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**THE IMPACT OF SNOW-MELT-RAIN FLOOD ON RUNOFF  
DENUDATION FROM SMALL LOWLAND CATCHMENTS  
(ON EXAMPLE OF LEFT-BANK TRIBUTARIES  
OF THE LOWER WIEPRZA RIVER)**

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**Abstract**

The aim of the paper is the evaluation of the surface runoff impact on chemical composition of waters, transport of suspension and dissolved substances out of the catchment in two left-bank tributaries of the lower Wieprza River – Potok Starokrakowski and Jarosławianka. During the flood discharges were several tens times higher than the average recorded in that period. In Potok Starokrakowski the discharge was 500 dm<sup>3</sup>/s (typical discharges 10-20 dm<sup>3</sup>/s) and in Jarosławianka 1500 dm<sup>3</sup>/s (typical discharges 10-40 dm<sup>3</sup>/s). The rapid increase in discharge in the streams caused activation of suspension transport in both catchments. In Potok Starokrakowski the suspension content in the flood period was 56.5 mg/dm<sup>3</sup>, while in Jarosławianka 160.3 mg/dm<sup>3</sup>. In the flood period, a considerable decrease in the concentration of some dissolved substances, including Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and Cl<sup>-</sup>, was observed. Simultaneously, an increase in the concentration of ammonium nitrogen (NH<sub>4</sub>-N), potassium, total organic carbon and Kjeldahl's nitrogen (N<sub>K</sub>) was observed in both streams. Observed flood had huge meaning in suspended and soluted substances transport out of both catchments.

**Key words:** the Wieprza River, surface flow, runoff denudation, water chemistry, suspension

**INTRODUCTION**

The basis of surface alimentation of rivers are small streams gathering waters from the areas of small catchments. The alimentation sources of the streams are outflows and seepage of ground waters as well as surface flow of water. The proportion of particular alimentation forms depends on several factors, including land relief within the catchments, land cover, soil properties, distribution of precipitation during the year, etc. The value of runoff from the catchments depends, in turn, mainly on the

hydrological regime of the stream, physico-geographical properties of the catchments (morphology, its geomorphological, lithological and soil features, climatic and hydrological conditions, structure of land use) and hydrotechnical constructions (Kostrzewski et al. 1999, Kubiak-Wójcicka 2004). A significant role in the formation of runoff can also be played by phenomena of above-average character, which include, especially in lowland catchments, surface flow. Surface flow of waters is generated when the ground cannot absorb water which occurred on its surface. The frequent cause is spring thaw, and the factor which is favourable for the occurrence of this phenomenon is frozen, impermeable ground. Snow melting can supply large quantities of water during a short time, which leads to rapid swelling in streams. The effectiveness of this process increases considerably when the thaw is accompanied by rainfall. A direct effect of the occurrence of surface water flow is the initiation of material transport down the slopes. In the valleys of rivers and smaller streams, part of the material is supplied to the channel and then transported out of the catchment. A high intensity of surface flow can activate suspended sediment load even several hundred times higher than during normal runoff, hence phenomena of this type, of above-average or even extreme character often play a fundamental role in the formation of the morphology of river valleys, and not only of their bottoms (Collins

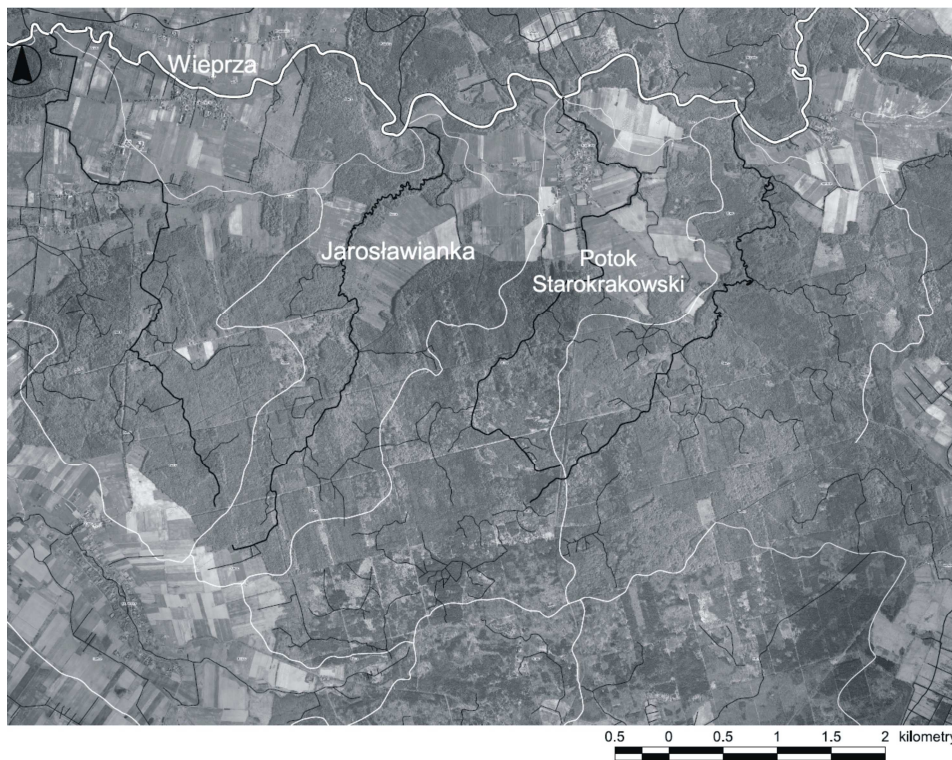


Fig. 1. Study area (black lines – streams; white lines – catchments borders according to Atlas podziału... 2005)

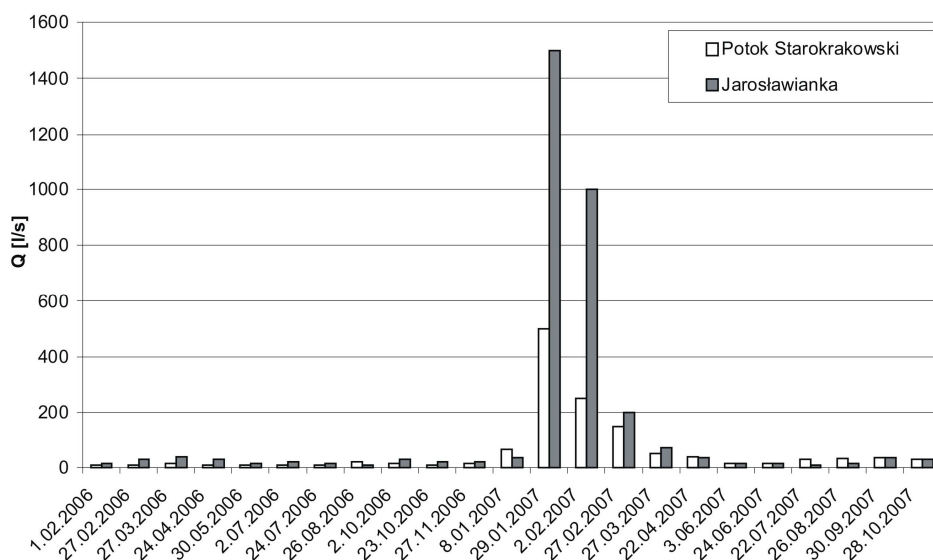


Fig. 2. Discharges in Potok Starokrakowski and Jarosławianka during 2006-2007

1981, Froehlich 1982). Research on surface flow is usually conducted in mountainous regions, where the flow is most effective, whereas, it is common also in lowland and highland areas.

In January 2006, in several small catchments of the left-bank tributaries of the Wieprza River (hereinafter the Wieprza), (Fig. 1), near Stary Kraków, studies on chemical and physico-chemical properties of water discharged to the Wieprza by streams and an analysis of surface flow, transport of dissolved and suspended matter were initiated. At the end of January and beginning of February 2007, rapid warming was observed (Fig. 2), which resulted in fast melting of the snow cover within the catchments under study. The simultaneous occurrence of large rainfall resulted in the activation of surface flow of a high intensity. The aim of this paper is the evaluation of the impact of the observed surface flow on the chemical composition of water and transport of dissolved and suspended matter out of the catchment in two streams – Potok Starokrakowski and Jarosławianka.

## METHODS

Studies were conducted within the catchments of the left-bank tributaries of the lower Wieprza River near Stary Kraków (10 km N of Sławno). Presented results concern catchment number 4 674 (Potok Starokrakowski) and 46 752 (Jarosławianka) (according to Atlas podziału... 2005), (Fig. 1). The catchments are drained by streams flowing directly into the Wieprza. Their characteristic feature is a deep cut of the valley bottoms into the ground in the outlet section (reaching about 10 m) and a considerable grade. Catchment of Potok Starokrakowski is in majority agricultur-

ally used, while catchment of Jarosławianka covers mainly forest areas. The area of the catchments, according to Atlas podziału... (2005), is 8.44 km<sup>2</sup> and 6.00 km<sup>2</sup> respectively.

Since January 2006 at monthly intervals, measurements of discharge in streams have been conducted and samples taken for analyses. In case of an occurrence of phenomena of above-average character in the catchments, the frequency of measurements was increased. Each time water samples were analyzed to determine the following:

- reaction and conductivity using conductimeter ELMETRON CP-401,
- suspended matter by gravimetric method after filtration using glass microfibre filters WHATMAN GFC,
- dry residue content by weight method,
- total organic carbon content (TOC) by Tiurin method – after vaporizing the sample,
- nitrogen content by Kjeldahl method,
- nitrate, nitrite, ammonium nitrogen content by colorimetric methods,
- phosphates, chlorides, sulphates and iron content by colorimetric methods,
- potassium and sodium content by flame spectrophotometry,
- calcium and magnesium content by versenate method.

Reaction, conductivity, TOC and Kjeldahl's nitrogen were determined in unfiltered samples of water, the remaining determinations in water samples after filtration. The determinations were performed on the day the samples were taken. In case it was necessary to postpone some determinations, the samples were preserved according to the Polish norm PN-EN ISO 5667-3.

## RESULTS

A characteristic feature of the left-bank tributaries of the Wieprza near Stary Kraków is a deep cut of their valleys in the quite flat ground formed by stagnation sediments (clayey silts with thin insertions of very fine-grain sands) deposited on boulder clay, which could suggest a high intensity of denudation processes in the past (probably at the end of the Vistulian Glaciation). What is also noteworthy is the highly developed hydrological network within the catchments. The particular streams have numerous tributaries. The alimentation basis of the streams is seepage of ground waters from valley slopes and periodically drainage waters. The 2006 research results concerning the value of discharges in streams as well as suspended sediment load and concentrations of dissolved substances revealed a small intensity of denudation processes within the analysed catchments at present (Fig. 3-6). Suspended sediment transport ranged from 3.0-48.6 kg/day in Potok Starokrakowski and 5.4-89.5 kg/day in Jarosławianka with discharges respectively 10-20 l/s in Potok Starokrakowski and 10-40 l/s in Jarosławianka. Taking into consideration the fact that the areas of the catchments are 8.44 km<sup>2</sup> for Potok Starokrakowski and 6.00 km<sup>2</sup> for Jarosławianka, the daily suspended sediment loads discharged out of them are small.

At the end of January and beginning of February 2007 within the analysed catchments rapid warming occurred, which caused intense melting of an about 30-centi-

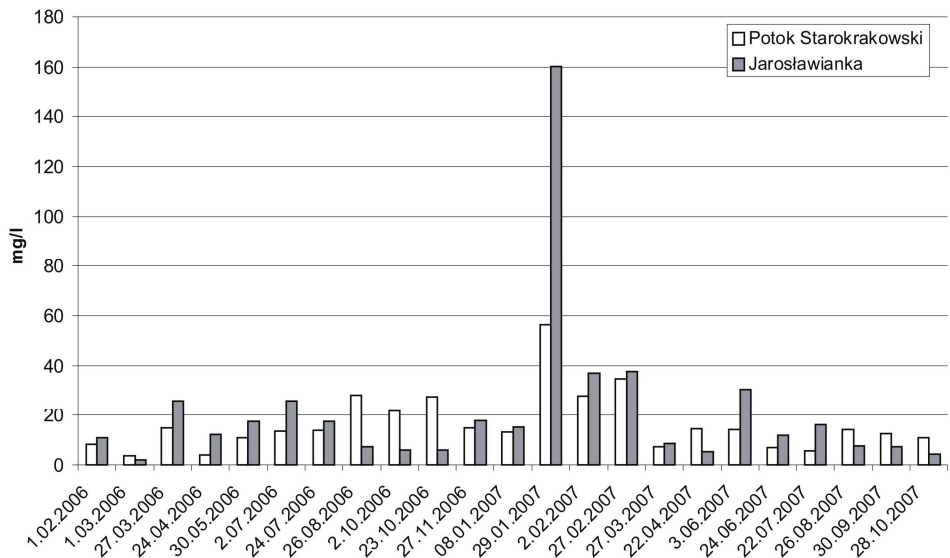


Fig. 3. Concentration of suspension (mg/l) in water of Potok Starokrakowski and Jarosławianka during 2006-2007

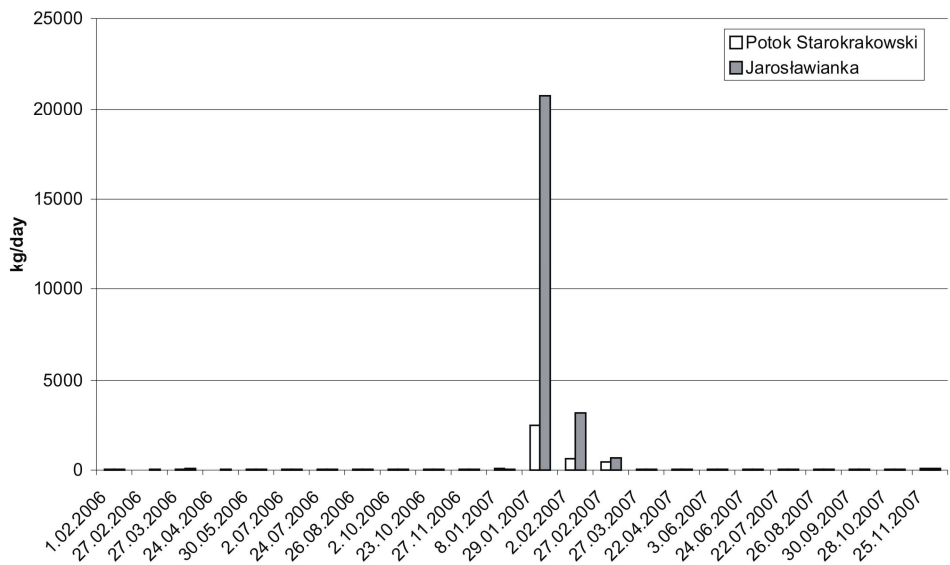


Fig. 4. The impact of flood on daily transport of suspension (kg/day) from catchments of Potok Starokrakowski and Jarosławianka

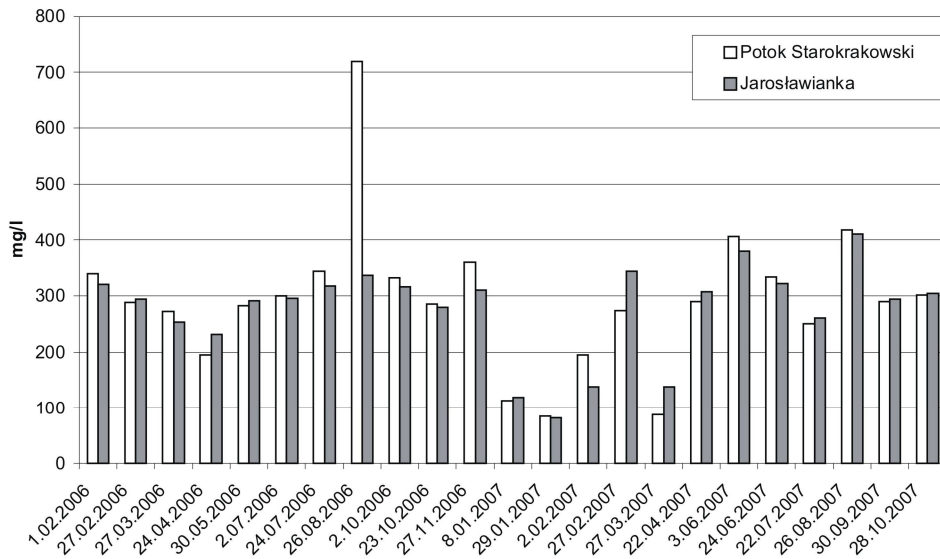


Fig. 5. Dissolved matter concentration (mg/l) in water of Potok Starokrakowski and Jaroslawnianka during 2006-2007

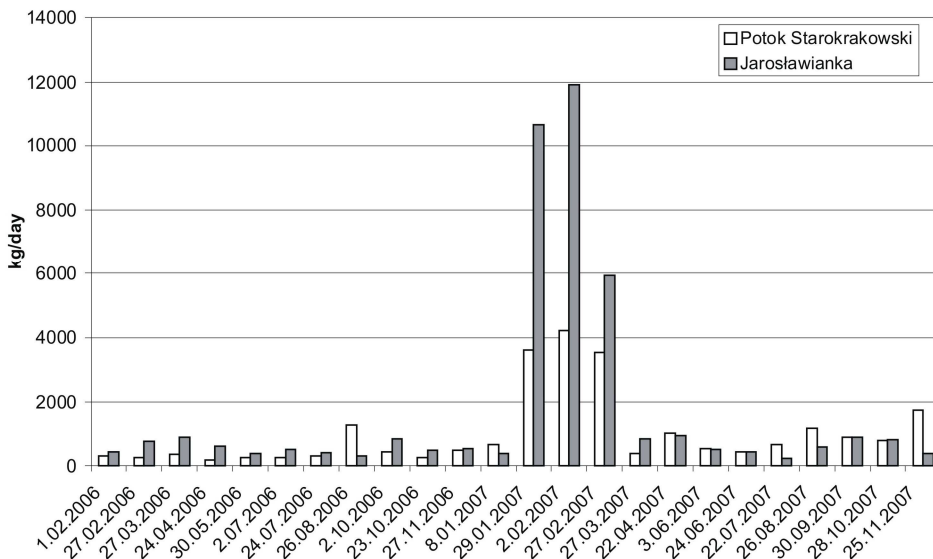


Fig. 6. The impact of flood on daily load of dissolved matter (kg/day) in catchments of Potok Starokrakowski and Jaroslawnianka

metre snow cover. This was accompanied by rainfall. As a result, large quantities of water started flowing on the surface over the frozen ground to the streams. In this period, discharges several dozen times higher than the average were observed. In Potok Starokrakowski the discharge was 500 l/s and in Jarosławianka 1 500 l/s (Tab. 1 and 2, Fig. 2). The much higher runoff observed in catchment of Jarosławianka probably results from higher denivelations of the ground, which lead to a more rapid runoff. The area of both catchments given in Atlas podziału... (2005) also raises some doubts. This question is being analysed in detail by the authors at the moment. The rapid increase in the discharge in streams caused an activation of suspended sediment transport in both catchments. The observed suspended sediment content in Potok Starokrakowski during the swelling period was 56.5 mg/l, while in Jarosławianka 160.3 mg/l. In both cases these are values several times higher than those observed in periods with an average water discharge (Fig. 3-6). In the swelling period, a considerable decrease in the concentration of some dissolved substances – including  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Cl}^-$  was observed (Tab. 1). Simultaneously in both streams, an increase in the concentration of ammonium nitrogen ( $\text{NH}_4\text{-N}$ ), potassium, TOC and Kjeldahl nitrogen ( $\text{N}_K$ ) was observed. The remaining high concentrations of  $\text{K}^+$  and  $\text{NH}_4\text{-N}$  despite increased water discharges is caused by the high mobility of these ions in the environment and susceptibility to leaching from the soil both in the agricultural and forest catchment. The high TOC and  $\text{N}_K$  concentration are related to the activation of the transport of suspended sediment which in part has an organic character. On balance, the sum of substances dissolved in water in the

Table 1  
The impact of flood on pH and ions concentration in water of Potok Starokrakowski and Jarosławianka

	Concentration of ions (mg/l)							
	Potok Starokrakowski				Jarosławianka			
	min <sup>1</sup>	max <sup>2</sup>	mean <sup>3</sup>	flood <sup>4</sup>	min <sup>1</sup>	max <sup>2</sup>	mean <sup>3</sup>	flood <sup>4</sup>
pH	6.7	8.40	7.8	6.3-7.5	6.7	8.50	7.8	6.9-7.5
TOC	2.42	33.40	11.73	19.96	1.20	41.70	12.52	28.60
$\text{N}_K$	0.28	2.07	1.02	0.84	0.28	1.46	0.91	0.56
$\text{NO}_3\text{-N}$	0.00	4.54	0.84	1.79	0.00	4.09	0.84	1.93
$\text{SO}_4^{2-}$	12.50	45.00	27.90	46.50	7.00	67.50	26.80	31.00
$\text{Ca}^{2+}$	44.30	82.40	70.74	36.22	56.75	86.82	74.10	52.48
$\text{Mg}^{2+}$	5.82	36.80	12.87	24.53	3.60	19.02	10.62	15.74
$\text{K}^+$	2.26	4.30	3.11	3.81	0.50	1.65	1.24	2.50
$\text{Na}^+$	6.24	12.70	8.71	9.08	5.92	9.46	8.08	8.62

1 – minimum value observed during 2006-2007 years besides flood period

2 – maximum value observed during 2006-2007 years besides flood period

3 – mean value for years 2006-2007 besides flood period

4 – maximum value observed during flood

Table 2

The impact of flood on daily load of ions in catchments of Potok Starokrakowski and Jarosławianka

	Daily load (kg/day)							
	Potok Starokrakowski				Jarosławianka			
	min <sup>1</sup>	max <sup>2</sup>	mean <sup>3</sup>	flood <sup>4</sup>	min <sup>1</sup>	max <sup>2</sup>	mean <sup>3</sup>	flood <sup>4</sup>
TOC	2.2	157.0	26.9	862.2	3.1	71.5	26.1	3706.4
Nk	0.0	8.7	2.0	30.3	0.0	4.6	1.9	72.6
NO <sub>3</sub> -N	0.0	14.0	2.4	77.3	0.0	10.4	2.2	250.1
SO <sub>4</sub> <sup>2-</sup>	12.5	252.7	64.7	1900.8	6.5	181.4	60.4	3758.4
Ca <sup>2+</sup>	38.3	437.0	145.6	1489.2	62.1	386.2	168.2	2719.4
Mg <sup>2+</sup>	6.0	47.7	22.7	77.2	7.8	91.9	26.9	27.2
K <sup>+</sup>	2.0	20.2	6.8	164.7	0.7	7.9	2.9	324.0
Na <sup>+</sup>	5.4	56.0	18.1	35.0	7.6	45.7	18.6	19.4

1 – minimum value observed during 2006-2007 years besides flood period

2 – maximum value observed during 2006-2007 years besides flood period

3 – mean value for years 2006-2007 besides flood period

4 – maximum value observed during flood

swelling period was even several times lower than during average discharges, which is manifested in the content of the so-called dry residue.

The research showed that phenomena of an above-average character, like the observed flash surface flow, have a great impact on the transport of matter out of the catchment (Fig. 4, 6, Tab. 2), and thus play a fundamental role in the shaping of the morphology of the analysed catchments, especially the very valley of the stream. The daily suspended sediment load in the swelling period in Potok Starokrakowski rose 145 times, and in Jarosławianka 780 times in comparison with the average values for the remaining research period. 2 440.8 kg of suspended sediment was carried daily out of the catchment of Potok Starokrakowski and 20 774.9 kg from the catchment of Jarosławianka. These figures are comparable to those recorded by other researchers within sub-mountainous catchments (Krzemień 1996). During the thaw in 2007, unit suspended sediment load was about two times higher than dissolved matter load, whereas in average conditions dissolved matter load was many times (even a hundred times) higher than unit suspended sediment load. The diversity of the relationship of these two values is even bigger than it was documented by Kostrzewski et al. (1992) for the catchment of the Młyński Potok, where during a swelling in July 1988 unit suspended sediment load was on average 5 times higher than dissolved matter load. In average conditions, 10-100 times domination of chemical denudation processes over physical denudation processes was observed.

The occurrence of a swelling lasting for several days causes results, which with average discharges would take place only after a few years. The observed swelling also played a key role in the transport of particular substances dissolved in water. Irre-



spective of whether in the swelling period, lower or higher concentrations of substances with regard to the average situation were observed, taking into consideration the value of discharge, the swelling period decidedly influenced the annual load of particular components in both catchments. During one day of the swelling, loads of dissolved substances, from several to several hundred times higher than in average conditions, are transported out of the catchment. The sum of dissolved substances transported daily during the swelling period out of the catchment of Potok Starokrakowski was 3 629 kg, and Jarosławianka 10 627 kg.

During the swelling period, in both streams a decrease in water reaction by about one unit in comparison with the remaining study period was observed. This decrease can be attributed to the varying intensity of the activation of ions with acidic and basic character during the swelling period.

## CONCLUSIONS

The increase in the flow and energy of water caused by rapid snow melting and rainfall within the analysed tributaries of the Wieprza contributed to the activation of several hundred times larger daily load of suspended sediment in comparison to loads transported in discharges within average values.

During the swelling a decrease in the concentration of substances dissolved in water was observed. Various and different reactions of particular ions were observed. A considerable decrease in the concentrations of  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Cl}^-$  ions occurred. Simultaneously, an increase in the concentration of ions considered mobile in the environment –  $\text{NH}_4\text{-N}$  and  $\text{K}^+$  – was observed. During the thaw in 2007 unit suspended sediment load was about two times higher than dissolved matter load, while in average conditions dissolved matter load was many times (even a hundred times) higher than unit suspended sediment load.

Taking into consideration the value of discharges during the swelling, despite the lower concentrations of some dissolved substances, for the annual load of ions discharged out of the catchments, it is the swelling that has a fundamental significance. The intensity of runoff denudation of the catchment during the swelling period is several hundred times higher than during the rest of the year. This reveals the significant role of phenomena of above-average character in the shaping of the valleys of the analysed Wieprza tributaries.

## SUMMARY

In January 2006, in several small catchments of left-bank tributaries of the Wieprza near Stary Kraków investigation on the chemical and physical-chemical properties of water discharged into the Wieprza by streams was begun, and a quantitative and qualitative evaluation of the surface runoff and the intensity of the transport of dissolved and suspended material was undertaken. Between the end of January and beginning of February 2007 a rapid warming was observed in the area of the catch-

ments, which caused fast melting of the snow cover. The simultaneous occurrence of considerable rainfall brought about the activation of surface runoff of a high intensity. The aim of the paper is the evaluation of the impact of the observed surface runoff on the waters chemical composition, transport of suspension and of dissolved substances out of the catchment in two left-bank tributaries of the lower Wieprza. The results of the 2006 research concerning the volume of discharges in streams and the load of suspension and concentrations of dissolved substances indicated a small intensity of denudation processes within the analysed catchments. The suspension transport ranged from 3.0 to 48.6 kg/day in Potok Starokrakowski and 5.4-89.5 kg/day in Jarosławianka, with discharges of 10-20 dm<sup>3</sup>/s in Potok Starokrakowski and 10-40 dm<sup>3</sup>/s in Jarosławianka. Discharges several tens times higher than the average were recorded in flood period. In Potok Starokrakowski the discharge was 500 dm<sup>3</sup>/s and in Jarosławianka 1500 dm<sup>3</sup>/s. The rapid increase in discharge in the streams caused activation of suspension transport in both catchments. In Potok Starokrakowski the suspension content in the flood period was 56.5 mg/dm<sup>3</sup>, while in Jarosławianka, 160.3 mg/dm<sup>3</sup>. In both cases these are values several times higher than the values observed in periods of average water discharge. In the flood period, a considerable decrease in the concentration of some dissolved substances, including Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and Cl<sup>-</sup> was observed. Simultaneously, an increase in the concentration of ammonium nitrogen (NH<sub>4</sub>-N), potassium, total organic carbon and Kjeldahl's nitrogen (N<sub>K</sub>) was observed in both streams. The maintenance of high concentrations of K<sup>+</sup> and NH<sub>4</sub>-N despite increased discharges is caused by a high mobility of these ions in the environment and susceptibility to leaching from the ground both in agricultural and forest catchments. On the other hand, the high concentrations of total organic carbon and N<sub>K</sub> are related to the activation of suspension transport which partially has an organic character. In the ultimate balance, the sum of substances dissolved in water in the flood period was even several times lower than in a period of average discharge, which is indicated by the content of the so-called dry residue.

Examinations showed that phenomena of an extreme character, like the observed rapid surface runoff, have a great impact on the transport of matter out of the catchments, and thus play a basic role in the shaping of the catchments morphology, especially of the very Jarosławianka valley. The daily suspension load during the flood period in Potok Starokrakowski rose 145 times and in Jarosławianka 780 times in comparison with the mean value for the remaining research period. 2 440.8 kg of suspension daily was carried out of the Potok Starokrakowski catchment, and 20 774.9 kg out of the Jarosławianka catchment. The sum of dissolved substances transported daily during the flood period out of the Potok Starokrakowski catchment was 3 629 kg and Jarosławianka catchment 10 627 kg.

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WPLYW GWAŁTOWNEGO WEZBRANIA ROZTOPOWO-OPADOWEGO  
NA DENUDACJĘ ODPLYWOWĄ Z MAŁYCH ZLEWNI NIŻOWYCH  
(NA PRZYKŁADZIE LEWOBRZEŻNYCH DOPŁYWÓW DOLNEJ WIEPRZY)

**Streszczenie**

Począwszy od stycznia 2006 roku, w kilku małych zlewniach lewobrzeżnych dopływów Wieprzy, w okolicy Starego Krakowa, rozpoczęto badania właściwości chemicznych i fizykochemicznych wody odprowadzanej do Wieprzy przez ciek i oraz przystąpiono do ilościowej i jakościowej oceny odpływu powierzchniowego, a także natężenia transportu materiału rozpuszczonego i zawiesiny. Na przełomie stycznia i lutego 2007 roku zaobserwowano na terenie zlewni gwałtowne ocieplenie, co spowodowało szybkie topnienie pokrywy śnieżnej. Równoległe wystąpienie znacznych opadów deszczu spowodowało, że został uruchomiony spływ powierzchniowy o dużej intensywności.

Celem niniejszej pracy jest ocena wpływu obserwowanego spływu powierzchniowego na chemizm wód, transport zawiesiny oraz transport substancji rozpuszczonych poza zlewnię w dwóch lewobrzeżnych dopływach dolnej Wieprzy – Potoku Starokrakowskim i Jarosławiance. Cechą charakterystyczną tych cieków jest głębokie wcięcie ich dolin w dość płaskie podłoże utworzone przez osady zastoiskowe (mułki ilaste z cienkimi wkładkami bardzo drobnoziarnistych piasków) spoczywające na glinach zwałowych. Na uwagę zasługuje silnie rozwinięta sieć hydrologiczna w obrębie zlewni. Podstawą zasilania cieków są wysięki wód gruntowych ze zboczy dolinek oraz okresowo wody drenarskie. Wyniki badań z roku 2006 dotyczące wielkości przepływów w ciekach oraz ładunku zawiesiny i stężeń substancji rozpuszczonych wskazywały na małą intensywność procesów denudacji w obrębie analizowanych zlewni. W okresie wezbrania odnotowano w ciekach kilkadziesiąt razy większe przepływy wody w stosunku do przeciętnych. W Potoku Starokrakowskim przepływ wyniósł 500 l/s, a w Jarosławiance 1500 l/s. Gwałtowne zwiększenie przepływu w ciekach spowodowało uruchomienie transportu zawiesiny w obydwu zlewniach. W Potoku Starokrakowskim odnotowano jej stężenie na poziomie 56,5 mg/l, zaś w Jarosławiance 160,3 mg/l. Dobowy ładunek zawiesiny w okresie wezbrania w Potoku Starokrakowskim wzrósł 145-krotnie, a w Jarosławiance 780-krotnie w stosunku do wartości średniej dla pozostałego okresu badań. W trakcie wezbrania ze zlewni Potoku Starokrakowskiego wynoszone było 2440,8 kg/dobę zawiesiny, zaś ze zlewni drugiego cieku 20774,9 kg/dobę.

Wraz ze wzrostem stężenia zawiesiny, która ma częściowo charakter organiczny, odnotowano wzrost stężenia węgla organicznego oraz azotu Kjeldahla ( $N_K$ ). Również stężenia jonów uznawanych za ruchliwe w środowisku, takich jak  $K^+$  i  $NH_4$  utrzymywały się na wysokim poziomie. W przypadku pozostałych substancji rozpuszczonych ( $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$  i  $Cl^-$ ) obserwowano znaczne spadki stężeń.

Przeprowadzona seria pomiarów wykazała, że zjawiska o charakterze ponadprzeciętnym, jak obserwowany gwałtowny spływ powierzchniowy, mają ogromne znaczenie w transporcie materii poza zlewnię rzek, a tym samym odgrywają podstawową rolę w kształtowaniu morfologii zlewni, szczególnie samych dolin rzecznych. Wystąpienie kilkudniowego wezbrania powoduje skutki, które przy przeciętnych przepływach zaszłyby dopiero po kilku latach. Obserwowane wezbranie odgrywało kluczową rolę w transporcie poszczególnych substancji rozpuszczonych w wodzie. Niezależnie od tego, czy w okresie wezbrania obserwowano niższe czy wyższe stężenia jonów w stosunku do sytuacji przeciętnej, biorąc pod uwagę wielkość przepływu, okres wezbrania w sposób decydujący wpłynął na roczny ładunek poszczególnych składników w obydwu zlewniach. W ciągu jednej doby wezbrania poza zlewnię są transportowane od kilku do kilkuset razy większe ładunki substancji rozpuszczonych niż poza okresem wezbrania.