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Influence of Restored External Spoil Tip of a Lignite Mine on the Discharge in a Cross-Border Watercourse (PL–CZ)

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1. Introduction

In recent decades, the need for research on the impact of lignite mine spoil tips on hydrographic conditions and the magnitude of flows in watercourses has been frequently reported both in Poland and abroad; however, no adequate methodology has been developed for such research so far. Moreover, there is no up-to-date information on the hydrological and hydraulic inventory of watercourses in the vicinity of reclaimed sites and water structures on these watercourses (Stachowski et al. 2013, Szafrański et al. 2011). The case also becomes very important when such studies concern catchment areas located in cross-border zones (Czamara et al. 2009, Wiatkowski et al. 2015).

Opencast lignite mining is always associated with the disturbance of the landscape and groundwater conditions. It results from deep transformations of the natural environment, carried out by opencast mining (Kasztelewicz et al. 2007a, Kocher et al. 2009, Kołodziejczyk et al. 2007, Rehor & Ondrácek 2008). Both the soil cover and geological structure, as well as landform features and the structure of soil use (Bender 1995, Szafrański et al. 2011) are subject to considerable changes, which are followed by a change in water conditions and a visible impact on soil degradation, devastation and infertility (Dimitrijević et al. 2014). Excavation pits and soil tips are formed and the area is drained (Szafrański et al. 2011). Operation in opencast mines requires rational and environmentally friendly engineering solutions (Oparin et al. 2012; Kasztelewicz et al. 2007b) because only properly performed reclamation gives an opportunity to minimise the negative effects of mining interference in the natural environment and to return to conditions similar to those prevailing before exploitation (Galiniak et al. 2015), including water conditions and the hydrographic network.

The Report on the Lower Silesia Province Environment Condition (WPOŚWD 2008) shows that the Lower Silesia region is ranked second in Poland in terms of the area of degraded and devastated land. The reasons for such a situation should be seen primarily in the intensive development of industry, including operations related to mining and energy sectors. One of the areas degraded on a large scale in the past by removing overburden and forming a spoil tip is "Turów" Lignite Mine in Bogatynia. Negative impact in this region is manifested by land transformation, destruction of the natural morphology of the area and disturbance of the water regime (WPOŚWD 2008, Opracowanie 2005). The cross-border character of the watercourses flowing through the spoil tip, including the Bezimienny Stream (Czech: Minkovický Potok), is of the interest to the R Group, which deals, among others things, with the issues of the impact of the external spoil tip on the surface waters on the Czech side. This is performed within the framework of the agreement between the Government of the Republic of Poland and the Government of the Czech Republic on the water management of border waters.

This paper presents an assessment of the impact of the reclaimed external spoil tip of the "Turów" Lignite Mine on the volume of flows in the cross-border watercourse of the Bezimienny Streem – Minkovický Potok, on the Polish-Czech border. Furthermore, the paper presents the methodology of hydrological and hydraulic calculations for the needs of such an assessment and indicates possible needs for flood protection of the areas located below the spoil tip on the Czech side.

2. Material and method

2.1. The water catchment area of the Bezimienny Stream

In the hydrographic division of the external spoil tip of the "Turów" Lignite Mine, the catchment area of the Bezimienny Stream (Czech: Minkovický Potok) belongs to the "eastern mountain slope region." Surface waters from its area reach the Lusatian Neisse via the river Witka (Czech: Smědá) at the 167+300 km of its course. The spoil tip in the Bezimienny Stream catchment was commenced in 1980 and completed in 1991. The surface drainage in this area is based on drainage ditches, embankments and sedimentation tanks, which are made as the works on the formation of particular levels of the spoil tip body progress. The construction of these facilities resulted in a significant increase in the retention capacity of the catchment area (Wojarnik & Iwaniak 2009).

The Bezimienny Stream (Czech: Minkovický Potok) is a left-bank tributary of the river Witka (Czech: Smědá), to which it flows at the 19+250 km of its course on the territory of the Czech Republic, in Minkovice. Until 1980, in the area of Wigancice Żytawskie, the Bezimienny Stream served as a reservoir for water from drainage ditches and drainage systems. The catchment area of the analysed profile of Tank No. 4, determined on the map in the scale 1:25000, is 1.08 km^2 (Fig. 1).

The southern part of the catchment area has large declines of up to 20%. The declines in the central and northern parts are between 2 and 5%. The ordinate of the area in the calculative profile H_o is 253.5 m a.s.l. The ordinate of the area on the water divide H_{max} is 378.4 m a.s.l. The average decline in the catchment area is 12.02%. The actual average decline in the catchment area is much lower, with more than two thirds of the catchment area falling by 2-5%. A large decline – about 20% – occurs only in the area of Świniec Mountain, on a small area. The length of the Bezimienny Stream valley is approx. 1.0 km. The Bezimienny Stream Valley was divided by two partitions, forming dry retention reservoirs.

The land use pattern in the catchment area of the Bezimienny Stream is as follows: arable land (0.76 km^2, i.e. 70%), grassland (0.22 km^2, i.e. 20%), forests (0.10 km^2, i.e. 10%).

On the 1:5 000 scale situation and altitude map (Fig. 2), the borders of partial catchment areas in the profiles of individual sedimentation tanks were determined, marking them with an index corresponding to the numbering of particular tanks. The catchment areas were determined together with their characteristics, including the area of slopes, shelves and tops of the spoil tip, the average decline of the catchment area and the degree of afforestation. The total area of the catchment area in the profile of Tank No. 4 is 1.45 km^2, of which 0.82 km^2 is the spoil tip (Wojarnik & Iwaniak 2009).

2.2. Climate characteristics

The precipitation characteristics for the area of the eastern slope of the external spoil tip, including the catchment areas of the Okleśna and Bezimienny Streams, were prepared based on the study (Prace 2008). For hydro-meteorological calculations, the values of precipitation recorded with the rain gauge and pluviograph, situated at an altitude of 320 m a.s.l on the eastern slope of the spoil tip, were assumed. The measurements of precipitation were carried out during the summer half-year (i.e. from May to October). The amounts of precipitation recorded at rainfall stations of the Institute of Meteorology and Water Management (IMiGW) in the close vicinity, i.e. in Wyszków [330 m a.s.l.] and Bogatynia [295 m a.s.l.], were used as a reference material.

Fig. 1. Catchment of the Bezimienny Stream – original condition

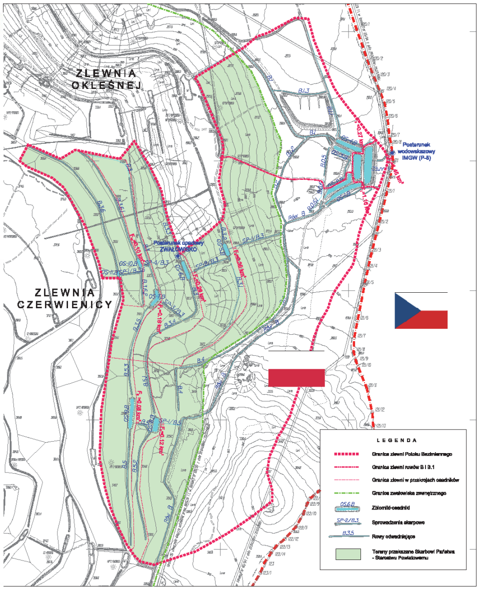

Fig. 2. Catchment of the Bezimienny Stream – current condition

Based on the lists of daily precipitation sums presented in the work (Measurement and Research Report 2002-2008), a breakdown of monthly and annual precipitation sums covering the years 2002-2008 was made in comparison with the average monthly and annual precipitation for the years 1971-2000. The work also presents the average monthly air temperatures for the Działoszyn station.

2.3. Hydrology – maximum likelihood flows

The calculations of maximum flows with a specified likelihood of occurrence due to the lack of measurements of water levels were performed with empirical formulae. As experience in engineering practice shows, the maximum annual flows with a certain likelihood of exceeding are the basic hydrological characteristics. For catchment areas where long-term observation lines exist, these flows are determined using generally accepted methods based on the analysis of likelihood curves of maximum flows. The situation is different in the case of catchment areas where long-term observations of water levels and flow measurements are not carried out. In such a case, indirect methods are used, characterised by a much higher degree of uncertainty. These are hydraulic analogy and empirical methods (Banasik et al. 2012, Wałęga & Młyński 2015).

In this paper, the Wołoszyn's method was adopted due to the fact that it is the most suitable for the Lower Silesia region (Wołoszyn 1967). It takes into account the intensity of rain that causes maximum flows. This method uses the analysis of the elements of the catchment area and assumes that the relations established for Wrocław are important for regional localities. The Wołoszyn's method consists in transposing the rain intensity from the station in Wroclaw to regional stations. Rainfall intensity is presented as a function of its duration and the likelihood of exceeding it with the storminess index, defined as the product of the many-year average of precipitation and the air temperature for the months from May to September. This relation applies to catchment area of the up to 100 km^2 (Wołoszyn 1967, Czamara & Krężel 1983). In the Wołoszyn's method, applied in this paper to calculate the flows of large waters, a significant role of the forest influence on the magnitude of runoff (surface runoff velocity) is emphasised. Specialists pay great attention to the fact that the forest is able to take over and store considerable amounts of water for some time, delaying the flow of water, reducing the culmination of large waters and limiting the frequency of floods (Miler 2015, Mioduszewski 2016, Stasik et. al 2011).

The map in the scale of 1:25 000 was used to determine the catchment area in the calculation profile of water discharge from the Tank No. 4.

2.4. Reduction in swelling flows in sedimentation tanks

In order to determine the retention capacity of the Bezimienny Stream catchment, in the profiles of sedimentation tanks, calculations of the reduction of large water flows ($Q_{1\%}$ and $Q_{10\%}$) were carried out based on the mapped swell hydrograph, assuming that the falling time of the wave t_o is equal to 2 times the concentration time t_k ($t_o = 2t_k$) (Metodyka 2009). The usable capacity of the sedimentation tanks was used to calculate the reduced flow $Q_{1\%reduced}$ and $Q1_{0\%reduced}$, which were then increased by the flows authoritative for the sedimentation tanks located below, assuming that the waves peaks overlap (unfavourable option).

2.5. Maximum likelihood flows in the stream gauge profile

On the Bezimienny Stream, below Tank No. 4, the Wigancice Żytawskie (P–8) water gauge station is located, belonging to the Institute of Meteorology and Water Management in Wrocław, where water levels and flows have been observed since 1995.

On the basis of data obtained from the "Turów" Lignite Mine (Measurement and Research Report 2002-2008), measurement sequences were compiled from the maximum annual flows of WQ [$m^3 \cdot s^{-1}$]. The above data were used to calculate the likelihood flows, using statistical methods. Calculations were made with the Kaczmarek's method and additionally with the maximum likelihood method (Metodyka 2009).

2.6. The capacity of the Bezimienny Stream river bed and the structure located in the Czech Republic territory

As the Bezimienny Brook (Minkovický Potok) in the Czech Republic serves as a reservoir of drainage and rainwater, the capacity of the Stream's river bed was calculated. The flow $Q_{max} = 1.19\ m^3 \cdot s^{-1}$ (corresponding to the flow of p = 20%), calculated for the 1.45 km^2 catchment area, was used as the basis for the dimensioning of the Streams' river bed. In addition, an analysis of the impact of existing communication structures on the flow conditions of large waters was carried out. This is extremely important as the condition for proper functioning of irrigation and drainage systems is to maintain the network of ditches with structures in technical efficiency (Mioduszewski 2016, Wiatkowski & Gruss 2017).

3. Test results

3.1. Precipitation

Average monthly and annual total precipitation for Bogatynia, Wyszków and Zwałowisko stations are listed in Table 1. Average annual rainfall of 1971-2000 ranges from 704 mm in Bogatynia to 720 mm in Wyszków. Between 2002 and 2008, the average monthly precipitation totals in the period from May to September at the stations in Bogatynia and Zwałowisko are similar. Compared to Bogatynia, lower precipitation at the Zwałowisko station was recorded only in June (8 mm) and in July (14 mm), whereas in August, it was 14 mm higher.

The maximum recorded daily precipitation of 144 mm was recorded at the Zwałowisko rainfall station on 10 August 2007. The highest intensity of rainfall occurred between 3 p.m. and 4 p.m. when about 100 mm of rain fell on the spoil tip. Much lower amounts of precipitation were recorded in Bogatynia (69.5 mm) and in Wyszków (45.8 mm), which proves that that exceptionally heavy precipitation had a very local character (Wojarnik & Iwaniak 2009).

3.2. Air temperatures

Average monthly air temperatures for the Działoszyn station, quoted in this work (Wojarnik & Iwaniak 2009), are summarised in Table 2.

Table 1. Monthly and annual mean total precipitation for the stations in Bogatynia, Wyszków and Zwałowisko

Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Climate station Bogatynia [295 m a.s.l]													
2002-2008	53.1	34	36.9	37.3	58	53.5	101	112.6	52.8	53.6	57.1	41.3	689.4
1971-2000	38	32	42	44	68	94	96	90	59	48	47	46	704
Precipitation station Zwałowisko [320 m a.s.l.]													
2002-2008	-	-	-	-	62.3	61.9	87.2	126.5	49.9	56.1	-	-	-
Precipitation station Wyszków [330 m a.s.l.]													
1973-2000	45	37	47	49	69	84	93	84	59	46	52	55	720

Table 2. Mean monthly air temperature in °C for Działoszyn station

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
-2.8	-2.9	2.3	6.9	11.6	14.4	16.8	16.6	13.1	8.2	2.4	-0.1	7.2

3.3. Maximum likelihood flows

The following data were used for calculations:

- Water catchment area F = 1.08 km^2,
- Longest runoff course L = 1.92 km,
- h_{max} = 300.00 m a.s.l.,
- h_{min} = 253.50 m a.s.l.,
- Mean decline of the catchment area $I_{average}$ = 4.47%,
- Afforestation of the catchment area Z = 10%,
- Runoff velocity v = 1.61 m·s^{-1} (as read for mean decline and afforestation).

The list of maximum likelihood flows in the calculative profile is presented in Table 3.

Table 3. Summary of maximum likelihood flows calculated by the Wołoszyn's method

p [%]	1	2	5	10	20	50	100
Reduction coefficient	1	0.70	0.47	0.33	0.23	0.15	0.10
$q_{p\%}$ [m^3·s^{-1}·km^{-2}]	7.86	5.50	3.69	2.59	1.81	1.18	0.79
$Q_{p\%}$ [m^3·s^{-1}]	8.49	5.94	3.99	2.80	1.95	1.27	0.85

3.4. Drainage system in the external spoil tip

The spoil tip in Bezimienny Stream catchment area started in 1980 and was completed in 1991. As the spoil tipping progressed, reclamation operations were carried out, including the formation of slopes and spoil tipping shelves as well as the afforestation of slopes. In the catchment area of the Bezimienny Stream, all the reclaimed land on the external spoil tip of the area 0.82 km^2 is owned by the State Treasury under the control of the County Office in Zgorzelec. Parallel to the reclamation works, a number of surface drainage solutions were constructed, such as drainage ditches, slope flows, and sedimentation tanks. The total length of the drainage ditches located on the shelves of the spoil tip is approx. 5.7 km, and on the foreland of the spoil tip – approx. 3.2 km. In order to secure the purity of the Bezimienny Stream waters and increase the flood retention in Wigancice, Tank No. 4 was constructed on the foreland of the spoil tip, which consists of the following:

- OS–1.B and OS–2.B sedimentation tanks in the mouth section of ditch B;
- OS–3.B and OS–4.B sedimentation tanks in the mouth section of ditch B.1;
- Two-chamber retention reservoir (4.1 and 4.2).

In the current operating manual of Tank No. 4, two variants of operation of the sedimentation tanks and the reservoir were adopted:

- Variant I assumes simultaneous operation of the sedimentation tanks OS–2.B and OS–3.B and chamber 4.2 of the reservoir;
- Variant II, on the other hand, envisages simultaneous operation of the OS–1.B and OS–4.B sedimentation tanks and chamber 4.1 of the reservoir.

List of sedimentation tanks with their characteristics is given in the Table 4 below.

Table 4. Summary of sedimentation tanks in the catchment area of the Bezimienny Stream

Sedimentation tank name	Dimensions of the bottom [m]		MaxPP [m a.s.l.]	Maximum sedimendation level [m a.s.l.]	Volume in m^3		
	Length	Width			V_{max}	V_{os}	$V_{uż}$
OS-11.B	17	5.0	354.60	353.76	350	190	-
OS-10.B	34	6.0	339.50	337.95	660	160	500
OS-9.B	108	10.0	341.00	339.44	2880	510	2370
OS-8.B	50	15.0	330.40	329.60	1790	940	850
OS-7.B	66	10.0	337.40	336.50	1910	960	950
OS-6.B	72	11.0	323.10	321.90	2360	910	1450
OS-5.B	43	13.0	300.00	298.60	2060	790	1270
OS-4.B	-	-	-	-	2510	680	850
OS-3.B	-	-	-	-	3740	1650	1830
OS-2.B	-	-	-	-	3740	850	2890
OS-1.B	-	-	-	-	4300	660	3640
Reservoir 4.2	-	-	-	-	5130	1160	3970
Reservoir 4.1	-	-	-	-	9200	2200	7000
Total:					40630	11660	27570

3.5. Maximum likelihood flows in the profiles of sedimentation tanks

Due to a too short a period of hydrological observations (14 years) made by the Institute of Meteorology and Water Management at the Wigancice Żytawskie (P–8) water gauge station, the calculation of the flows of large waters with a certain probability of occurrence was performed with the use of the Wołoszyn's method. Drainage coefficient α was adopted depending on the percentage share of the slope area in the calculative catchment area, as shown in Table 5.

Table 5. Summary runoff coefficient values on the "Turów" Lignite Mine external Soil tip

No.	Share of slopes in the total area	Drainage coefficient α
1	0-10	0.30
2	10-20	0.35
3	20-30	0.40
4	30-40	0.45
5	40-50	0.50
6	50-60	0.55
7	60-70	0.60
8	70-80	0.65
9	80-90	0.70

The process and calculation results are presented on the example of Tank No. 4 and the results are presented in Tables 6-8.

Calculation data:

- Water catchment area of the Fzl = 1.45 km^2
- Longest runoff course L = 2.260 km
- h_{max} = 372.,20 m a.s.l.
- h_{min} = 253.50 m a.s.l.
- Mean decline of the catchment area $I_{average}$ = 9.86%
- Afforestation of the catchment area Z = 70%. For the mean decline and afforestation the run-off velocity v = 1.08 m·s^{-1} as was read.

The list of maximum likelihood flows in the calculative profile is presented in Table 6.

Table 6. Summary of maximum likelihood discharge calculated using the Wołoszyn's method in the profile of Tank 4

p [%]	1	2	5	10	20	50	100
Reduction coefficient	1	0.81	0.6	0.45	0.33	0.21	0.14
$q_{p\%}$ [$m^3 \cdot s^{-1} \cdot km^{-2}$]	8.29	6.71	4.97	3.73	2.74	1.74	1.16
$Q_{p\%}$ [m^3/s]	12.02	9.74	7.21	5.41	3.97	2.52	1.68

3.6. Reduction in swelling flows in sedimentation tanks

Sedimentation tank OS–11.B (Fig. 2), due to its small retention capacity, was excluded from the calculations of flood wave reduction, assuming that it has only a sedimentation function.

Table 7 shows the reduced flows of $Q_{1\%reduced}$ and $Q_{10\%reduced}$ in the profiles of sedimentation tanks.

Table 7. Summary of results of calculations of flows $Q_{10\%}$ and $Q_{1\%}$ in profiles of sedimentation tanks/reservoirs

Sedimentation tank's name	$Q_{1\%}$ [$m^3 \cdot s^{-1}$]	$Q_{1\%reduced}$ [$m^3 \cdot s^{-1}$]	$Q_{10\%}$ [$m^3 \cdot s^{-1}$]	$Q_{10\%reduced}$ [$m^3 \cdot s^{-1}$]	Comments
OS–10.B	1.52	0.85	0.68	0.23	
OS–7.B	1.52	0.68	0.53	0.04	
OS–6.B	2.20	1.09	0.72	0.09	
OS–5.B	2.77	1.65	0.83	0.22	
OS–9.B	1.25	0.00	0.56	0.00	
OS–8.B	0.61	0.03	0.28	0.00	
OS–2.B	7.87	5.29	3,01	1.42	Variant I
OS–1.B		4.98		1.22	Variant II
OS–4.B	3.20	1.83	1.44	0.52	Variant II
OS–3.B		1.18		0.09	Variant I
Reservoir 4.2	6.47	3.61	1.51	0.13	Variant I
Reservoir 4.1	7.34	2.92	1.86	0.00	Variant II

Table 8. Summary of discharge calculations $Q_{10\%}$ and $Q_{1\%}$ in the profiles of sedimentation tanks/reservoirs

Sedimentation tank's name	Designation of the catchment area	Area of the catchment area [km^2]	Average decline in catchment areas [%]	Afforestation [%]	Drainage speed [m·s^{-1}]	Final time [h]	Drainage coefficient [-]	Authoritative flows calculated by the Woloszyn's [m^3·s^{-1}·km^{-2}] [m^3·s^{-1}]			
								q10%	Q10%	q1%	Q1%
OS10.B	F_{10}	0.10	10.28	90	0.73	0.31	0.65	6.82	0.68	15.16	1.52
OS-7.B	F_7–F_{10}	0.06	6.94	90	0.64	0.29	0.45	5.06	0.30	11.24	0.67
	F_7	0.16	8.80	90	0.69	0.39	0.60	5.28	0.85	11.74	1.88
OS-6.B	F_6–F_7	0.10	6.04	90	0.57	0.28	0.60	6.82	0.68	15.15	1.52
	F_6	0.26	10.06	90	0.72	0.48	0.60	4.38	1.14	9.74	2.53
OS-5.B	F_5–F_6	0.09	10.57	90	0.74	0.25	0.65	8.19	0.74	18.21	1.64
	F_5	0.35	12.20	90	0.78	0.52	0.60	4.13	1.45	9.18	3.21
OS-9.B	F_9	0.08	4.95	90	0.48	0.27	0.60	7.03	0.56	15.62	1.25
OS-8.B	F_8–F_9	0.04	6.25	90	0.58	0.25	0.55	6.90	0.28	15.34	0.61
	F8	0.12	6.35	90	0.59	0.28	0.55	6.25	0.75	13.90	1.67
OS-2.B OS-1.B	F_1-F_8-F_5	0.69	15.04	80	1.10	0.53	0.60	4.04	2.79	8.97	6.19
	F_1	1.16	11.02	80	0.92	0.63	0.60	3.49	4.04	7.75	8.99
OS-4.B OS-3.B	F_3	0.27	7.56	80	0.90	0.27	0.45	5.33	1.44	11.83	3.20
Reservoir No. 4	F_{res4}	1.45	10.37	70	1.08	0.58	0.60	3.73	5.41	8.29	12.02

Table 7 shows that in tanks and reservoirs located in the catchment area of the Bezimienny Streem, a reduction in the flow $Q_{1\%}$ = 12.02 $m^3 \cdot s^{-1}$ (Tab. 7) will be noted, depending on the variant of operation of Tank No. 4, to:

- $Q_{1\%reduced}$ = 3.61 $m^3 \cdot s^{-1}$ – for variant I
- $Q_{1\%reduced}$ = 2.92 $m^3 \cdot s^{-1}$ – for variant II

and flow $Q_{10\%}$ = 5.41 $m^3 \cdot s^{-1}$ (Tab. 8) to:

- $Q_{10\%\ reduced}$ = 0.13 $m^3 \cdot s^{-1}$ – for variant I
- $Q_{10\%\ reduced}$ = 0.00 $m^3 \cdot s^{-1}$ – for variant II

As a result of changes in the management of the catchment area, including forest reclamation, and after taking into account the retention of sedimentation tanks located on the shelves of the spoil tips in the catchment area of the Bezimienny Stream, the calculated values of flows of large waters significantly decreased. The results obtained confirm the information presented in the literature (Miler 2015, Mioduszewski 2016, Stasik et al. 2011).

3.7. Maximum likelihood flows in the gauge profile

Table 9 presents measurement sequences from the maximum annual flows of WQ [$m^3 \cdot s^{-1}$].

Table 9. Summary of maximum annual flows WQ [$m^3 \cdot s^{-1}$] from the gauging station P–8 water recorded in 1995-2008

Summer Half-year						
1995	1996	1997	1998	1999	2000	2001
3.00	0.16	0.17	0.11	0.11	0.15	0.34
2002	2003	2004	2005	2006	2007*	2008
0.49	0.12	0.18	0.25	0.61	3.95*	0.51
Winter Half-year						
1995	1996	1997	1998	1999	2000	2001
0.23	0.09	0.03	0.02	0.13	0.11	0.20
2002	2003	2004	2005	2006	2007	2008
0.49	0.25	0.11	0.35	0.33	0.22	0.18

*Due to the incidental, exceptionally catastrophic rainfall caused by an atmospheric storm, 2007 was not taken into account in the calculation for the summer half-year.

The above data were used to calculate the likelihood flows, using statistical methods. Calculations were made with the currently used Kaczmarek's method (Czamara & Krężel 1983) and with the maximum likelihood method. Due to the short period of hydrological observations (14 years), the results obtained are treated as comparative. As the results obtained using the Wołoszyn's method are based on maximum likelihood flows, calculated on the basis of precipitation take place from May to September, the following calculations were made separately for summer and winter half-year periods.

3.7.1. Maximum annual rain flows

The results of calculations for the summer half-year (rainy) are presented in Tables 10-11 and on the likelihood scale (Kaczmarek's method).

Table 10. Maximum likelihood rain flows calculated by the Kaczmarek's method in the water profile Żytawskie Wigancice on the Bezimienny Stream

p%	50%	10%	5%	3%	1%	0.3%	0.1%
$Q_{max\ p\%}$	0.3	1.0	1.3	1.6	2.1	2.7	3.2
$Q_{max} + \delta\ (Q)$	0.4	1.4	1.9	2.3	3.1	4.1	5.0

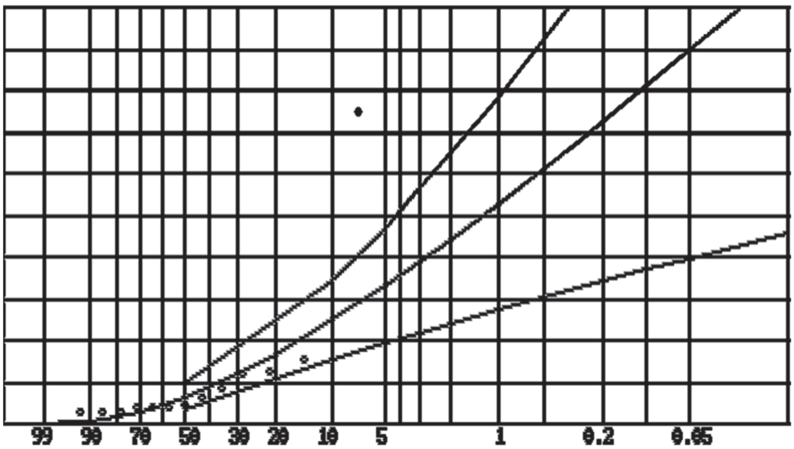

Fig. 3. Graph of likelihood curve in the water profile Żytawskie Wigancice on the Bezimienny Stream – Kaczmarek's method, summer half-year

Table 11. Maximum likelihood rain flows calculated by the maximum likelihood method in the water profile Żytawskie Wigancice on the Bezimienny Stream

p%	50%	10%	5%	2%	1%	0.2%	0.1%
$Q_{max\ p\%}$	0.2	1.1	1.6	2.4	3.0	4.4	5.0

3.7.2. Maximum annual melt flows

The results of calculations for the winter half-year (snowmelt) are presented in Tables 12-13 and on the likelihood scale (Kaczmarek's method).

Tabela 12. Maximum likelihood melt flows, calculated with the Kaczmarek method in the water Profile Żytawskie Wigancice on the Bezimienny Stream

p%	50%	10%	5%	3%	1%	0.3%	0.1%
$Q_{max\ p\%}$	0.1	0.5	0.7	0.8	1.1	1.4	1.7
$Q_{max} + \delta\ (Q)$	0.2	0.7	1.0	1.2	1.6	2.1	2.6

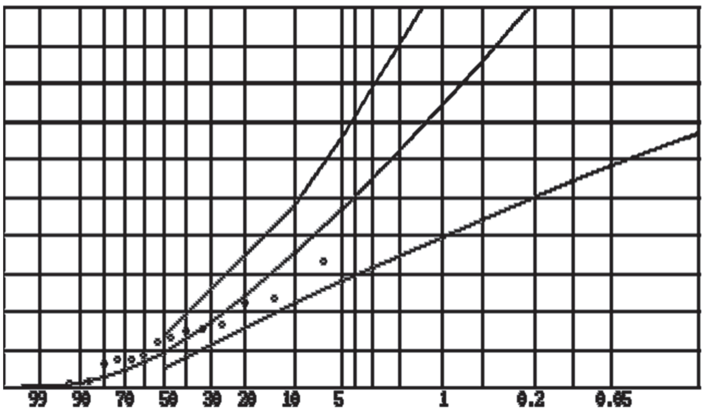

Fig. 4. Graph of likelihood curve in the water profile Wigancice Żytawskie on the Bezimienny Stream – Kaczmarek's method, winter half-year

Table 13. Maximum likelihood melt flows, calculated with the maximum likelihood method in water profile Żytawskie Wigancice on the Bezimienny Stream

p%	50%	10%	5%	2%	1%	0.2%	0.1%
$Q_{max\ p\%}$	0.1	0.4	0.6	0.8	0.9	1.2	1.4

The maximum likelihood flows in the gauge profile (Tank No. 4), calculated using the Kaczmarek's method and the maximum likelihood method, confirm the convergence of two applied calculation methods: empirical and statistical.

3.8. Flow capacity of the Bezimienny Stream river bed and the structure located in the Czech Republic territory

Minkovický Potok was regulated in 1994 at the length of 1.1 km, i.e. from the Frydlant-Višňová road bridge (km 0+000) to the state border (Studium hydrologiczne 1995). The hydraulic calculations made in the Study (Wojarnik & Iwaniak 2009) confirm that the river bed in the upper section will accommodate the regulatory flow assumed in the project. At flows greater than 1.7 $m^3 \cdot s^{-1}$, the adjacent area will be flooded.

Mainly, the conditions of the large waters flow in the estuary section are influenced by the existing communication structures, i.e.:

- The railway culvert located about 15 m from the left bank of the river Witka; dimensions: width b = 1.0 m, height h = 3.5 m,
- The road culvert situated 12 m above the railway culvert, dimensions; width b = 1.1 m, height h = 1.8 m.

According to the hydraulic calculations included in the study (Studium hydrologiczne 1995), the flow capacity of the road culvert is 2.8 $m^3 \cdot s^{-1}$ and is closely related to the water levels in the Witka river.

4. Conclusions

The catchment area of the Bezimienny Stream in the calculative profile before the transformation, i.e. before the start of overburden dumping on the external spoil tip, amounted to 1.08 km^2. The calculated flows of large waters with a certain probability of occurrence, for the original surface of the catchment area and the way in which the catchment was used at that time, are as follows:

- $Q_{10\%} = 2.80\ m^3 \cdot s^{-1}$, $q_{10\%} = 2.59\ m^3 \cdot s^{-1} \cdot km^{-2}$,
- $Q_{1\%} = 8.49\ m^3 \cdot s^{-1}$, $q_{1\%} = 7.86\ m^3 \cdot s^{-1} \cdot km^{-2}$.

Currently, after the transformation of the Bezimienny Stream catchment area, i.e. after the formation of the spoil tip, the execution of reclamation works and surface drainage facilities (ditches, embankments/slopes, and sedimentation tanks), the catchment area in the profile of Tank No. 4 amounts to 1.45 km^2, which is an increase of 33% in relation to the original area. Out of this area, the spoil tips cover 0.82 km^2, while the remaining 0.63 km^2 is the natural catchment area of the Bezimienny Stream.

The flows of large waters with a certain likelihood of occurrence, calculated for the current catchment area, without taking into account artificially created retention in sedimentation tanks, are as follows:

- $Q_{10\%} = 5.41\ m^3 \cdot s^{-1}$, $q_{10\%} = 3.73\ m^3 \cdot s^{-1} \cdot km^{-2}$,
- $Q_{1\%} = 12.02\ m^3 \cdot s^{-1}$, $q_{1\%} = 8.29\ m^3 \cdot s^{-1} \cdot km^{-2}$.

The results of the large water flow calculations show that the unit runoffs increased as a result of the catchment area transformation, for the probability of p = 10% by 1.14 $m^3/s/km^2$, i.e. by 44%, and for p = 1% by 0.43 $m^3/s/km^2$, i.e. by 5.4%.

As a result of the retention established in the sedimentation tanks, the floodwater flows are reduced. The calculated values of reduced flows of $Q_{10\%reduced}$ and $Q_{1\%reduced}$, using their total retention capacity, are as follows:

– for variant I (retention capacity approx. 16.000 m^3):

- $Q_{10\%reduced} = 0.13\ m^3 \cdot s^{-1}$
- $Q_{1\%reduced} = 3.61\ m^3 \cdot s^{-1}$

– for variant II (retention capacity approx. 19.000 m^3):

- $Q_{10\%reduced} = 0.00\ m^3 \cdot s^{-1}$
- $Q_{1\%reduced} = 2.92\ m^3 \cdot s^{-1}$

Calculations of the flow capacity of the Bezimienny Stream and water structures show that in Minkovice, in the Czech Republic, the minimum flow capacity of the river bed and water structures is approx. 1.7 $m^3 \cdot s^{-1}$. Higher flows will result in water from the river bed and flooding of adjacent areas.

The main cause of the flood risk in Minkovice are the existing transport structures (railway and road culverts), whose capacity does not ensure the drainage of large waters, and therefore they should be rebuilt.

In order to further improve the level of flood protection of areas located below Tank No. 4, it is advisable to rebuild the drain devices in order to ensure the possibility of regulating the outflow from the sedimentation tanks, as well as to increase the capacity of the inlet buildings to the settlers together with the adjacent sections of the supply ditches.

On the basis of calculations and analyses, it was stated that the construction of the external spoil tip together with the reclamation and the system of hydro-technical devices did not adversely affect the hydrological regime in the Bezimienny Stream catchment area.

The retention capacity established in the sedimentation tanks located in the Bezimienny Stream catchment area, with proper water management, improves flood protection of the areas located below Tank No. 4.

The presented methodology has been developed for the exploitation of the external spoil tip in Turów (south-western Poland, at the border with the Czech Republic). The main assumptions and principles of the work implementation are universal and can be used in other facilities of this type.

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Abstract

This article presents a novel method for the assessment of the influence of a restored external spoil tip in "Turów" Lignite Mine (Poland) on the discharge in the cross border watercourse called in Poland Bezimienny Potok and in the Czech Republic – Minovickỳ Potok. Moreover, possible flood protection needs of the areas below the spoil tip in the Czech Republic (below the Tank No. 4) are indicated. In the investigated area, after the spoil tip had been formed, restoration work was carried out, i.e. a forest was planted on it. This restoration work, combined with the surface drainage structures, helped to reduce the rate of surface runoff. This, in turn, reduced the flood risk, since the high water culmination and the frequency of flood events were reduced. The hydrological and hydraulic calculations of the watercourse channel and hydro-technical structures' flow capacity indicate that the creation of the external spoil tip followed by the restoration work and the system of hydro-technical devices do not adversely affect the hydrological regime in the Bezimienny Potok catchment area, near the village of Minkovice in the Czech Republic. The forests planted as part of the restoration work play a significant role in reducing the high water culmination and the frequency of flood events. These forests cover the entire surface of the spoil tip and slow down the runoff of water. Moreover, it was confirmed that alternative solutions based on reservoirs – waste ponds located in the Bezimienny Potok catchment area – will improve the flood protection of the areas located in the Czech Republic (thanks to their storage capacity and provided that appropriate water management is ensured). The main stages of the method used for the assessment of the influence of the external spoil tip of "Turów" Lignite Mine on the discharge in the investigated cross-border watercourse are explained by means of the calculation of maximum discharge with a given probability of exceedance by the Wołoszyn's method used in Poland in the Lower Silesia region. This method accounts for the intensity of rainfall. Moreover, in order to determine the retention capacity of the investigated watercourse catchment area, the reduction of high water discharge ($Q_{1\%}$ and $Q_{10\%}$) was calculated in the profiles of the sedimentation tanks, based on the reproduced hydrograph of the flood wave and with the assumption that the time required for the flood wave to go down t_o equals twice the time of concentration t_k ($t_o = 2t_k$). The sedimentation tanks' useful capacities were used to calculate the reduced discharge $Q_{1\%reduced}$ and $Q_{10\%reduced}$. These values were added to the design flows for the sedimentation tanks located below, with the assumption that the swell waves coincide (the most unfavourable case). The calculation of probable discharges was carried out using the Kaczmarek's method (adopted in Poland) and using the maximum likelihood method.

The methodology presented has been developed for the purpose of operation of the lignite waste external spoil tip in Turów (South-West of Poland, on the border with the Czech Republic). The main assumptions and implementation rules are universal and may be used for other sites of this kind.

Keywords:
open-cast mining, borrow pit and spoil tip management, river network, hydrological and hydraulic calculations, Wołoszyn's method, Kaczmarek's method, cross-border catchment

Wpływ zrekultowywanego zwałowiska zewnętrznego kopalni węgla brunatnego na wielkości przepływów w cieku transgranicznym (PL−CZ)

Streszczenie

W pracy zaprezentowano nowatorską metodę oceny wpływu zrekultywowanego zwałowiska zewnętrznego, znajdującego się w Kopalni Węgla Brunatnego „Turów" (Polska) na wielkości przepływów w cieku transgranicznym o nazwie Potok Bezimienny – Minovický Potok (Republika Czeska). Ponadto wskazano na ewentualne potrzeby w zakresie ochrony przeciwpowodziowej terenów położonych poniżej zwałowiska na terenie

Republiki Czeskiej (poniżej Zbiornika nr 4). Na omawianym obszarze po zakończeniu formowania zwałowiska prowadzono zabiegi rekultywacyjne, które polegały na zalesianiu. Przeprowadzone prace rekultywacyjne i wykonane urządzenia odwodnienia powierzchniowego przyczyniły się do zmniejszenia natężenia spływu powierzchniowego. To spowodowało zmniejszenie zagrożenia powodziowego poprzez zmniejszenie kulminacji wielkich wód i ograniczenie częstotliwości wezbrań. Wykonane w pracy obliczenia hydrologiczne i hydrauliczne przepustowości koryta cieku i budowli wodnych wskazują na to, że budowa zwałowiska zewnętrznego wraz z wykonaną rekultywacją i systemem urządzeń hydrotechnicznych nie wpływa ujemnie na reżim hydrologiczny w zlewni Potoku Bezimiennego w obrębie miejscowości Minkovice w Republice Czeskiej. Dużą rolę w zmniejszeniu kulminacji wielkich wód i ograniczeniu częstotliwości wezbrań pełnią powstałe w wyniku rekultywacji obszary leśne, obejmujące całą powierzchnię zwałowiska, które opóźniają spływ wody. Wyniki badań potwierdziły, że alternatywne rozwiązania wykorzystujące zastosowanie zbiorników wodnych – osadników zlokalizowanych w zlewni Potoku Bezimiennego, poprzez utworzoną pojemność retencyjną i przy właściwie prowadzonej gospodarce wodnej, wpłyną na poprawę ochrony przed powodzią terenów położonych w Republice Czeskiej. Główne etapy stosowanej metody oceny wpływu zwałowiska zewnętrznego kopalni węgla brunatnego „Turów" na wielkości przepływów w cieku transgranicznym wyjaśnione zostały za pomocą obliczeń przepływów maksymalnych o określonym prawdopodobieństwie przewyższenia metodą Wołoszyna stosowaną w Polsce w regionie Dolnego Śląska, uwzględniającą natężenie deszczu. Ponadto w celu określenia zdolności retencyjnej zlewni rozpatrywanego cieku, w przekrojach zbiorników-osadników przeprowadzono obliczenia redukcji przepływów wielkich wód ($Q_{1\%}$ i $Q_{10\%}$), opartej na odwzorowanym hydrogramie fali wezbraniowej, przy założeniu, że czas opadania fali t_o jest równy 2-krotności czasu koncentracji t_k ($t_o = 2t_k$). Pojemności użytkowe zbiorników-osadników posłużyły do obliczenia zredukowanego przepływu $Q_{1\%zred}$ i $Q_{10\%zred}$, o które następnie zostały powiększone przepływy miarodajne dla osadników położonych poniżej, przy założeniu, że szczyty fal nakładają się na siebie (wariant niekorzystny). Wykonane w pracy obliczenia przepływów prawdopodobnych wykonano obowiązującą w Polsce metodą Kaczmarka oraz dodatkowo metodą największej wiarygodności.

Przedstawiona metodyka została opracowana na potrzeby eksploatacji zwałowiska zewnętrznego kopalni Turów (południowo-zachodnia Polska, przy granicy z Czechami). Główne założenia i zasady realizacji prac mają charakter uniwersalny i mogą być wykorzystywane na innych tego typu obiektach.

Słowa kluczowe:
górnictwo odkrywkowe, zagospodarowanie wyrobiska i zwałowiska, sieć rzeczna, obliczenia hydrologiczne i hydrauliczne, metoda Wołoszyna, metoda Kaczmarka, zlewnia transgraniczna