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Investigations of Hydrological Regime Changes in an Area Adjacent to a Mine of Rock Raw Materials

Robert Kasperek[*], Mirosław Wiatkowski[*], Czesława Rosik-Dulewska[**]
[*]Wrocław University of Environmental and Life Sciences
[**]Institute of Environmental Engineering PAS, Zabrze

1. Introduction

Water conditions for a given area are the outcome of a number of various factors, either natural or related to the human impact on the natural environment [1,5,7,14,17]. Apart from the geological structure, these factors also include the surface morphology and the mining. The most important consequences of the open pit mining include the occupation and the transformation of land for the purpose of mining activities and the changes thus caused to the water conditions in the area adjacent to the pit in relation with its dewatering [13,15,16]. Open pit mining of calcareous aggregates requires the rock mass to be drained before other activities can commence. This involves sweeping changes in the water conditions in the area which is either directly used for exploitation, or only adjacent to it. These changes are concerned with the quality of both the surface and the groundwater, the water usage patterns and the transformation of the surface hydrographic network [3,9,10,23].

Drainage within the mine mainly shows through the formation of a depression cone and the change in the direction of the groundwater flow. This last phenomenon leads to a decreased flow in the surface watercourses. It also lowers the groundwater table and the humidity of soils, which ultimately translates to reduced yield of crop. Mine dewatering is related to the lowering of the groundwater table below the mining level and to the drainage of the precipitation water from the excavation site and its forefield [6,19,20,21]. The overall inflow of water to all the mines in Poland is estimated at 3 million m^3/day (24 hours), of which: 43% goes to the brown coal mining, 23% goes to the hard coal mining, 16% – rock raw material mining (including the Triassic limestone), 15% – zinc and lead ore mining and 3% – any others [4,11,24].

This paper analyses the impact of the rock (limestone) mining to the water conditions in the vicinity of mines. Our discussion is exemplified by the mine in Tarnów Opolski.

On the one hand the operation of this mine translates to the depression in the surrounding area and the lowering of the groundwater table. On the other, however, the dumping of mine water supplements the scarce surface water resources in the drainage basin of the river Struga. This water shortage is caused by the slotted structure of soil (Triassic limestone) and the low level of precipitation in this part of Poland. The dumping of water from the mine conditions the ecological continuity of the Struga watercourse and enables the ecosystem to develop by ensuring a certain supply of water for various purposes, e.g. agriculture or fire-fighting or other [2].

This paper is concerned with:

- a characterisation of the mine and of the river Struga,
- the measurements on the river Struga,
- an analysis of the precipitation and a hydrological calculation of inflow of the surface water from the drainage basin and from the pipelines that evacuate water from the mine,
- the hydraulic calculations of the flow capacity of the river and an initial numerical simulation of the water levels.

2. Characterisation of the Mine and of the River Struga

The limestone plant and the Tarnów Opolski mine are located to the south of Tarnów Opolski, between the villages of Kosorowice and Kamień Opolski and the town of Tarnów Opolski (Fig. 1). The surface in the area is slightly undulating, with slopes going down to the north and to the west. The elevation is in the range of 200 m ASL, with 185 m ASL in the mine and 173 m ASL in the region of Tarnów Opolski.

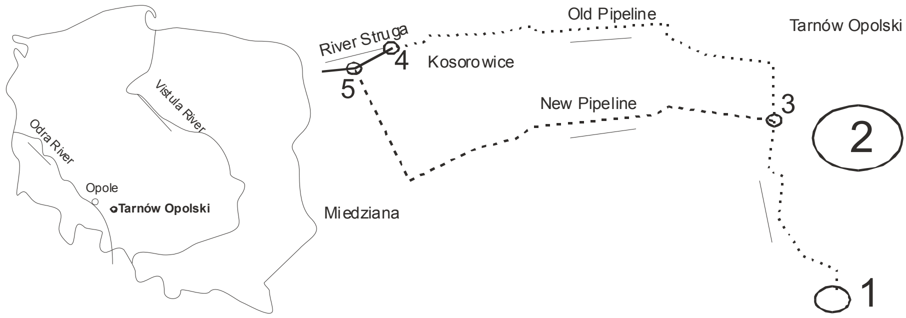


Fig. 1. Location of the research site and a schematic diagram of the system which evacuates water from the Tarnów Opolski mine to the river Struga: 1– the mine, 2–the production plant, 3–connection between the old and the new pipeline, 4–mouth of the old pipeline to the Struga river, 5–mouth of the new pipeline to the Struga river

Rys. 1. Lokalizacja obiektu badawczego i schemat systemu odprowadzającego wody kopalniane z kopalni Tarnów Opolski do rzeki Strugi: 1–kopalnia, 2–zakład produkcyjny, 3–połączenie starego i nowego rurociągu, 4–wylot starego rurociągu do rzeki Strugi, 5–wylot nowego rurociągu do rzeki Strugi

The mine is situated in the basin of the Struga which joins the Odra on its right bank. The mine and the limestone plant are located in the communes of Tarnów Opolski (the Opolski district) and Gogolin (the Krapkowicki district). Geologically, the area under study consists of the Quaternary and Triassic formations made of shell limestone. The thickness of the Quaternary layers varies from several dozen cm to about fifteen or so meters. The deposit of the Triassic limestone, which consists of the eastern and western field, is located almost entirely on the lands belonging to Kamień Śląski. Only about 3 ha belong to the commune of Tarnów Opolski. Currently, only the eastern field is used. The raw material being mined is used for the production of lime. The mining is done in two open pits at two levels: level 1 at 167–170 m ASL and level 2 at 155 m ASL. The second level is below the groundwater table and has to be continuously drained. Water from the mine is removed through pipelines to the Struga, and from there to the Odra (Fig. 1, 2, 3).

Originally, the existing old pipeline built in the 1970s had a capacity of about 8,000 m^3/day. Water from the receiving pit is transported through pumps and two steel pipelines of 500 mm in diameter and 650 m in length each. Next, both these pipelines join to form a third one, which is also made of steel, has a diameter of 800 mm and is 965 m long. There is a concrete collector in its final section having 1,000 mm in diameter with a mouth in the river channel of the Struga (Fig. 1). Currently both the mine water and the precipitation water flows through this pipeline.

The second pipeline, which is a new one, receives water from the mine and also evacuates it to the Struga. The mouth of this pipeline is about 300 m down of the mouth of the old pipeline. It is located on the left bank of the Struga (Fig. 1). The new pipeline is to receive all the water which is removed from the mine and helps to protect the inhabitants of the Kosorowice village from flooding during intensive rainfalls. This pipeline passes though the lands of the villages Tarnów and Kosorowice. According to the calculations carried out by the authors, the velocity of water "v" in the new pipeline depends on the volume of water discharged from the mine Q_z and varies from v=1.35 m/s for the current discharge Q_z=74,000 m^3/day to v=2.55 m/s for the forecast discharge Q_z=14,000 m^3/day.

3. Characterisation of the Areas Adjacent to the Mine and to the River Struga

3.1. Adjacent Areas

The Opolskie province is situated in the south-western part of the country. The area has a character of a compact basin with mountain fragments in it and is a lowland region with a poorly varied topographic profile. In the lowland band, the terrace-dune valleys, accumulation plains and old glacial denudation plains are dominant. The share of the cultivated land in the overall province surface is 62.7%, and that of the areas protected for their natural values is about 30% of the province.

<u>Soils</u>

The main factor which determines the spatial distribution and the quality of soils is the geological structure. The quality of soils, i.e. their production capacity is relatively high. This is proved by the existence of soils classified as very good and good (class I – III). Arable land constitutes 43.2% of the overall surface of the Opolskie province. The share of soils of medium quality (class IV) stands at 33.5%. The soils of poor quality are 22.4% of the total.

Mineral raw materials

The geological structure and the topographic profile are related to the type and availability of raw mineral materials. In the geological structure post-glacial forms prevail, which are the basis for the concrete-lime industry. The largest deposits are near Opole, Krapkowice and Strzelce Opolskie. Other raw materials include filling sands (13.9%), moulding sands (12.7%), natural aggregates (10.6%), silty raw materials (4.1%) and phyllite shales (100% of national resources). Other raw materials are of no importance for the industry.

Climate

The Opolskie province is one of the warmest regions in Poland. Most of the area belongs to the Lower Silesian Southern Climatic Region. According to the Romer's agricultural and climatic classification, the climate in the entire province is that of the submontage lowlands and valleys. One of the characteristic features of this climate is the low variation of temperature. The warmest town is Opole, with the average yearly temperature at 8.4°C and the coldest is Olesno with 7.7°C. The warmest month is July (av. temp. 18°C) and the coldest ones are January and February with the temperatures averaging about -1.5°C. The vegetation season starts early and lasts 200–225 days. The long growing season and the mild winters create favourable conditions for the agriculture in this area.

Precipitation

The multiannual average yearly precipitation for the investigated area is around 650 mm. An analysis of precipitation in the flood year 2010, during which intensive flooding took place in the village of Kosorowice among others, revealed that:

- over the period of 16–31 May the total precipitation amounted to only 76.8 mm,
- over the period of May–June–July the cumulative precipitation was 414 mm, i.e. two-thirds of the average yearly total,
- monthly precipitation totals were as follows: January 55.4 mm, February 24 mm, March 63.1 mm, April 51 mm, May 210 mm, June 70 mm, July 134 mm, August 89.3 mm, September 106.9 mm.

In the area under study, the amount of water from precipitation penetrating through infiltration to the water-bearing layers was 20% (115 mm/year) on the average.

3.2. The Struga River

The Struga joins the Odra on its right bank at km 145.35 in the region of the villages Przywory and Grotowice (Fig. 2). The total surface area of its drainage basin is 41 km^2. This basin includes several small watercourses and drainage ditches. The adjacent land consists of meadows, pastures, forests and arable land. The river starts at the mouth of the old pipeline which evacuates water from the mine. Part of the drainage basin dried due to the cone of depression formed as a result of aggregate mining. In the 1980s, some river regulation works were carried out on the Struga. Its channel was considerably widened and deepened. These works changed the conditions of water infiltration from the river to the ground. Apart from it, the flow capacity of the channel increased considerably. Measurements carried out by the authors in the drainage basin of the Struga prove that abundant rainfall has no influence on the increase of flow along the watercourse. The run-off of water at the start and at the end of the river remains the same and in some periods even decreases. This is caused by the specific geological structure of the river basin. A considerable increase in the run-off rate in the river over the last several years results from its widening and deepening and is also caused by the very good hydraulic conditions (systematic maintenance and strengthening of the river channel).

Fig. 2. The channel of the River Struga at its confluence with the Odra (left) and below the mouth of the pipeline from the Tarnów Opolski mine (right)
Rys. 2. Koryto rzeki Strugi przy ujściu do rzeki Odry (strona lewa) i poniżej wylotu rurociągu z kopalni Tarnów Opolski (strona prawa)

4. Water Conditions in the Facility – Research and Discussion

4.1. Cone of Depression within the Mine

In the Tarnów Opolski mine a constant drainage of water from the adjacent land can be observed. In natural conditions water was being received by the Struga River valley. Because of the dewatering of the mine a downflow of groundwater was forced from the main natural north-west (NW) direction to the south-east (SE) direction and to the centre of the excavation site.

The range of the mine depression cone is delimited by the isoline of the lowering of the water table with respect to the average multiannual position. The dynamics and the development of the depression cone depend on the discharge of the mine dewatering system, the geological structure, the hydrogeological conditions in the vicinity of the excavation site and the meteorological conditions (mainly the amount of precipitation) [6,14,15,19].

The range of the depression cone is now as follows:

- 4 km to the east (near Izbick),
- 2.7 km to the north and to the west (near Tarnów Opolski and Kosorowice),
- 2 km to the south (near Kamień Śląski).

The range of the depression cone visibly increases on the north-eastern side. Due to the intensive and long-lasting rainfall in the period from May to July 2010 and because of the spring melt in March and April 2010, the inflow of underground water to the mine increased markedly. As a result, the groundwater table rose in the mine and the intensity of pumping of water had to be increased too.

The monitoring of groundwater levels near the mine confirms a highly dynamic nature of the changes in the water table. In May 2010 the water table rose by 1.5 m within 15 days. A similar rise was observed in August 2010: up to 162.62 m in the area of Kosorowice and up to 170.68 m in the area of Izbick. Compared to May, this means a rise by 2.31 m and 3.29 m, respectively.

4.2. Mine Water Dumping into the Struga River

Because of the scarce surface water supply in the drainage basin of the Struga, an analysis was carried out of the management of water being dumped from the Tarnów Opolski mine to the Struga. Dumping of water to this river is fundamental for:

- its channel to be kept in an appropriate technical and natural condition. The most important role is to prevent the river from overgrowing due to the insufficient amount of water [8],
- its ecological continuity to be maintained,
- the various fire-fighting purposes,
- the groundwater table to be kept at an appropriate level in the forested areas, green lands and arable land [8],
- the irrigation and the supply of water to small reservoirs and fish ponds [22].

Calculations were carried out for the years 2010 and 2011. 2010 was the so called "flood year", during which heavy rainfall occurred in the river basin of the upper and central Odra, as well as on its tributaries. In contrast, the 2011 was a year of a very limited precipitation and even drought in the area under study. During the heavy rains in June 2010, it was necessary to increase the pumping of water to prevent the mine from being flooded. The pumping of water increased from 3,000 m^3/h to 4,200 m^3/h. Water from the mine was evacuated by the old concrete collector having 1,000 mm in diameter and passing through the village of Kosorowice to the Struga. The existing section of this collector is 2997 m long and has a diameter of 1,000 mm. In the region of Kosorowice this collector is not entirely watertight, which is due to its age and wear and to the technical problems or damage (very deep ploughing, the use of the pipeline by the inhabitants of Kosorowice for irrigation during dry years etc.). Over the last years, a new pipeline was built to transport the mine water. This pipeline is also intended to evacuate the excess amounts of water during extreme (abnormal) rainfalls.

The authors compared the mine water dumping to the Struga channel in selected research periods: in May 2010 and in November 2011. During this time, the mine water dumping volumes in m^3/day and the corresponding discharges on the river in m^3/s were at a similar level:

- May 2010: 73,400 m^3/day (0.850 m^3/s) – 74,000 m^3/day (0.856 m^3/s),
- November 2011: 65,250 m^3/day (0.755 m^3/s) – 74,400 m^3/day (0.861 m^3/s),
- The average dumped volume stood at 73,755 m^3/day (0.854 m^3/s) and 71,223 m^3/day (0.824 m^3/s) in May 2010 and November 2011, respectively.

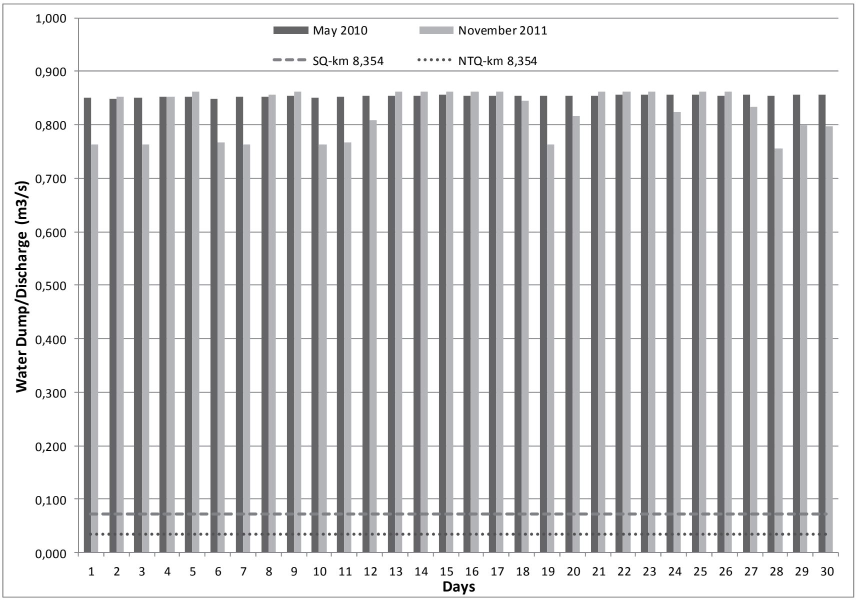
Our hydrological calculation of the so called own flows resulting from the inflow of water from the drainage basin to the Struga river showed that:

- the average multiannual discharge SQ took the following values: 0.072 m^3/s (km 8,354 of the Struga i.e. at the cross section at the mouth of the old pipeline); 0.156 m^3/s (km 6.080 of the Struga); 0.191 m^3/s (km 0.0 of the Struga, i.e. at the cross section where the river joins the Odra),
- the longest multiannual discharge (of the longest duration during the year) NTQ took the following values: 0.034 m^3/s (km 8.354 of the Struga i.e. at the cross section at the mouth of the old pipeline); 0.082 m^3/s (km 6.080 of the Struga); 0.100 m^3/s (km 0.0 of the Struga, i.e. at the cross section where the river joins the Odra).

A comparison between the discharge on the Struga which is due to the mine water dumping Q_z and the characteristic own discharges SQ and NTQ, which correspond to the water incoming from the drainage basin (Fig. 3), leads us to believe that:

- if a SQ discharge occurs on the Struga, then the dumping Q_z is 4–11 times higher than SQ (depending on the location of the measurement cross section),
- if a NTQ discharge occurs on the Struga, then the dumping Q_z is 8–24 times higher than SQ (depending on the location of the measurement cross section).

An analysis carried out by the authors reveals that the own flows on the Struga resulting from the precipitation and the surface flow cannot meet all the needs (ecology, agriculture, irrigation, fishing etc.) of the area. Mine water dumping, however, enables an efficient water management of the river and of the adjacent land. Thus it becomes a very important and positive element of the natural environment.



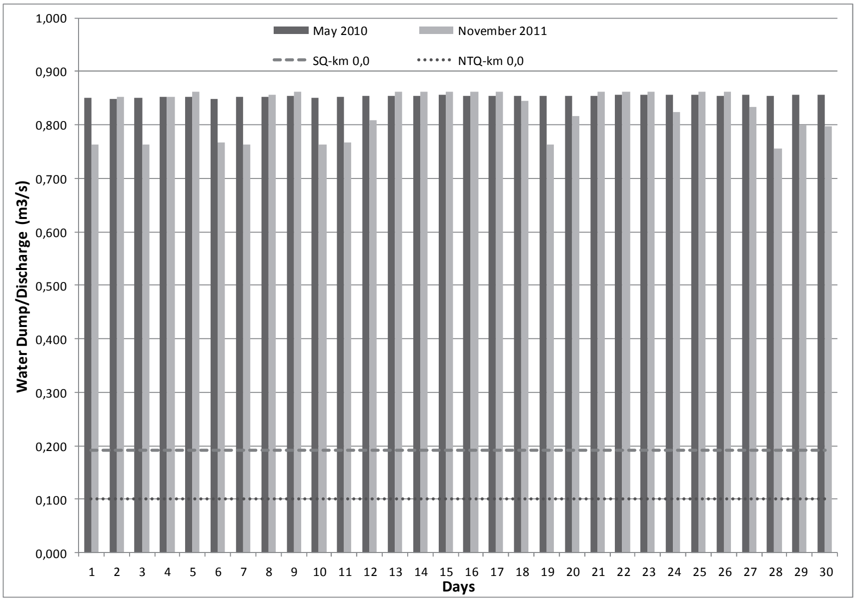


Fig. 3. Dumping from the mine and own flows on the Struga River in May 2010 and November 2011, km 8.354 (upper) and km 0.0 (lower)
Rys. 3. Zrzuty z kopalni i przepływy własne rzeki Struga w maju 2010 roku i listopadzie 2011 roku, km 8.354 (góra) i km 0.0 (dół)

4.3. Velocity and Flow Rate Measurements in the River Channel of the Struga

The measurements of the velocity and volume of the water flow through the river basin of the Struga were carried out in October and November 2011 (Fig. 4). These measurements were performed using a handheld flow meter, the FLO–MATE 2000. Such a research allows the velocities and the flow/discharge values on the Struga to be determined realistically. Hence, it can be determined which part of the flow comes from the mine and which form the drainage basin. The obtained velocities and discharge values are also a basis for the development and the calibration of a numerical model allowing a simulation of the flow capacities and the water levels in the watercourse and on the adjacent land.

The measurements show that:

- the water level in the river channel was approx. 0.40 m,
- the total discharge on the Struga (about 50 m down the mouth of the old pipeline) was about 0.70 m^3/s and coincided with the value of the mine water dumping,
- the average velocity in the cross section was 0.40 m/s,
- the pointwise velocities in the trapezoid cross section ranged from 0.21 to 0.63 m/s.

Fig. 4. Velocity and flow rate measurements on the Struga river
Rys. 4. Pomiary prędkości i przepływu wody w rzece Strudze

4.4. Hydrological Calculations of the Run-Off of Surface Water in the Drainage Basin of the River Struga

Heavy rains and melting result in a surface flow and in the consequent water erosion [18]. This erosion is particularly problematic in those areas where the slopes are of several % and more. Land adjacent to the Struga consists of dusty limestone soils which is highly susceptible to erosion. Among the many agricultural and technical actions aimed to prevent the erosion of soils and the loss of crop, the technical land improvement work is particularly noteworthy. The network of land improvement structures, both the basic ones and the very specific ones, is equally important and includes e.g. the so called absorptive ditches. These ditches collect the excess of water and prevent it from forming streams, prevent the surface flow and the washing out of soil and crop.

The authors calculated and analysed the surface flow of water coming from precipitation for the investigated area during the flood period in May 2010. During this period the dumping of water from the Tarnów Opolski mine was in the range of 73,400 – 74,000 m^3/day, similarly to November 2011, when the flow measurements on the Struga were carried out. The maximum discharge WQ through the Struga took place in May 2010 and was calculated empirically based on the precipitation formula:

$$WQ = 0.278\alpha IA = BA \ (m^3/s) \tag{1}$$

where: 0.278 – coefficient, α – coefficient of the run–off from the rainfall for the maximal flows equal to 0.65, I – intensity of rain (mm/h), A – surface area of the Struga discharge basin at a given cross section used for the measurements and calculations (km^2).

The calculation of the maximal discharge in the Struga corresponding to the rainfall in May 2010 was carried out for two periods, at three research cross sections:

- 16–18 May 2010, rainfall=59.9 mm, I=0.832 mm/h,
- 21–22 May 2010, rainfall=55.3 mm, I=1.150 mm/h.
- The cross section at km 8.354, at the mouth of the old pipeline from the mine, A=14.0 km^2,
- The cross section at km 7.820, at the mouth of the new pipeline from the mine, A=15.5 km^2,
- The cross section at km 6.080, A=33.1 km^2.

Our calculations show that:

- At the cross section at the mouth of the old pipeline (km 8.354) which evacuates water from the mine, the run-off corresponding to the rainfall on 21–22 May 2010 was at most 2.91 m^3/s. The overall discharge through the Struga, i.e. the sum of the rainfall component, the mine water dumping component (74,000 m^3/d = 0.86 m^3/s) and the sewage dumping component from the sewage treatment plant in Kosorowice (102 m^3/h = 0.028 m^3/s) was 3.80 m^3/s. This flow passes through the river channel of the Struga without breaking its banks.
- At the cross section at the mouth of the new pipeline (km 7.820) which also evacuates water from the mine, the run-off corresponding to the rainfall on 21–22 May 2010 was at most 3.22 m^3/s. The overall discharge through the Struga, i.e. the sum of the rainfall component, the mine water dumping component (74,000 m^3/d = 0.86 m^3/s) and the sewage dumping component from the sewage treatment plant in Kosorowice (102 m^3/h = 0.028 m^3/s) was 4.108 m^3/s. This flow passes through the river channel of the Struga without breaking its banks.
- At the cross section at km 6.080 (near the gravel pit on the left bank of the Struga) the run–off on 21–22 May 2010 was at most 6.88 m^3/s. The overall discharge through the Struga, i.e. the sum of the rainfall component, the Tarnów Opolski mine water dumping component (74,000 m^3/d = 0.86 m^3/s) and the sewage dumping component from the sewage treatment plant in Kosorowice (102 m^3/h = 0.028 m^3/s) was 7.77 m^3/s. This flow passes through the river channel of the Struga without breaking its banks.

Hydrological calculations of the maximal yearly discharges with given probabilities of occurrence of the average and low discharges were carried out at the cross sections of the Struga at km 8.354, km 6.080 and km 0.0. These hydrological calculations were performed using the formula of Lambor for the maximal discharge and that of Iszkowski for the average and low discharge (Tab. 1).

Initial numerical simulations of the flow capacity of the Struga river channel and of the water levels in the river were performed using the HEC–RAS software. This system was calibrated for the previously known hydraulic conditions in the Struga River channel [12]. Calculations were performed for four discharge values i.e. 4.60 m^3/s, 6.00 m^3/s, 10.80 m^3/s and 20.60 m^3/s. These discharges are the sum of the Struga's own discharge (corresponding to the inflow from its drainage basin, with a given probability), the dumping of water from the mine and the sewage component from the sewage treatment plant in Kosorowice. Simulation of the water levels in the Struga shows that only the catastrophic flows (which have never occurred yet) with a discharge of about 20 m^3/s could cause the water to break through the river banks. All other discharge values, i.e. 4.6 m/s, 6.0 and 10.8 m/s pass through the channel and do not cause any flooding of the adjacent land.

Table 1. The likely and characteristic maximal discharges on the Struga River
Tabela 1. Przepływy maksymalne prawdopodobne oraz charakterystyczne w rzece Strudze

Probable flows (m^3/s)			
p (%)	km 8.354	km 6.080	km 0.0
1	5.60	9.30	11.37
2	5.10	8.51	10.33
3	4.79	7.98	9.75
5	4.36	7.32	8.92
10	3.81	6.36	7.75
20	3.31	5.89	7.11
25	3.16	4.50	6.70
50	2.61	4.50	5.51
100	2.10	3.64	4.46
Characteristic flows (m^3/s)			
SQ	0.072	0.156	0.191
NQ	0.011	0.024	0.029
SNQ	0.022	0.048	0.058
NTQ	0.034	0.082	0.100

SQ – average multiannual discharge, NQ – low multiannual discharge, SNQ – average low multiannual discharge, NTQ – longest multiannual discharge (longest duration within the year).

5. Conclusions

The deep drainage of groundwater shapes the water environment not only in the vicinity of the Tarnów Opolski mine, but even at a considerable distance from it. Dewatering of the Triassic limestone deposits required to ensure a safe operation of the mine, has a significant impact on both the groundwater and the surface water environment. Drainage within the mine mainly shows through the formation of a depression cone and the change in the direction of the groundwater flow. The range of the mine depression cone varies from 2 km to the south to 4 km to the east. In 2010, after the heavy precipitation and floods on the tributaries of the Odra, groundwater levels rose in the mine surroundings by approx. 5 m.

A comparison between the mine water dumping volumes and the own flows from the drainage basin of the Struga indicates that the dumping is from several times to fifteen or so times higher than the natural flow through the river.

It should also be noted that the dumping of water evacuated from the mine during its dewatering supplements the heavy surface water shortage in the basin of the Struga. This water scarcity is caused by the slotted structure of soil (the Triassic limestone) and the low level of precipitation in this part of Poland. The dumping of water from the mine conditions the ecological continuity of the Struga watercourse and enables the ecosystem to develop by ensuring a certain supply of water for various purposes – agriculture or fire-fighting, among other things.

The water flow measurements on the Struga show that the volumes of water passing through the channel do not change or even decrease. This is due to the very specific geological structure of the terrain with numerous faults, cones and splits which often have considerable dimensions and make the surface waters to run-off and penetrate deeper into the ground.

The authors' analysis shows that the flooding of Kosorowice in 2010 was caused by the damage of the pipeline carrying the water from the mine.

Calculations of the flow capacity of the Struga channel and computer simulations of the water levels along the entire reach of this river indicate that for the maximal own flows with a 20% probability, the Tarnów Opolski mine water dumping at a rate of about 140,000 m^3/day and the dumping of sewage from the treatment plant in Kosorowice, there will be no flooding of the adjacent land. The free surface of water will remain within the channel of the Struga. Our analysis also indicates that even flows of which the probability exceeds 20% will not break through the banks of the river.

Lastly, the authors claim that the systematic maintenance works and the strengthening of the Struga River bed and banks enables flows and dumping with no adverse impact in the form of excessive rise in the groundwater level or flooding.

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Badania zmian reżimu hydrologicznego na obszarze przyległym do kopalni surowców skalnych

Streszczenie

Stosunki wodne określonego obszaru są wypadkową czynników pochodzenia naturalnego oraz oddziaływania człowieka na środowisko przyrodnicze [1,5,7,14,17]. Oprócz budowy geologicznej należą do nich morfologia terenu oraz działalność górnicza. Do najistotniejszych skutków eksploatacji, jakie powoduje górnictwo odkrywkowe można zaliczyć zajmowanie i przekształcanie terenów pod działalność górniczą oraz zmianę stosunków wodnych w rejonie funkcjonowania odkrywki, związaną z jej odwodnieniem [13,15,16]. Drenaż w obrębie kopalni ujawnia się głównie w postaci leja depresji i zmianie kierunku przepływu wód podziemnych. W efekcie powoduje on zmniejszanie przepływu w ciekach powierzchniowych, obniżanie poziomu wód gruntowych i zmniejszanie stanu uwilgotnienia i plonowania gleb [6,19,20,21].

Niniejsza praca jest poświęcona analizie wpływu działalności górnictwa wapieni na kształtowanie się stosunków wodnych terenów przyległych na przykładzie kopalni Tarnów Opolski. Zakres pracy dotyczy charakterystyki kopalni i rzeki Strugi, pomiarów w rzece Strudze, analizy opadów i hydrologicznych obliczeń dopływu wód powierzchniowych ze zlewni i z zrzutu wód kopalnianych, hydraulicznych obliczeń przepustowości rzeki i wstępnych numerycznych symulacji położenia zwierciadła wody.

Z jednej strony działalność tej kopalni powoduje depresję terenów wokół oraz obniżanie zwierciadła wód gruntowych. Natomiast z drugiej strony, zrzuty wód kopalnianych uzupełniają duże niedobory wód powierzchniowych w zlewni rzeki Strugi, spowodowane szczelinowatą budową podłoża (wapienie triasowe) oraz małą ilością opadów w tym regionie Polski. Dzięki zrzutom wody z kopalni możliwa jest ciągłość ekologiczna cieku Struga, rozwój ekosystemu oraz zapewnienie określonej ilości wody dla celów m.in. rolniczych, hodowlanych (stawy rybne) i przeciwpożarowych [2].

Teren kopalni znajduje się w zlewni rzeki Struga, która uchodzi do Odry na jej prawym brzegu. Kopalnia i zakłady wapiennicze położone są na terenie gminy Tarnów Opolski (powiat Opolski) i Gogolin (powiat Krapkowicki). Badany obszar pod względem geologicznym charakteryzuje się utworami czwartorzędowymi i triasem z wapienia muszlowego. Wydobywany surowiec służy do produkcji wapna. Wydobycie prowadzone jest metodą odkrywkową na dwóch poziomach wydobywczych. Wody kopalniane odprowadzane są do rzeki Strugi za pomocą rurociągów, a następnie do rzeki Odry (Fig.1, 2, 3).

W wyniku odwodnienia kopalni spływ wód podziemnych został wymuszony z głównego naturalnego kierunku północno-zachodniego NW w kierunku

południowo–wschodnim SE, do centrum wyrobisk górniczych. Zasięg leja depresji wynosi obecnie: 4 km w kierunku wschodnim, 2,7 km w kierunku północnym i zachodnim (okolice Tarnowa Opolskiego i Kosorowic), oraz 2 km w kierunku południowym (okolice Kamienia Śląskiego).

Ze względu na niewielkie zasoby wód powierzchniowych w zlewni rzeki Strugi przeanalizowano zrzuty wód kopalnianych oraz ich zagospodarowanie w zlewni rzeki Strugi. Zasilanie rzeki tymi wodami ma szczególne znaczenie m.in. dla utrzymania jej koryta w odpowiednim stanie techniczno-przyrodniczym oraz zasilania w wodę zbiorników małej retencji, stawów rybnych oraz nawadniania [22].

Na podstawie analizy porównawczej zrzutów wód kopalnianych oraz własnych przepływów rzeki Strugi (Fig. 3) autorzy stwierdzają, że:

- w przypadku wystąpienia przepływów średnich SQ, zrzuty Q_z są 4–11 razy wyższe od SQ,
- w przypadku wystąpienia przepływów najdłużej trwających NTQ, zrzuty Q_z są 8–24 razy wyższe od NTQ (w zależności od położenia przekroju pomiarowego).

Należy również zaznaczyć, że zrzuty wód kopalnianych z jej odwodnienia uzupełniają duże niedobory wód powierzchniowych w zlewni rzeki Strugi. Niedobory te są spowodowane szczelinowatą budową podłoża (wapienie triasowe) oraz niską ilością opadów w tym regionie. Dzięki zrzutom wody z kopalni możliwa jest ciągłość ekologiczna cieku Struga, rozwój ekosystemu oraz zapewnienie określonej ilości wody dla celów np. rolniczych, gospodarczych i przeciwpożarowych.

Pomiary przepływu wody w Strudze wskazują, że ilość wody wraz z jej biegiem nie zmienia się, a nawet zmniejsza się. Spowodowane jest to specyficzną budową geologiczną tego terenu (liczne uskoki, leje i rozłamy o znacznych rozmiarach, powodujące odpływ wód powierzchniowych w głąb podłoża).

Obliczenia przepustowości koryta rzeki Strugi oraz symulacje komputerowe położenia zwierciadła wody wzdłuż całego jej odcinka wskazują na to, że podczas maksymalnych przepływów własnych ze zlewni o prawdopodobieństwie 20% wraz z zrzutami z kopalni (rzędu 140,000 m^3/dobę) i z oczyszczalni Kosorowice, nie będzie podtopień terenów przyległych. Zwierciadło wody będzie się mieścić w korycie Strugi. Analiza wykazała również, że przepływy o prawdopodobieństwie wyższym od 20% będą mieścić się w korycie rzeki.

Słowa kluczowe:
zrzut wody z kopalni, rzeka, reżim hydrologiczny

Keywords:
water dumping from the mine, river, hydrological regime