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Suspended sediment concentration and yield in snowmelt flood events in a small lowland river

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Abstract: *Suspended sediment concentration and yield in snowmelt flood events in a small lowland river*. Results of investigation on suspended sediment delivery from small lowland, agriculturally used catchment of Zagożdżonka River, located in central Poland, during snowmelt periods of 2001––2007 are presented. The study catchment's area, upstream of the well equipped gauging station at Czarna, is 23.4 km^2. Suspended sediment concentration and sediment yield has been calculated and analysed for 15 snowmelt flood events. The relationship between suspended sediment concentration and the discharge has been analyzed. It has been found that the relation, in majority of the cases, has the form of clockwise hysteresis, however the existance of other types of hysteresis i.e. anticlockwise and "8" shape, have been also confirmed. Significant relation between suspended sediment yield and runoff volume of snowmelt flood events has been also found.

Key words: snowmelt flood, suspended sediment concentration, sediment yield, hysteresis.

INTRODUCTION

Intensive suspended sediment transport occurs mainly during flood runoff, caused by heavy rainfall or rapid snowmelt events. Increase of suspended sediment concentration has negative influence on biological life in river, on economic use of water and on recreation conditions of reservoirs. It may degrade aquatic ecosystems by increasing turbidity, reducing light penetration and may damage habitats by sedimentation. The particles of suspended sediment play also important role in transport of nutrients and contaminates (Droppo et al. 2000; Martinez-Carreras et al. 2010). In order to reduce the problems, effective sediment control strategies are requiret (Walling and Collins 2008). Previous investigation carried out by the Department of Water Engineering and Environmental Restoration of Warsaw University of Life Sciences – SGGW have shown an intensive suspended sediment transport during the winter and spring time (Banasik 1983). So the detailed investigation of the snowmelt floods in the small catchment of Zagożdżonka should help in explaining the dynamics of sediment concentration the sediment fluxes. The literature put the attention on the suspended sediment transport in general, but the processes connected with the snowmelt floods are not very well known (Ollesch et al. 2006).

STUDY CATCHMENT AND MONITORING GAUGE

Location and area: Zagożdżonka watershed, shown in Figure 1 is located in central Poland, about 100 km south of

Warsaw. Watershed area is 82.4 km^2 at Plachty gauging station (A in Fig. 1), whereas the subwatershed area at Czarna (B in Fig. 1) is 23.4 km^2.

Rainfall and runoff: The mean annual precipitation and runoff are estimated at 606 mm and 107 mm respectively, on the base of 46-year data records collected by the Department of Water Engineering and Environmental Restoration of Warsaw University of Life Sciences at Plachty, except precipitation data for the period 1963–1982. This period data was taken from available publications of Polish hydro-meteorological service IMiGW for the nearest rain gauge Zwoleń. The maximum precipitation of 941 mm were recorded in 1974 and the minimum of 414 in 1991. Maximum annual runoff of 209 mm was measured in 1980 and the minimum of 52 mm in 1992. Annual runoff coefficients (i.e. ratio of runoff to precipitation) for the investigated area to Plachty gauge have a range from 0.088 in 1992 to 0.320 in 1979, with mean value of 0.177. The snow cover usually appears between 25–30 of November and disappears between 20–25 of March. The mean annual suspended sediment concentration (SSC) is low and has been estimated for ca 14 mg/l, however during floods the concentration increased to the highest recorded reaching 219 mg/l (Hejduk 2001; Hejduk et al. 2006). The average discharge of the years 1963–2008 for Zagożdżonka River is 0.069 (m^3/s).

Topography: Zagożdżonka watershed is of lowland type. Absolute relief is 26,5 m in the upper subcatchment (shown as B in the Fig. 1), and 34 m in the entire watershed (A). The mean slopes of main streams are from 2.5 m to 3.5 m per 1000 m.

Land use and soils: Local depressions, which do not contribute to direct runoff and sediment yield from the watershed, constitute a significant part of the area,

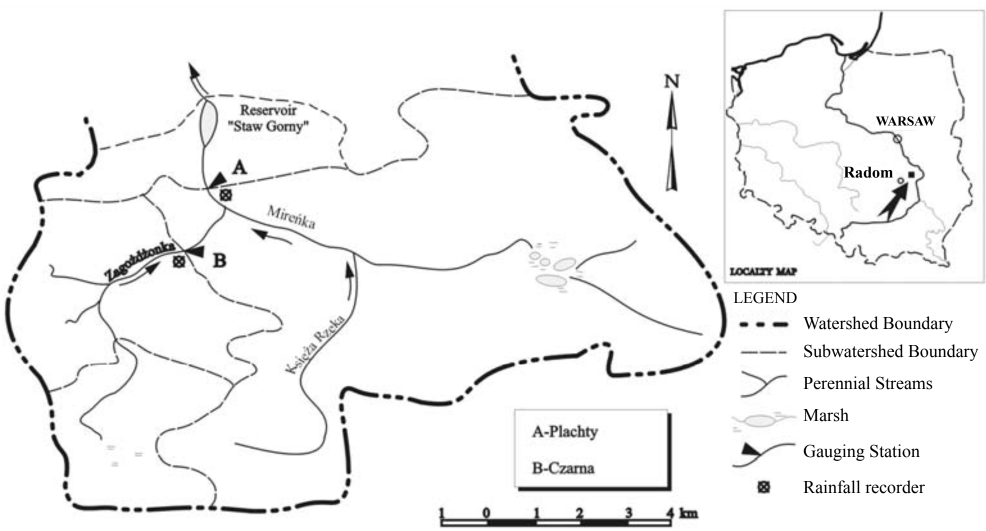

FIGURE 1. Locality map of the watershed

i.e. 3.8 km^2 upstream of Czarna and 19.8 km^2 upstream Plachty gauge station. So the catchment area, which contribute to direct runoff and sediment delivery to river system, upstream of the Czarna gauge, is 19.6 (i.e. 23.4–3.8) km^2. Land use is dominated by arable land (small grain and potatoes). 20% of the contributing area is covered by forest, 70% is arable lands, 9.4% is pastures and 0.6 is paved areas. The dominant soil type is sandy soil, ranging from almost pure to loamy sands. In local depressions and river flood planes, peaty soils can be found. Generally sandy soils cover over 90% of watershed to Czarna gauging station.

Measurement and characteristics of the events: River flow has been estimated based on the water level continuous records upstream of sharp-crested weir (Fig. 2) and its rating curve, checked also by hydrometric current meter measurements. View of the stream gauging station is shown on the Figure 3. General characteristics of the collected data are presented in the Table 1.

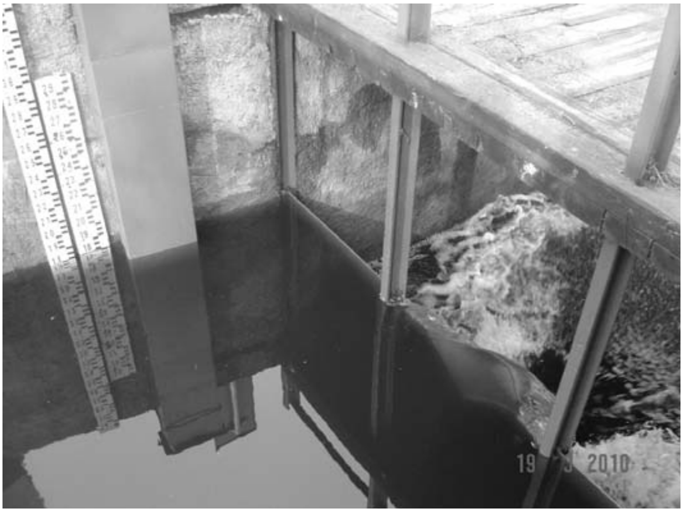

FIGURE 2. Upstream view of the sharp-crested weir of the gauging station at Czarna

TABLE 1. General characteristic of 15 collected snowmelt events of Zagożdżonka River at Czarna gauge

Category	Average	Range
1	2	3
Runoff, H (mm)	4.37	0.60–17.7
Direct runoff, H_D (mm)	3.27	0.26–16.1
Peak discharge, Q_{max} (m^3/s)	0.766	0.144–3.44
$Q_{max}/WQ_{50\%}$	0.74	0.14–3.31
Sediment yield (Mg)	2.20	0.32–9.75
Event mean SSC	19.5	10.7–25.2

Where $WQ_{50\%}$ is two-year-flood discharge = 1.04 m^3/s.

FIGURE 3. View of the stream gauging station at Czarna (photo is looking upstream and was taken during snowmelt period at discharge, which is close to the 2-year flood)

METHODS OF FIELD INVESTIGATIONS

The gauging station in Czarna at Zagożdżonka River, operated by Warsaw University of Life Sciences – SGGW, Department of Water Engineering and Environmental Restoration, is equipped with electronic system of data collection and transmitting them through Internet. Beside water stage also continues water turbidity, air, soil and water temperature, precipitation with the 10 minutes time step were measured, recorded and transmitted. Also the depth of snow and snow water equivalent during the winter time are measured each day or twice a day during snowmelts period. The time integrated bathometers self-acting bathometers, refrigerated samplers and settling tanks collect samples for suspended sediment grain size analysis were also in use.

RESULTS AND DISCUSSION

In the period of 1998–2007 fifteen flood events, with continues suspended sediment concentration, were collected (Hejduk 2009). Characteristics of the events are presented in Table 2. Snowmelt floods in Zagożdżonka catchment were not rapid, but the amount of transported sediment was notable.

The mean annual sediment yield from Zagożdżonka catchment upstream of Czarna gauge was estimated for ca 60 Mg (Hejduk 2001). Sediment yield of the 15 analyzed snowmelt flood events fluctuated between 0.32–9.75 Mg, with the average value of 2.20 Mg (see column 8 in Tab. 2). Floods number 7 and 9 trans-

TABLE 2. Main parameters of the analysed snowmelt events of Zagożdżonka River at Czarna gauge

Counter	Beginning of the snowmelt period	Peak discharge – Q_{max} ($m^3 s^{-1}$)	Average discharge during the snowmelt period – Q_{mean} ($m^3 s^{-1}$)	Volume of base flow – V_{base} (10^3 m^3)	Volume of direct runoff – V_{direct} (10^3 m^3)	Mean event SSC – c (mg/l)	Sediment yield Y (Mg)
1	2	3	4	5	6	7	8
1	5.02.2001	0.265	0.114	23.6	13.0	18.8	0.69
2	20.01.2002	0.636	0.241	28.9	82.3	16.3	1.81
3	3.01.2003	0.164	0.093	24.8	14.7	10.7	0.42
4	1.02.2004	0.156	0.090	6.9	7.1	22.9	0.32
5	10.03.2004	0.627	0.157	15.3	8.8	19.8	0.48
6	22.02.2005	0.231	0.144	55.9	32.2	21.2	1.86
7	14.03.2005	3.444	1.268	43.3	316.3	25.2	9.07
8	23.12.2005	0.219	0.091	24.2	17.9	22.3	0.94
9	20.03.2006	2.781	0.792	118.4	295.7	23.5	9.75
10	5.11.2006	0.184	0.104	20.0	13.4	17.8	0.59
11	28.01.2007	0.144	0.118	21.4	5.0	19.7	0.52
12	31.01.2007	1.105	0.448	25.8	70.9	22.0	2. 13
13	2.02.2007	0.799	0.301	77.6	39.5	18.7	2.19
14	9.02.2007	0.307	0.184	42.3	20.5	16.7	1.05
15	13.02.2007	0.427	0.190	42.8	25.4	17.0	1.16
Minimum value		0.144	0.090	6.9	5.0	10.7	0.32
Maximum value		3.444	1.268	118.4	316.3	25.2	9.75
Average value		0.766	0.289	38.1	64.2	19.5	2.20

ported over 9 Mg of suspended sediment each. Relation of sediment yield in the events versus total flood volume is shown on Figure 4.

The relationship in the following form has been found:

$$Y = 18.6 \cdot V^{1.06}$$

where:
Y – sediment yield (Mg),
V – Volume of direct runoff (10^3 m^3).

With the coefficient of determination $r^2 = 0.962$.

The recorded value of mean SSC during the snowmelt floods contained in a range 16.29–25.21 (mg/l), with the average value of 19.5 (mg/l). The highest value of SSC has been observed during the biggest floods 7 and 9, where the water discharge was respectively 3.444 and 2.781 (m^3/s). The lowest SSC (10.7 mg/l) was observed during flood 3.

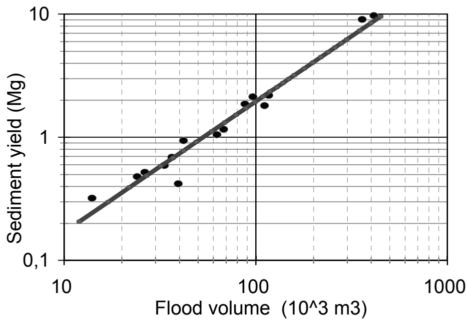

FIGURE 4. Sediment yield vs flood volume of snowmelt events in Zagożdżonka river at Czarna gauge

The relation between SSC and the water discharge in rainfall floods were studied by Williams (1989) and Jasson (2002). Usually five types of hysteresis occur and clock- and anticlockwise are the most common (Morris and Fan 1998). The relationship between SSC and the water discharge during snowmelt floods is not as well documented. In case of this investigation in most of the analyzed events the pick of suspediment sediment concentration occurred before the pick of flood flow. For majority of the floods (eleven cases), the relationship between SSC and the discharge shows the clock-wise hysteresis. In two cases (floods 2 and 15) this relationship shows the anticlockwise hysteresis and in two

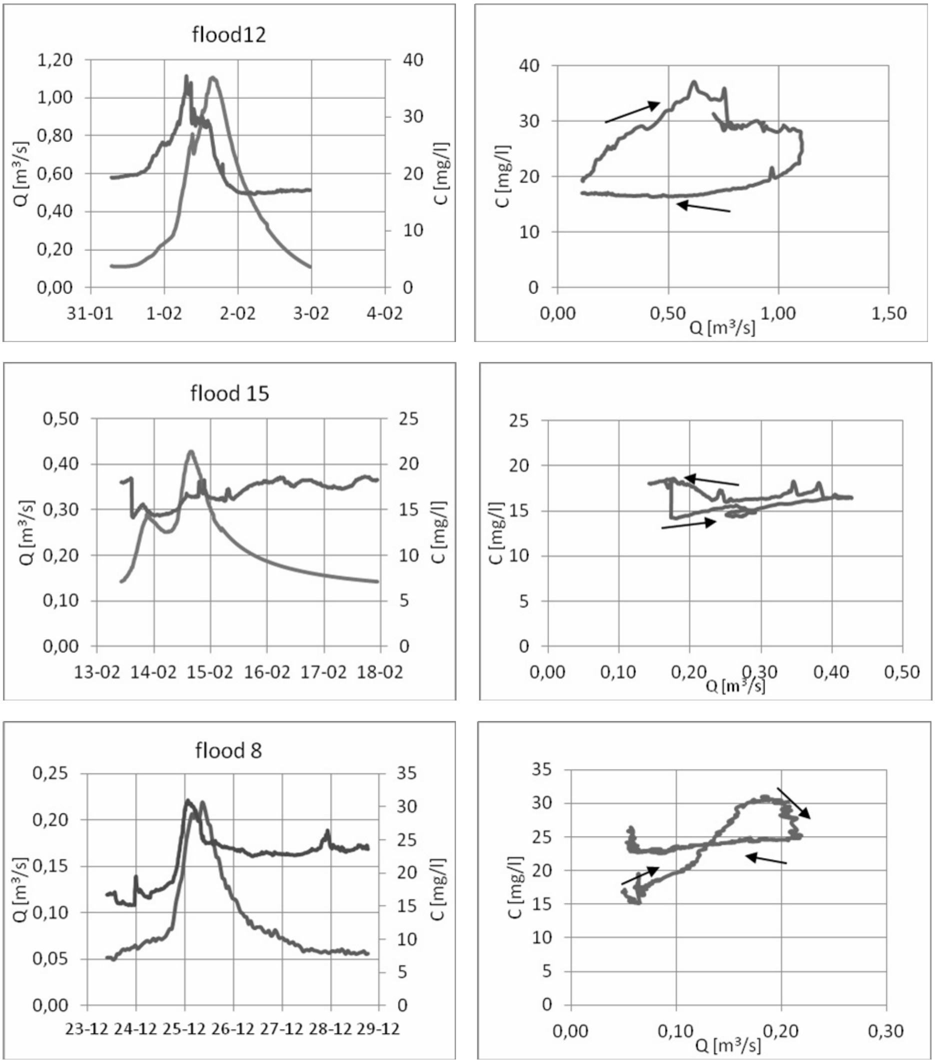

FIGURE 5. The examples of relationship between SSC and the water discharge; flood hydrographs and their SSC are shown on the left pictures and respective hysteresis are shown on the right pictures

others (floods 4 and 8) the hysteresis had an eight-shape.The example of the relationship between SSC and discharge is shown on Figure 5. The clock-wise hysteresis may suggest that in the first phase of the flood, the smallest particles are washed out and transported. In case of anticlockwise relation it can be assumed, that area snowmelt and precipitation variability causes sediment delivery from those parts of the catchment, which are more susceptible to erosion.

Suspended sediment concentration during the snowmelt floods is lower than during rainfall floods recorded in this catchment (Hejduk et al. 2006), and its average value is a bit higher than the mean annual SSC for Zagożdżonka River. Similar results presented Lenzi i Marchi (2000). The explanation of this phenomenon can be the fact that in summer the erosion of the slope is the main source of sediment particles transported with the water. The rain makes the mechanic impact on the surface, separates the particles which are moved by water runoff. In winter time the rain, which occurs during the snowmelt periods has an impact on snowmelt intensity, but doesn't have direct contact with soil surface, as long as the snow cover exists. Similar results have presented Lenzi i Marchi (2000) from the catchment in Dolomites. The soil moisture conditions as well as the conditions of freezing have great importance in the formation of surface runoff. (Øygarden 2003; Ollesch et al. 2006). In this investigation the soil hasn't been frozen during analyzed snowmelt periods.

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Streszczenie: *Koncentracja i wydatek rumowiska unoszonego w wezbraniach roztopowych w małej rzece nizinnej.* W pracy przedstawiono wyniki badań transportu rumowiska unoszonego, przeprowadzonych w małej zlewni nizinnej (A = 23,4 km^2) położonej na Równinie Radomskiej. Przeanalizowano 15 wezbrań z lat 2001–2007, dla których zarejestrowano kompletne dane obejmujące zasilanie zlewni, przepływ i koncentracje.

Analiza zależności koncentarcji z przepływem wskazuje na występowanie w większości z analizowanych zdarzeń histerezy prawostronnej (tj. zgodnej z ruchem wskazówek zegara). Koncentracja rumowiska unoszonego wzrastała wraz z przepływem, a jej kulminacja w większości z badanych przypadkach wystąpiła przed kulminacją przepływu. Ustalono zależność, statystycznie istotną, wydatku rumowiska od objętości wezbrania.

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