\text{-}NO_3$; f — $Fe_{tot.}$; g — Ca; h — electrolytic conductivity; i — soluble parts

Mg, $Fe_{tot.}$, soluble parts, and electrolytic conductivity. This dependence was most frequently represented by the square function (figs 4, 5). The values of pH, $N\text{-}NH_4$, $N_{org.}$, PO_4, SO_4, Cl, Na, K, Mn did not show a sufficiently strong connection with the flow volume at the assumed significance level.

Suspension, oxidability, BOD_5, $Fe_{tot.}$, $N\text{-}NO_3$, and $P_{tot.}$ showed an increase in the concentration values with increasing flow. At high flows, amounting to 30—40 $m^3\ s^{-1}$, the concentration of most parameters showed a tendency to decrease (figs 4, 5). Changes in the concentration of soluble parts, electrolytic conductivity, Ca, and Mg were of different character. With increasing flow at first a considerable fall in the

values of these parameters was observed, to be followed by their increase ($25 \leqslant Q \leqslant 30$ m^3 s^{-1}).

Interesting was the dispersion of the concentration values for $N\text{-}NO_3$, $Fe_{tot.}$, $P_{tot.}$, and suspension at the highest flow values (40—50 m^3 s^{-1}). Such hydrological conditions occurred during heavy rainfall in May 1987 and during a winter thaw in February 1987. In the first case the soil played a role in the formation of NPP, although its participation was limited by the vegetation cover. The concentrations of the above parameters were very high at that time. They are indicated by points corresponding to the flow of 40—50 m^3 s^{-1}, lying above the regression curves (figs 4, 5). In the periods of winter thaw, when the soil remained frozen, the values of these indices were much lower. They are represented by points corresponding to the same flow values but lying below the regression curves.

Regression equations calculated on the basis of empirical data were used to determine the chemical composition of the water in the Skawinka at the station in Radziszów in periods of the most frequent flow and in the zones of low, medium, and partly high flow ($Q \leqslant 28$ m^3 s^{-1}). Table III shows the values of 10 indices of water quality which correspond to the hydrological conditions in the Skawinka lasting for about 360 days in the year (multiannual data). Higher values of flow, for which the chemical composition of the Skawinka waters was not determined, occur only on 5 days in the year.

5. Discussion

F r o e h l i c h (1982) when quoting many authors, observed that in periods of flooding, owing to chemical and mechanical denudation, the concentrations of soluble parts and suspension in the Beskid rivers and streams increases from the source to the mouth. In the case of the Skawinka this tendency was retained although it was somewhat disturbed at stations below the inflow of wastes (Station 2), as well as below the outlet of the polluted inflow (Station 5). In the Cedron stream, which receives large amount of wastes from PP this regularity was observed within a very limited range. It was not maintained for most parameters.

In periods of low water level the loads of suspension and $Fe_{tot.}$ and $N\text{-}NO_3$ constituted a very small parts (1—3%) of the value observed during thaws. The share of phenolic compounds, detergents, $N\text{-}NH_4$ (22—30%), i.e. of indices illustrating the inflow of wastes, was relatively large. The period of thaw flooding brought a considerable deterioration of water quality owing to the inflow of eroded soil material from the catchment basin. However, the unfavourable effect of wastes from PP was evident even under conditions of increased flow, mainly at stations

Table III. Concentration ranges (mg dm^{-3}) of quality parameters of the River Skawinka waters at the Radziszów station under various hydrological conditions

Parameter	Most frequent flow 0.40—2.20	Zones of flow ($m^3 s^{-1}$) low 0.20—1.50	medium 1.52—9.30	high 9.40—28.0
Suspension	8.0—42.0	4.1—29.0	29.4—161	162—355
Oxidability	5.6—5.9	5.6—5.8	5.8—6.9	6.9—10.6
BOD_5	2.7—3.3	2.7—3.1	3.1—5.0	5.0—6.9
$N\text{-}NO_3$	0.75—1.1	0.71—0.98	0.98—2.37	2.37—4.12
$P_{tot.}$	0.15—0.19	0.14—0.17	0.18—0.34	0.34—0.59
$Fe_{tot.}$	0.48—0.75	0.45—0.65	0.65—1.63	1.64—2.66
Ca	57—56	58—56	56—50	50—44
Mg	19—9.8	30—10.8	10.8—8.2	8.2—7.9
Soluble parts	313—302	314—325	325—266	266—225
Electrolytic conductivity	477—445	460—457	457—344	344—259

below their deposition. Increased water flow in the Skawinka was accompanied by a tendency towards an increase in the concentrations of those chemical components which illustrate the inflow of eroded soil material from the catchment basin (suspension, $P_{tot.}$, $N\text{-}NO_3$, $Fe_{tot.}$), and at the same time a decrease in the concentrations of soluble parts, electrolytic conductivity, Ca, and Mg. Similar dependences were observed when investigating other streams in the Carpathian Plateau (Stachowicz 1986a) and the Carpathian rivers (Stachowicz 1990). With regard to soluble parts, electrolytic conductivity, and suspension this observation confirms the findings of Froehlich (1982). However, Chmieleńska (1986) when examining the chemical composition of the River Rudawa as depending on flow, noted such a dependence only in the case of $N\text{-}NO_3$.

In the River Skawinka the concentrations of suspension, $P_{tot.}$, $N\text{-}NO_3$, $Fe_{tot.}$ during heavy rainfall were higher than in periods of winter thaw with similar hydrological parameters of flooding ($40 \leqslant Q \leqslant 50$ $m^3 s^{-1}$). Such observations were made when studying other catchment basins of the Carpathian Plateau (Stachowicz 1986b). Very heavy rainfall causes splashing of the soil. This leads to intensive washing away and linear transport along the field tracks, which are the main sources of supply of soil material for the streambeds (Gerlach 1976, Froehlich, Słupik 1980).

During the period of spring melt in the catchment basin of the Mogiłka stream, an area in typical agricultural use, the recorded elementary runoff and loads of suspension, $N\text{-}NH_4$, $N\text{-}NO_3$, PO_4, $P_{tot.}$, K,

and Ca were many times higher than those in the catchment area of the Włosanka stream where arable and forests prevail. This regularity was reported from other catchment basins of the Carpathian Plateau (Pawlik-Dobrowolski 1983, Stachowicz 1986a), as well as from the Beskid ones (Pawlik-Dobrowolski 1983). However, in the Włosanka catchment the share of the loads of suspension and nutrients in the annual outflow balance was about twice as high. In this basin, distinguished by a greater fall in terrain, the runoff in 4 days of thaw ammounted to 84% of the annual load. According to Kudeyarov and Bashkin (1980), the N losses during periods of thaw amount to 65% of the annual load. Strong leaching of the soil, occurring during periods of snow melt, results in very great losses of one of the main components fertilizer.

The unfavourable changes in the chemical composition of the waters in the drainage area of the Skawinka in periods of flooding can be reduced. To achieve this, anti-erosion procedures would have to be undertaken and, in particular, changes in land use in the catchment basin introduced in favour of forests and pasture the biological lining of watercourses is also recommended.

6. Polish summary

Wpływ wezbrań na skład chemiczny wód w dorzeczu Skawinki (południowa Polska)

Praca jest kontynuacją badań dotyczących jakości wody w dorzeczu Skawinki w okresach stanów niskich. W prezentowanej pracy przedstawiono dane obrazujące zmiany składu chemicznego wody Skawinki w okresach wezbrań, gdy istnieją sprzyjające warunki do powstawania zanieczyszczeń obszarowych (ZO).

Część badawczą poprzedziła analiza czynników przyrodniczych i antropogennych, wpływających na powstawanie ZO w całej zlewni Skawinki oraz w zlewniach cząstkowych potoków Włosanka i Mogiłka (tabela I).

Skład chemiczny wód w dorzeczu Skawinki w okresie roztopów wiosennych kształtowany był głównie przez ZO pochodzące ze zlewni (tabela II). Jednakże negatywny wpływ ścieków z zanieczyszczeń punktowych (ZP) pozostawał widoczny nawet w warunkach zwiększonego przepływu.

Szczegółową analizę wpływu wezbrania roztopowego na wody powierzchniowe w dorzeczu Skawinki przeprowadzono w 2 zlewniach cząstkowych. Stwierdzono kilkakrotnie wyższy spływ jednostkowy oraz ładunki zawiesiny, $N\text{-}NH_4$, $N\text{-}NO_3$, P og., PO_4, Ca i K w potoku Mogiłka, odwadniającym zlewnię typowo rolniczą, w porównaniu z rolno-leśną zlewnią potoku Włosanka (ryc. 1—3).

Ponadto przeprowadzono badania jakości wody Skawinki na stanowisku w Radziszowie w zmiennych warunkach hydrologicznych. Stosując analizę regresji i korelacji badano zmiany wartości stężeń składników chemicznych wody w miarę wzrostu przepływu (ryc. 4, 5).

Obliczone na podstawie danych empirycznych równania regresji posłużyły do określenia stężeń odpowiadających przepływom niskim, średnim i wysokim (tabela III).

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