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DETERMINATION OF SEDIMENT DELIVERY RATIO IN DRAINING SYSTEMS

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ABSTRACT

Determination of the amount of sediment that outflows from the draining system via ditches, based on the known intensity of erosion processes in the catchments of this system, requires the calculation of a sediment delivery ratio (*SDR*). As a result of investigations into erosion and sediment transport processes, conducted in the main R-ditch of the Łączany draining system, the assessment of the applicability of the *SDR* has been conducted. as determined according to empirical formulas. The *SDR* was established using nine models, developed on the basis of studies of sediment runoff from river catchments. The obtained results of calculations were compared with the *SDR*, defined as the soil loss quotient (*E*) in the partial sub-catchments calculated using the *USLE* method, and the mean annual sediment transport (*T*), calculated on the basis of the bathometric measurements. For this purpose, the catchment area of the draining system was divided into seven sub-catchments, closed by measuring cross-sections, in which measurements of the suspended sediment concentrations were conducted. It was found that the calculated *SDR* values are significantly smaller than the *SDR* values determined according to the nine formulas. Using the tested empirical formulas, the calculated sediment transport in the draining system would be several to several dozen times larger than the actual sediment transport. Only in the case of the Williams and Brendt formula and the Williams formula, *SDR* values are similar to those obtained from calculations based on a given average annual intensity of erosion, and average annual sediment transport.

Keywords: *USLE*, *SDR*, erosion, sediment, suspended sediment concentration

INTRODUCTION

Siltation of draining ditches is one of the factors limiting the proper use of these systems. As a result of the accumulation of eroded earth material, technical equipment and engineering objects, which are located in the draining systems, are suffering damage. According to Józefaciuk and Józefaciuk (1999), surface flushes relatively rarely cause complete destruction of permanent structures, but they contribute to their silting up. This causes the necessity of their constant renovation. According to Pierzgalski et al. (2012), the accelerated de-capitalisation of irrigation devices in Poland resulted, among others, in the silting the bottom of ditches with silts deposited from the catchment, in the ditches overgrowing with rush vegetation, and in various failures, such as silting up of culverts, and sliding of escarpments. In the study by Pierzgalski et al. (2012), regarding the verification of the land improvement systems for flood protection in the water region of the central Vistula River, it was asserted "the effect of the above-mentioned processes was to exclude the drained complexes from the operation and maintenance records". This means that ensuring proper operation of draining systems, including their use, as well as carrying out repairs and maintenance

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of individual elements of these systems during their operation, requires a thorough study and understanding of surface erosion conditions of drained areas, the conditions of supply of erosion products to ditches and their transport, as well as the sedimentation in ditches. As part of the on-going operation of draining systems, there are no measurements conducted of sediment transport, which is the product of the erosion in the draining catchment, and the erosion of slopes and bottoms of the ditches. In that case, the intensity of erosion and debris transport processes can be determined by means of indirect methods, developed on the basis of empirical, semi-empirical, and theoretical formulas (Michalec, 2009). From among many empirical methods, developed on the basis of the measured intensity of sediment transport carried in the cross-sections of watercourses, or based on the results of studying the intensity of erosive processes in the catchment, we include the following methods: Brański (1975), Reniger-Dębski (Reniger, 1959; Dębski, 1959), as well as those based on the universal soil loss equation: *USLE* (Wischmeier and Smith, 1965) or *RUSLE* (Renard et al., 1997). Based on the specific intensity of erosion using the universal soil loss equation and the determined dimensionless sediment delivery ratio (SDR), an average yearly sediment transport in the watercourse can be calculated. In many scientific works, the said ratio is determined from the functional dependence developed by Roehl (1962), among others, in the works of Bogárdi et al. (1974), Banasik and Górski (1992), Bednarczyk et al. (2000), Zarissa et al. (2007), and James (2013). The sediment delivery ratio (SDR) has been determined by many researchers, including Maner (1958), Renfro (1975), Vanoni (Xiaoqing, 2003), Boyce (1975), Williams and Berndt (1972), Mutchler and Bowie (1976), Williams (1977), Mou and Menga (1980), Hession and Shanholtz (1988), or Tim et al. (1992). An attempt to assess the applicability of formulas developed by these researchers was presented in the work of Michalec et al. (2013). These formulas have been developed for specific regions, and hence their general applicability is limited (Kent Mitchell and Bubenzer, 1980; Kaffas and Hrissanthou, 2017). Despite this, some of the formulas are more commonly used, such as for instance the Roehl method in Poland. Furthermore, in the scientific literature, in which the formulas of various authors are cited, applied in the determination of the sediment delivery ratio, there are usually no limitations on their use, or information for which conditions they have been developed.

Determination of the amount of sediment that outflows from the draining system with ditches, based on the known intensity of erosion processes in the catchments of this system, requires the knowledge of the sediment delivery ratio (SDR). Its correct determination by means of the developed formulas may not be possible due to the relatively small surface areas of the draining catchment, and slight decreases in the area, as compared to the natural river catchments for which they were created. The present paper attempts to evaluate the possibility of using methods for determining the sediment delivery ratio in a draining system.

RESEARCH METHODOLOGY

The studies were carried out in the Łączany water-bearing draining system on the Vistula River. A detailed description of this system is included in the works of Michalec (2012), Majerczyk and Michalec (2013), Michalec et al. (2013b), and Majerczyk and Michalec (2017). Due to the damming up of the Vistula River waters at the Łączany water barrage, it was necessary to secure the adjacent areas against the negative impact of the impact of this accumulation on the groundwater regime. The draining system created for this purpose for the right-bank areas along Vistula River is shown in Figure 1. The main element of this system is the main R draining ditch, taking off water from the drained area with a gravitational outlet to the Vistula River. The total area of the drained zone has been divided into sub-catchments in such a way that it is possible to determine for these catchments the outflow of sediment in the designated measurement cross-sections. In the seven cross-sections, hydrometric measurements of the water flow rate and suspended sediment concentration were made.

Hydrometric measurements of water flow velocity were made using the direct method, with the application of a hydrometric mill. The measurements were made in accordance with the “IMGW Measurement Procedure” (2002), designating hydrometric poles in each of the cross-sections. In these poles, depending

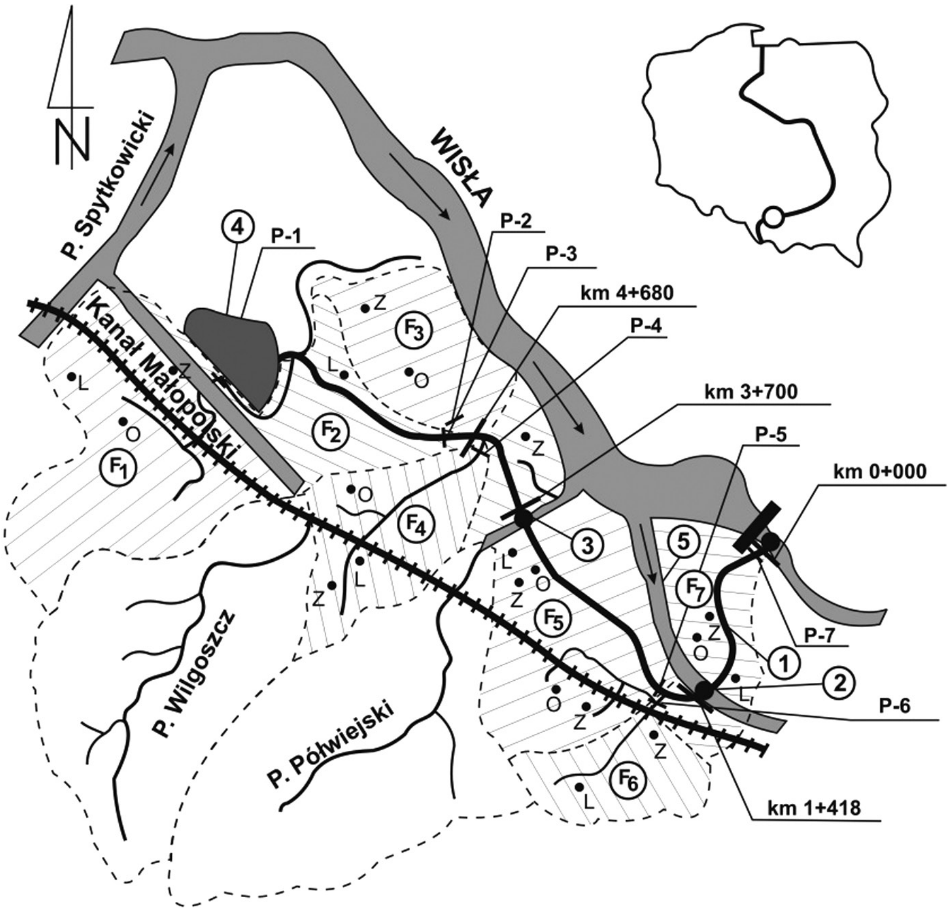

Fig. 1. Łączany draining system subdivided into sub-cachments. Soil sampling sites are marked: O – arable land, L – forests – Z – grassland, T – urbanized areas

on the filling, the water flow velocity was measured on at least three heights of the hydrometric pole, using the Nautilus C200 OTT inductive hydrometer.

Measurements of weight concentration of the suspended sediment were made in accordance with the method of water sampling, using the bottle bathometers [“Instruction for the execution...” 1990; Brański, 1966]. The sampling of water using a bottle collector was made at one point of the draining ditch cross-section, that is at its axis, at a depth of approximately 5 cm. Nine measurement series were conducted from May to November 2016. One measurement series consisted of performing measurements within one day, in the seven designated cross-sections of watercourses, marked as P-1 to P-7 in Figure 1, and serving as measurement cross-sections. In each measuring series, along with water sampling, the sediment concentration measurements in the whole cross-section were also taken. Measurements were made using the previously calibrated Portable Suspended Solids Monitor 740 from Partech. This measurement, being the so-called multi-point measurement (Brański, 1966), was performed in the same hydrometric poles, which were designated for the measurements of water flow velocity. The results of point measurements of sediment concentration in the measurement cross-sections made it possible to calculate the average daily lift value. These calculations were made using the so-called normal method, used by the Polish hydrological service (“Instruction for the execution...”, 1990; Brański, 1966). The calculation of suspended sediment transport based on point measurements is not reliable because it does not take into account the concentration of this sediment in the whole cross-section. On the basis of the performed concentration measurements at the water sampling point, and the concentration calculated for the whole cross-section, a correction coefficient (k) was determined for each cross-section of the draining ditch. This coefficient was determined from the linear regression function between the sediment volume concentration (C_p), determined on the basis of point measurements, and the sediment volume concentration (C_m), determined on the basis of measurements in the entire cross-section of the draining ditch. For the developed regression correlations, the Pearson R linear correlation coefficients were also determined, based on which it was possible to conclude whether the developed correlations are statistically significant at the assumed significance level of α, amounting to 0.05.

During the measurements of suspended sediment concentration, a series of water flow velocity measurements were also performed in each of the seven cross-sections. Simultaneous measurements of sediment concentration and water flow velocity measurements made it possible to determine the average diurnal intensity of sediment transport, corresponding to the average diurnal water flow in a given measurement cross-section. For this purpose, for each cross-section, the dependence of the sediment concentration at the sampling point (C_p) was developed as a function of the flow rate (Q). According to the recommendations given by Bates and Watts (1988), these correlations are described by regression equations in the power function. From these dependencies $C_p = f(Q)$, for annual mean flows, the mean annual sediment concentration at the C_{ps} measurement point was determined. Then, taking into account the correction factor (k), developed for each of the cross-sections, the mean annual concentration of suspended sediment C_{ms} in the whole measurement cross-section was calculated. Based on the debris concentration, the average annual sediment transport was calculated. For this purpose, sediment transport per second (U) was calculated as the product of the average annual flow (SQ) and the corresponding mean annual concentration of sediment at the C_{ps} measurement point. Knowing the sediment transport per second, the average annual sediment transport (T) was calculated in the given measurement cross-section.

In order to calculate the sediment delivery rate (SDR), for the given average annual sediment transport (T) in a given measurement cross-section, it was necessary to calculate the average annual mass of eroded soil (E) in the given sub-catchment. This was calculated from the universal soil loss equation USLE (Wischmeier and Smith, 1965). The USLE equation is a product of the following parameters: R – means the annual average rainfall and runoff erosivity factor, K – determining soil susceptibility to erosion, LS – dimensionless length coefficient and slope, C – dimensionless cropping management factors and mode of use, and P – dimensionless coefficient of anti-erosion treatments in the catchment.

In order to calculate the average annual mass of eroded soil, soil samples were collected in each of the designated catchments. These tests made it possible to determine the mechanical composition of the soil. From each of the sub-catchments (see: Figure 1), soil samples were collected from three types of land: forest, agricultural and meadow. The granulometric composition, both of the soil samples taken in the tested catchments and the samples of sediments taken from the bottom of the draining ditches, was determined using the Cassagrende method modified by Prószyński [PN-R-04032]. The results of these analyses were applied in the determination of the parameters for the universal soil loss equation (*USLE*). Other data necessary for calculations using the *USLE* method, such as lengths of watercourses, the slopes of the catchments, and lengths of individual contours, as well as the types of use and surface areas of particular land use categories of the analysed catchments, were determined from map foundations in the AutoCad program.

Having the information on the average annual sediment transport (T) in the given measurement cross-section, the values of the sediment delivery rate (SDR) was calculated. This rate was calculated as the quotient of soil losses in the partial catchments (E), calculated using the *USLE* method, and the average annual sediment transport (T), calculated on the basis of the bathometric measurements. The sediment delivery rate (*SDR*), calculated according to this method, has been compared with the one defined by other formulas, developed by various authors:

– Roehl's formula (1962), in which the *SDR* index is described as a function of the catchment area (*F* [mi²]):

$$\log SDR = 1.91349 - 0.33853 \cdot \log (10 \cdot F) \quad (1)$$

– Maner's formula (1958), in which the *SDR* depends on the height difference between the lowest and the highest point of the catchment (R_R), and catchment length (*L*), expressed in miles:

$$\log SDR = 2.962 + 0.869 \cdot \log R_R - 0.854 \cdot \log L \quad (2)$$

– Renfro's formula (1975), which is grounded upon the study of the 14 catchments in Texas, based on Maner's works from the 1950s, made the value of *SDR* dependent on the catchment area (*F*), expressed in square miles:

$$\log SDR = 1.7935 - 0.1419 \cdot \log F \quad (3)$$

– the formula developed by Vanoni in 1975 (Xiaoqing, 2003) based on the analysis of sediment ruonff results from more than 300 catchments of Europe and the United States, where the catchment area (*F*) is expressed in square miles:

$$SDR = 0.42 \cdot F^{-0.125} \quad (4)$$

– the formula developed by the Department of Agriculture of the United States (Boyce, 1975) which is an extension of the Vanoni model, in which the catchment area (*F*) is expressed in square miles:

$$SDR = 0.51 \cdot F^{-0.11} \quad (5)$$

– Boyce's formula [1975], in which the catchment area (*F*) is also expressed in square miles:

$$SDR = 0.31 \cdot F^{-0.3} \quad (6)$$

– the formula developed by Williams and Brendt (1972), which is a regional equation for catchments located in Texas, in which the *SDR* depends on the slope of the main watercourse (*I*), in the following form:

$$SDR = 0.627 \cdot I^{0.403} \quad (7)$$

– the formula by Mutchler and Bowie (1972), in which the sediment delivery rate depends on the catchment area (*F*) expressed in square miles and the annual runoff (R_A), where R_A is calculated as the product of constant 0.09, annual average rainfall (*P*) and runoff rate (R_V):

$$SDR = 0.488 - 0.006 \cdot F + 0.01 \cdot R_A \quad (8)$$

– Williams's formula (1977), developed for catchments located in Texas, takes into account the *CN* [−] number of the *SCS* curve, the catchment area (F [mi²]), the difference in height between the lowest and the highest point of the catchment (R_R) and the catchment length (*L*), expressed in miles:

$$SDR = 1.366 \cdot 10^{-11} \cdot F^{-0.1} \cdot \left(\frac{R_R}{L}\right)^{0.363} \cdot CN^{5.444} \quad (9)$$

RESULTS

On the basis of laboratory analyses of soil samples collected in partial catchments of the Łączany draining system, it was found that in these catchments the soils are almost homogeneous as far as their granulometric composition is concerned. The catchment area is made up of coarse silts or clayey silts with fine sands, constituting no more than 10% of their composition. Table 1 shows the percentage share of particular land uses in the total area of each of the sub-catchments, enclosed within individual measurement cross-sections.

Based on the calculated parameters of the universal soil loss equation for particular sub-catchments (see: Table 2), the mean annual mass of eroded soil was determined, marked with symbol *E* in Table 2. The calculation of the *SDR* sediment delivery rate for the established mean annual mass of eroded soil in a given sub-catchment requires determining the average value of annual sediment transport in the measurement cross-sections of the draining ditch *R*, which is enclosing these catchments.

Table 1. Percentage share of particular land uses in the total area of respective sub-catchments, enclosed within individual measurement cross-sections

Cross-section	Area of sub-catchment [km^2]	Share of the particular land use [%]			
		O	L	Z	T
P-1	$F_1 = 2.84$	64	6	22	8
P-2	$F_1 + F_2 = 2.84 + 1.32 = 4.16$	55	4	31	10
P-3	$F_3 = 1.41$	44	0	47	9
P-4	$F_4 = 1.59$	42	5	33	20
P-5	$F_1 + F_2 + F_3 + F_4 + F_5 = 2.84 + 1.32 + 1.41 + 1.59 + 6.60 = 10.73$	53	3	32	12
P-6	$F_6 = 0.55$	21	49	26	4
P-7	$F_1 + F_2 + F_3 + F_4 + F_5 + F_6 = 2.84 + 1.32 + 1.41 + 1.59 + 6.60 + 0.55 + 1.10 = 12.38$	51	5	32	12

Where: O – arable land, L – forests – Z – grassland, T – urbanized areas

Table 2. Parameters of the *USLE* equation for partial sub-catchments, enclosed within particular measurement cross-sections

Cross-section	Parameters of the USLE equation					
	R [Je · year^{-1}]	K [t · ha^{-1} · Je^{-1}]	LS [–]	C [–]	P [–]	E [t · rok^{-1}]
P-1	86.5	0.749	1.912	0.162	0.4	2279.7
P-2	86.5	0.731	1.901	0.158	0.39	3081.3
P-3	86.5	0.711	0.161	0.118	0.3	49.4
P-4	86.5	0.713	2.763	0.134	0.4	1452.3
P-5	86.5	0.682	1.671	0.138	0.43	6276.6
P-6	86.5	0.623	0.674	0.054	0.9	97.1
P-7	86.5	0.671	1.654	0.133	0.43	6797

Directional coefficients of the established linear regression equations, which are correction factors *k* together with the values of Pearson R linear correlation coefficients, are presented in Table 3. Correlation coefficients R of the developed correlations are greater than the critical values of this coefficient; and also statistic values $|t|$ are greater than critical values of the t_0 test. This means that the obtained correlations are statistically significant at the adopted significance level of $\alpha = 0.05$.

Knowing the concentration of sediment at the sampling point (C_p) as a function of the flow rate (Q), the correlations of $C_p = f(Q)$ were developed for each of the seven measurement cross-sections. An exemplary curve for the P-1 cross-section is shown in Figure 2.

From the dependence $C_p = f(Q)$, we have determined the average annual sediment concentration in the measurement cross-sections (C_{ps}) for the annual average flow (*SQ*) established for each measurement cross-section, according to the Punzet formula ["Construction of pumping station..." 1975]. The average annual sediment concentrations in the measurement cross-sections (C_{ps}) are shown in Table 4. The products of these concentrations and the respective correction factors *k* (see: Table 3) are shown in Table 4 as the mean annual sediment concentration in the C_{ms} measurement cross-section.

Table 3. Correction coefficients *k* determined for particular measurement cross-sections

Cross-section number	P-1	P-2	P-3	P-4	P-5	P-6	P-7
Correction coefficient *k*	1.284	1.188	1.241	1.237	1.221	1.328	1.211
Pearson's R correlation coefficient	0.9685	0.9623	0.9898	0.9935	0.9966	0.9907	0.9967
Sample size *n*	10	10	10	9	10	6	10
The critical value of Pearson's correlation coefficient for $\alpha = 0.05$	0.6319	0.6319	0.6319	0.6664	0.6319	0.7545	0.6319
Statistics *t*	10.99	10.01	19.70	23.05	34.18	14.57	34.97
Critical value of statistics t_0 for $\alpha = 0.05$	2.306	2.306	2.306	2.365	2.306	2.5706	2.306

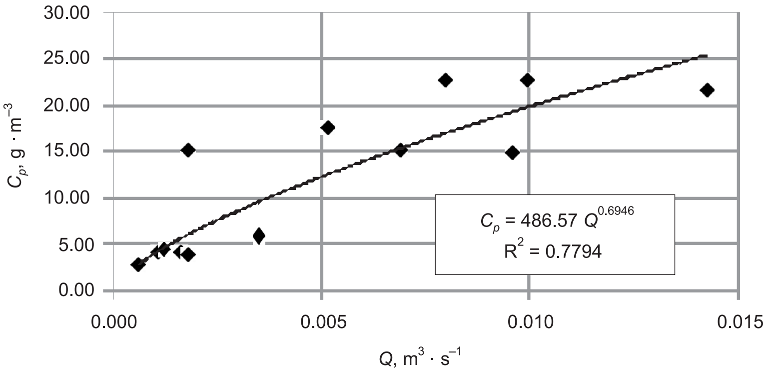

Fig. 2. Correlation between the sediment volume concentration at the sampling point (C_p) as a function of the flow rate (Q), developed for the P-1 measurement cross-section

Table 4. Calculation results of the mean annual suspended sediment concentration C_{ms} in the measurement cross-sections, corresponding to the mean annual flow rates *SQ* in these cross-sections

Cross-section	Equation $C_p = f(Q)$	Mean annual discharge SQ [m$^3 \cdot$ s^{-1}]	Mean annual concentration at point C_{ps} [g · m^{-3}]	Coefficient *k*	Mean annual concentration in particular cross-section C_{ms} [g · m^{-3}]
P-1	$C_p = 486.57Q^{0.6946}$	0.026	38.56	1.284	50
P-2	$C_p = 808.32Q^{0.8196}$	0.036	53.11	1.188	63
P-3	$C_p = 570.69Q^{0.6986}$	0.011	24.44	1.241	30
P-4	$C_p = 5273.7Q^{1.0513}$	0.015	63.77	1.237	79
P-5	$C_p = 290.35Q^{0.3998}$	0.095	113.30	1.221	138
P-6	$C_p = 500.61Q^{0.5739}$	0.005	23.93	1.328	32
P-7	$C_p = 1629.4Q^{0.8726}$	0.109	235.55	1.211	285

The calculated sediment transport per second (*U*), as the product of the average annual flow (*SQ*) and the corresponding mean annual sediment concentration in the measurement cross-section (C_{pm}), as well as mean annual sediment transport (*T*) and soil losses (*E*) in sub-catchments are given in the Table 5. The table also includes the calculated values of the sediment delivery ratio (SDR), as the quotient of soil losses in sub-catchments (*E*) calculated using the *USLE* method, and mean annual sediment transport (*T*), calculated on the basis of bathometric measurements.

The calculated sediment delivery rate (SDR) for each of the seven sub-catchments, ranging from 1.8 to 20.4%, was compared in Table 6 with the following formulas: (1) Roehl's, (2) Maner's, (3) Renfro's, (4) Vanoni's, (5) Department of Agriculture of the United States, (6) Boyce's, (7) Williams and Brendt's, (8) Matchel and Bowie's, and (9) Williams's.

Table 5. Sediment delivery ratio (*SDR*) determined on the basis of the results of bathometric sediment concentration measurements and soil losses calculated by means of the *USLE* method

Cross-section	Mean annual flow *SQ* [$m^3 \cdot s^{-1}$]	Sediment concentration in cross-section C_{mb} [$g \cdot m^{-3}$]	Transport per second *U* [$g \cdot s^{-1}$]	Mean annual sediment transport *T* [$t \cdot year^{-1}$]	*E* [$t \cdot year^{-1}$]	*SDR* [%]
P-1	0.026	50	1.31	41.18	2279.71	1.8
P-2	0.036	63	2.30	72.50	2359.64	3.1
P-3	0.011	30	0.32	10.10	49.42	20.4
P-4	0.015	79	1.15	36.32	1452.27	2.5
P-5	0.095	138	13.15	414.67	5499.05	7.5
P-6	0.005	32	0.17	5.36	97.09	5.5
P-7	0.109	285	31.17	983.08	5730.51	17.2

Table 6. Sediment delivery ratio (*SDR*) determined from the formulas developed by: (1) Roehl, (2) Maner, (3) Renfro, (4) Vanoni, (5) the US Department of Agriculture, (6) Boyce, (7) Williams and Brendt, (8) Matchel and Bowie (9) Williams

Cross-section	SDR [%] calculated from the formula:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	*SDR* = E/T
P-1	36.4	45.7	53.6	41.5	50.5	30.2	14.8	65.0	8.6	1.8
P-2	32.0	24.7	50.8	39.6	48.4	26.9	11.0	64.7	5.8	3.1
P-3	46.2	6.4	59.2	45.3	54.5	37.2	6.0	65.3	3.5	20.4
P-4	44.3	46.2	58.2	44.6	53.8	35.9	14.8	65.3	8.9	2.5
P-5	23.2	18.5	44.4	35.2	43.6	20.2	9.6	63.2	4.3	7.5
P-6	63.5	75.2	67.7	51.0	60.5	49.3	18.7	65.5	8.7	5.5
P-7	22.1	16.8	43.5	34.5	42.9	19.4	9.2	62.8	4.0	17.2

CONCLUSIONS

The obtained values of the sediment delivery rate (*SDR* = *E/T* as shown in Table 6), based on the results of soil loss calculations (*E*) in designated catchments and the results of sediment transport calculations (*T*) amount to several percentage points, except for the P-3 cross-section and the P-7 cross-section, for which the *SDR* is over twenty per cent and over seventeen per cent, respectively. The calculated *SDR* values are much lower than the *SDR* values determined according to nine formulas. By using the tested empirical formulas, the calculated sediment transport in the draining system would be several to several dozen times larger than the actual transport.

In river systems, whose catchment areas range from a few hectares to several square kilometres, the sediment delivery rate is several dozen per cent, which has been demonstrated by the use of methods proposed by different authors. As the catchment area increases, the value of the sediment delivery rate decreases, which is explained by Boyce's theory (1975), according to which the steepest catchment areas are the main sedimentary areas, and because the average slope increases with the catchment area, the intensity of erosion per unit of the area decreases. In addition, according to Boyce (1975), in larger catchments there are more places to stop sediments between the source and estuary areas of the catchment. The values of the sediment delivery rate of the draining system in the studied catchments, determined on the basis of the sediment balance, are between a few to a dozen times lower than those determined using empirical formulas. These catchments are mostly located in the Vistula River valley, and they are characterized by small slope gradients, only the upper parts of the F-1, F-4, F-5 and F-6 catchments are characterized by significant land differences and significant height decreases. However, these are not the catchments with the typical character of river catchments, and perhaps for this reason the *SDR* calculated using the formulas, in which the size of the catchment's area is an independent variable, turned out to be too high. The results obtained of *SDR* calculation according to empirical formulas indicate that only in the case of formula (7), developed by Williams and Brendt, and formula (9), developed by Williams, they are similar to the results obtained from the calculations based on a given average annual intensity of erosion and average annual sediment transport, determined based on bathometric measurements. Williams and Brendt (1972) provided the formula in which the *SDR* was dependent on the slope of the main watercourse (*I*), and according to Williams (1977), when determining the *SDR*, the *CN* of the *SCS* curve should be taken into account, as well as the size of the catchment area and its average slope, which is determined by the difference the height between the lowest and the highest point of the catchment and the length of the catchment. Perhaps these are the most appropriate parameters for the development of an empirical formula for determining the sediment delivery rate in the catchments of draining systems.

Over-estimation of the sediment delivery rate in the draining system could result in oversizing of its individual elements, e.g. retention reservoirs, or sumps at pumping stations due to sedimentation limiting their capacity. These formulas were developed based on data on natural river catchments. This means that in the case of the draining system subjected to the analysis, the use of empirical formulas to calculate the sediment delivery rate will result in erroneous results of sediment transport calculations. Furthermore, the results indicate the need to be very cautious in using the formulas available in the literature in the calculation of the *SDR*. If these formulas are used, the results of sediment transport calculations in the catchments of draining systems based on a given intensity of erosive processes may be burdened with overestimation compared to the actual values. It is therefore necessary to carry out additional tests in other draining systems, in order to obtain confirmation of the possibility of generalizing the obtained test results.

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OKREŚLENIE WSKAŹNIKA DOPŁYWU RUMOWISKA W SYSTEMIE ODWADNIAJĄCYM

ABSTRAKT

Określenie ilości rumowiska, odpływającego rowami systemu odwadniającego na podstawie znanego natężenia procesów erozyjnych w zlewniach tego systemu, wymaga dysponowania wskaźnikiem dopływu rumowiska (*SDR* – sediment delivery ratio). W wyniku badań procesów erozji i transportu rumowiska unoszonego w rowie głównym R systemu odwadniającego Łączany, dokonano oceny możliwości zastosowania *SDR* wyznaczonego według formuł empirycznych. Wskaźnik ten wyznaczono za pomocą dziewięciu wzorów, opracowanych na podstawie badań odpływu rumowiska ze zlewni rzecznych. Uzyskane wyniki obliczeń porównano z wartością *SDR*, określoną jako iloraz strat glebowych (*E*) w zlewniach cząstkowych obliczonych metodą *USLE* i średniego rocznego transportu rumowiska (*T*), obliczonego na podstawie wyników pomiarów batometrycznych. W tym celu powierzchnię zlewni systemu odwadniającego podzielono na siedem zlewni cząstkowych, zamkniętych przekrojami pomiarowymi w których wykonano pomiary koncentracji rumowiska unoszonego. Stwierdzono, że obliczone wartości *SDR* są znacznie mniejsze od wartości *SDR* określonych według dziewięciu formuł. Przy stosowaniu testowanych formuł empirycznych obliczony transport rumowiska w systemie odwadniającym okazałby się większy od kilku do kilkudziesięciu razy od transportu rzeczywistego. Jedynie w przypadku wzoru Williamsa i Brendta i wzoru Williamsa wartości *SDR* są zbliżone do otrzymanych z obliczeń, na podstawie określonego średniego rocznego natężenia erozji i średniego rocznego transportu rumowiska.

Słowa kluczowe: *USLE*, *SDR*, erozja, rumowisko, koncentracja rumowiska unoszonego