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EFFECTS OF SELECTED WASTEWATER MANAGEMENT SCENARIOS ON RIVER WATER QUALITY

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Abstract: For majority of running waters point pollution sources are the main sources of pollution. Knowing the water self-purification capacity one can modify the quality of waters through proper management of the discharged pollutants. This study focuses on identifying such solutions for pollutant discharge into the Kłodnica and Bytomka rivers, which would allow for achieving at least the III class of surface water quality. Simulation of selected wastewater management scenarios was carried out. The best solutions for the water environment were identified. Only environmental effects which resulted in improvement of the water quality were analyzed. The economical aspect of actions, the undertaking of which is indispensable for achieving the assumed goal, was not taken into account. The selection of the best solutions considering the cost effectiveness cannot be made until a feasibility study for particular undertakings has been completed. Salinity and biodegradable pollutants determined by BOD coefficient were taken into consideration. The simulation was carried out using an integrated simulation model IRM (Integrated River Model). In order to protect the river from excessive salinity the optimum solution for the Bytomka River would be desalination, whereas for the Kłodnica River – directing salty mining waters outside its catchment. For protection from biodegradable pollutants the only solution would be tightening the effectiveness criteria for municipal wastewater treatment. Meeting the minimum standards for wastewater treatment, currently obligatory in municipal wastewater treatment plants, will not ensure the assumed water purity level in these rivers.

INTRODUCTION

There are two main factors which have an impact on the quality of running waters – natural self-purification processes and human activity, defined as anthropopression, where the key role is played by wastewater discharge, or – to be more precise – discharge of pollutant loads contained in them. Natural factors are self-regulatory and at the current state of knowledge any interference is connected with the risk of occurring adverse effects in the environment. What can and should be interfered, however, is anthropopression. The most sensitive to anthropogenic pollutants, alien to the environment, are rivers of small natural flows. These are mainly short watercourses, containing pollutant loads coming from several sources, usually located close to one another. Their length and flow time are usually too short and do not allow to achieve the required water quality level due to self-purification processes.

Knowing the self-purification capacity of the running waters we can exert an influence on their quality by proper "steering" of the discharged pollutants. For the majority

of running waters point sources are the main sources of pollution. In contrast to other sources they can be easily identified and their emissions controlled. So far plans and actions aimed at reorganizing wastewater management systems in municipalities and large industrial plants, mainly in coal-mines, are generally "individual" ones, in which their mutual impacts on surface waters in catchments are rarely taken into account. Lack of co-ordination of these actions, although quite justified ones, may result even in the decrease of the water quality. One of the parameters which have an impact on the water self-purification process is water flow. Replacing numerous wastewater outflows, currently supplying the river in more or less scattered way with one cumulative outflow from the central wastewater treatment plant may have a negative impact on the river, both above and below the outlet. In some cases such solutions may significantly decrease water flows above the cumulative collector and reduce pollutants acceptance capacity of the river. Similar effects can be obtained by directing wastewater to another catchment. This can be observed in the case of waters with small natural flows, containing salty mining waters, whose contribution to the water flow is often quite significant. In such case the water protection problem comes down to making a decision – directing mining waters to the same river but in the place where their dilution to the required level will be possible, directing them outside the catchment or desalination. Desalination is rather expensive and should be used in cases when directing waters to another place in the river or to another catchment will not significantly reduce the river acceptance capacity of pollutants coming from other sources, e.g. the municipal ones.

The selection of suitable protection measures or actions reducing the negative effects of introducing pollutants to the water is difficult and requires carrying out simulation of different wastewater management scenarios in the catchment and the implementation of the selected solution must be preceded by a number of feasibility studies [5].

Below simulation results for the selected scenarios developed for the Kłodnica River and the right-bank tributary – the Bytomka River are presented.

RESEARCH METHODOLOGY

This study focuses on the implementation of such solutions for pollution discharge to the Kłodnica and Bytomka rivers which would ensure achieving at least the III class of surface water quality (BOD < 6 mg O_2/dm^3, COD_{Cr} < 12 O_2/dm^3, chlorides < 300 mg/dm^3 and sulphates < 200 mg/dm^3, according to the classification which was in force till the 31st of December 2004) [7]. At present in Poland there is no precisely defined classification method for the quality of running waters, therefore in this study it was assumed that any actions in the catchment could still refer to the criteria of this classification.

The idea was to point out such solutions which, taking into account the volume of the discharged pollutants and the place of discharge would ensure the required water quality. The economical aspect of the measures to be undertaken to achieve the assumed goal was not taken into consideration. The analyses focused only on environmental effects which were reflected in the form of water quality improvement.

To find the most suitable solutions an Integrated Simulation Model ZMR (Integrated Model River IMR), developed in the Institute for Ecology of Industrial Areas in Katowice, was used. The software is based on a mathematical model projecting changes of pollutants in running waters, determining the water absorbability of foreign pollutants [4].

The applied model is a strategic model for solving decisive problems on a long-term scale. It combines the water quality in the river with water and wastewater management in its catchment. It is designed to support water quality management in catchment systems by mapping water quality changes along the water course at a fixed inflow of pollutants and fixed flows in the river (in the form of hydrochemical profiles). It is not used for projecting temporary states. Its central part is a procedure of calculating hydrological and hydrochemical profiles based on a mathematical model projecting transport and biochemical changes of pollutants discharged to the river.

Before selection of a proper solution the model was verified for the Kłodnica and Bytomka rivers. The verification was carried out based on the characteristics of water flow data in the Kłodnica catchment [6, 8], data on the quality of water in running water quality monitoring cross-sections for 2005 obtained from the Voivodeship Inspectorate of Environmental Protection in Katowice and data on point pollutant emission sources for 2005, collected from IETU's own research work [3].

The ZMR Integrated Simulation Model was already used by the Institute for Ecology of Industrial Areas in 1994–2005 in research work on the permissible pollutant load in the Gostynia River and rivers of the Olza catchment [1–3].

In the carried out simulation biodegradable compounds (BOD) and salinity caused by sulphates and chlorides were taken into consideration. Effects of wastewater management scenarios were simulated. The analyzed scenarios assumed:

- raising the effectiveness of municipal wastewater treatment,
- desalination of mining waters and their discharge to the river using the existing outlets,
- directing all saline mining waters outside the catchment, without identifying the place of their discharge.

From the economical and technical point of view directing saline mining waters outside the catchment or to another place in the same river, where its dilution to the required level would be possible seems to be the simplest solution. While considering the application of this solution, however, one should take into account the possible unfavorable decrease of the water flow, particularly in rivers of small natural flows and significant reduction of their self-purification capacity.

The simulation was made with the assumption that the water quality would be achieved and maintained at the level of the average annual flow (SQ). As a reference water quality value the III class of surface water quality of the classification used for presenting surface water condition, which was in force till the end of 2005, was assumed: BOD < 6 mg O_2/dm^3, chlorides < 300 mg/dm^3 and sulphates < 200 mg/dm^3. The following scenarios were simulated:

in the Kłodnica River catchment:

- raising the effectiveness of Katowice-Panewniki wastewater treatment plant and reorganizing the municipal and domestic wastewater management systems in the Bielszowicki creek (impact on BOD);
- directing mining waters from Wujek Ruch Śląsk and Halemba coal mines discharged to the Kłodnica River outside its catchment (decrease of salinity and determination of the impact of the water flow reduction in the Kłodnica River on BOD);
- desalination of mining waters from Wujek Ruch Śląsk and Halemba coal mines to the level of 500 mg/dm^3 for chlorides and 300 mg/dm^3 for sulphates, without

directing them outside the catchment;

in the Bytomka River catchment:

- liquidation of collector outlets of untreated municipal wastewater with a simultaneous improvement of the effectiveness of the municipal wastewater treatment plant (simulation of the impact on BOD);
- desalination of mining waters from Centrum coal mine and waters discharged by the Central Coal-Mine Dewatering Plant (Siemianowice Chorzów Region, Szombierki and Pstrowski) to the level of 500 mg/dm^3 for chlorides and 300 mg/dm^3 – for sulphates;
- directing mining waters outside the Bytomka catchment after reorganizing the municipal wastewater management, i.e. after completing the scenario A (impact on BOD).

Results of the simulation of particular solutions were presented in the form of hydrochemical profiles with reference to the three classes of surface water quality.

OBTAINED RESULTS AND DISCUSSION

Water quality monitoring in the Kłodnica catchment shows gradual, although still insufficient improvement of the water quality only at the stretch from the spring to the mouth of the Bielszowicki creek. Commissioning the treatment plant in Mikołów (the Jamna catchment) and at the end of 2006 – the Halemba Centrum treatment plant in Ruda Śląska (direct catchment of the Kłodnica River) reduced the pollution with biodegradable compounds (BOD). The pollution, however, is still above the limit values determined for the III class of water quality. The main pollution sources are the Bielszowicki creek, Czarniawka creek and the Bytomka River (Table 1).

Table 1. Water pollution in the Kłodnica River catchment in 2005 (according to the Voivodeship Inspectorate of Environmental Protection – Katowice)

Monitoring cross-section	km	BOD [mg O_2/dm^3]	Chlorides [mg/dm^3]	Sulphates [mg/dm^3]
Above Jamna creek	68.2	6.7	3 199	359
Jamna creek (mouth)	64.5	8.0	246	207
Below Jamna creek	63.8	7.0	1 175	258
Bielszowicki creek (mouth)	54.4	21.6	2 962	924
Below Bielszowicki creek	53.9	9.0	2 924	480
Czarniawka creek (mouth)	53.8	14.3	4 609	887
Below Czarniawka creek	53.5	13.9	3 430	593
The Bytomka River (mouth)	49.9	14.5	2 087	750
Below the Bytomka River	47.2	10.8	–	–
Standard for the III water quality class		6.0	300	250

Without reorganizing the wastewater management in the catchments the Kłodnica waters will not even reach the level of the IV class surface of water quality. The current state of the Kłodnica and Bytomka pollution was illustrated in Figs. 1 and 2.

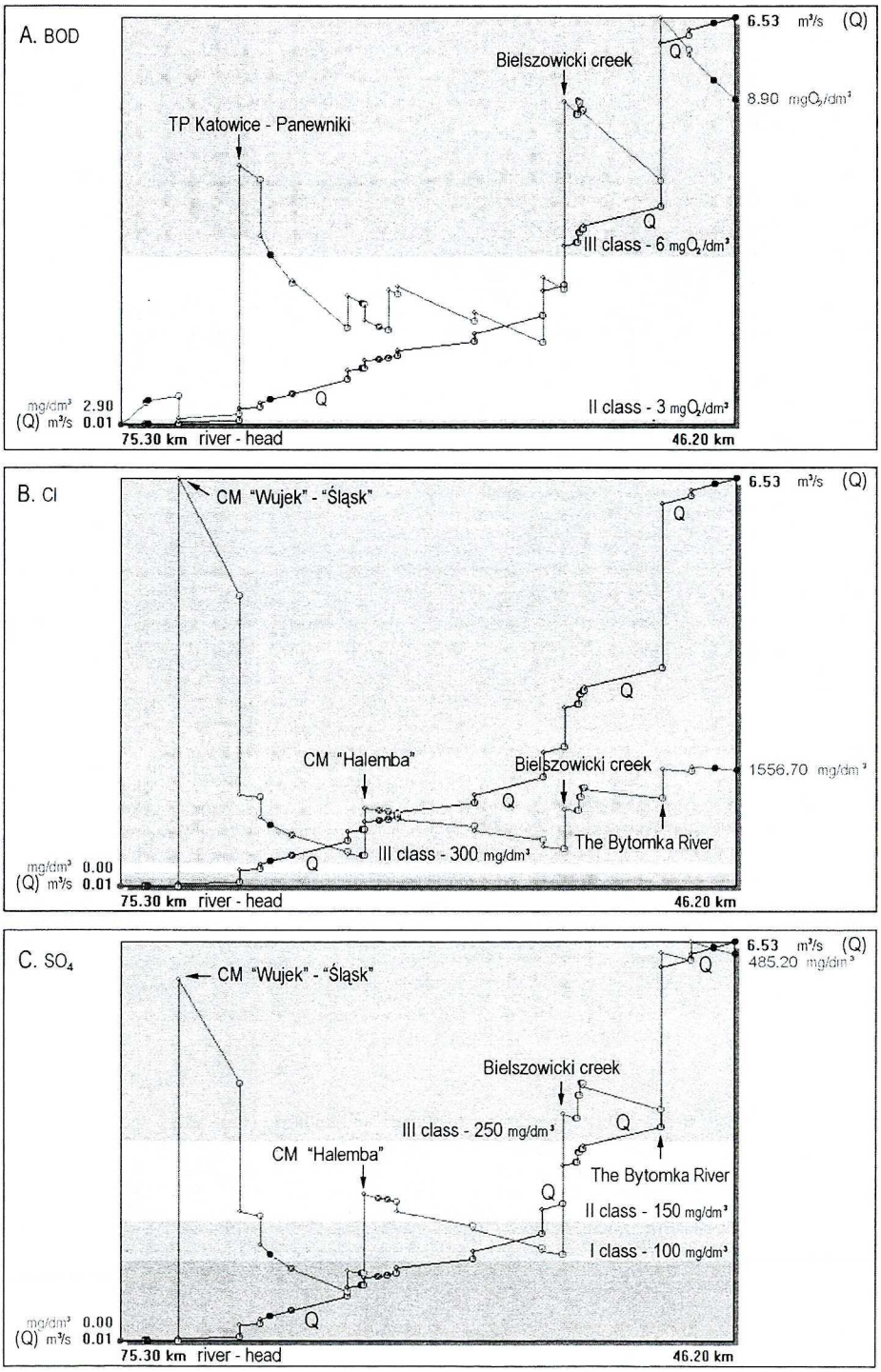


Fig. 1. The Kłodnica River, 2005, hydrochemical profiles: A – BOD; B – chlorides; C – sulphates

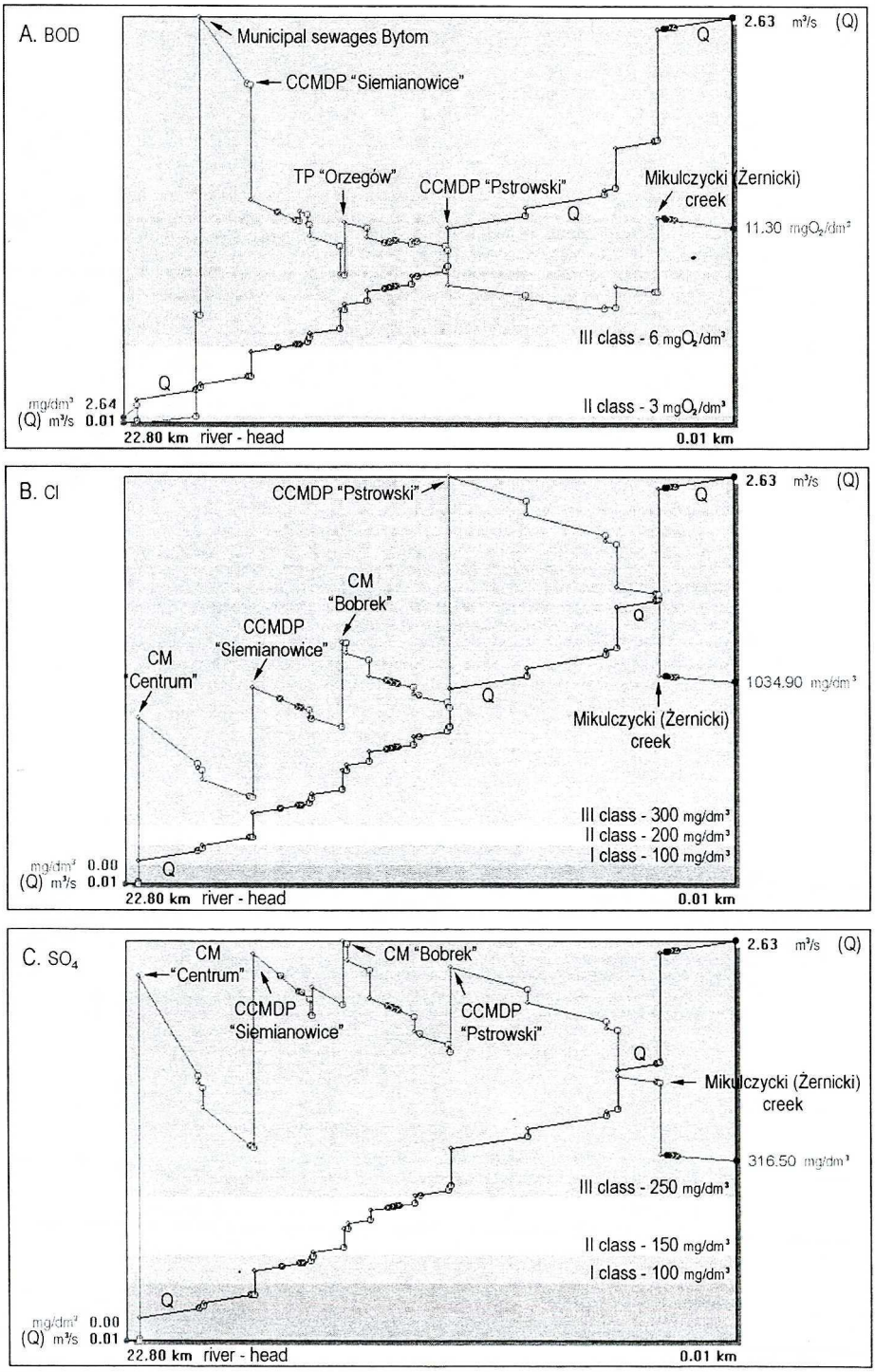


Fig. 2. The Bytomka River, 2005, hydrochemical profiles: A – BOD; B – chlorides; C – sulphates

The model verification showed good adjustment to the conditions occurring in both investigated rivers. For the Kłodnica River the relative error ranged from -4% to -26%, which means that the values calculated using the model were lower than the monitored averages, which ranged from 4% to 26%. Taking into account the fact that the verification had to be based on data provided by the unit responsible for the wastewater discharge, which usually come only from several measurement campaigns organized yearly, and data obtained from 12 water quality monitoring measurements, which are not correlated with water flows on the days of measurements the above-mentioned adjustment can be assessed as good. For the Bytomka River the verification could have been made only for the monitoring cross-section in the water-gauge cross-section in Gliwice, 2.5 km above the mouth of the Kłodnica River. The relevant error did not exceed -19%. The obtained adjustment can be assessed as good.

The verified model was used to calculate various options of pollutant loads in the Kłodnica and Bytomka rivers coming from point pollution sources.

SIMULATION OF SELECTED SCENARIOS

The Kłodnica River catchment

Scenario A – raising the effectiveness of wastewater treatment in the wastewater treatment plant in Katowice-Panewniki and re-organizing the management of municipal and domestic wastewater in the Bielszowicki creek catchment (impact on BOD).

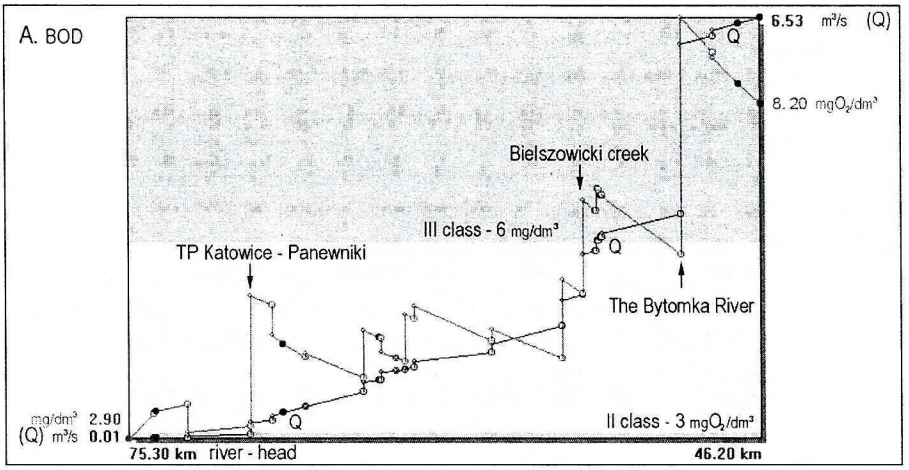
Lowering the BOD value to 6 mg O_2/dm^3 was assumed at the outflow from the Katowice-Panewniki wastewater treatment plant 40%. Another assumption was re-organizing of the wastewater management in the catchment of the Bielszowicki creek in order to obtain the water quality at its outlet to the Kłodnica River at least at the level of 8 mg O_2/dm^3, i.e. at the level of average treatment effectiveness in wastewater treatment plants, which, however, is connected with higher pollution of wastewater discharged to the creek.

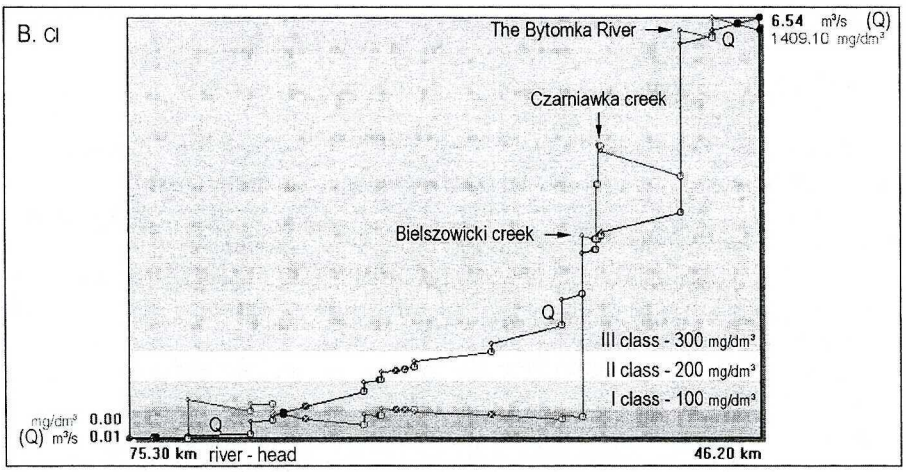
Assuming such a minimum requirement with regard to the wastewater treatment level in the creek catchment would allow to maintain the BOD value in the river at the level of the III water quality class until its merging point with the Bytomka River (Fig. 3a)

Scenario B – desalination of mining waters from Wujek Ruch Śląsk and Halemba coal mines to the level of at least 500 mg/dm^3 for chlorides and 300 mg/dm^3 for sulphates (reduction of the river salinity and determining the impact of the reduction of the river water flow on BOD value).

Implementation of this scenario would allow to reduce salinity with chlorides up to the level of the I class of the water quality but only up to the Bielszowicki creek (Fig. 3b); below the salinity will remain beyond the classification. The salinity with sulphate salts below the Czarniawka creek would remain at the level of the III water quality class but below the Bytomka River it would also be beyond the classification (Fig. 3c).

Scenario C – directing all salty mining waters from Wujek Ruch Sląsk and Halemba coal mines outside the Kłodnica River catchment (impact of the reduced water flow on BOD).





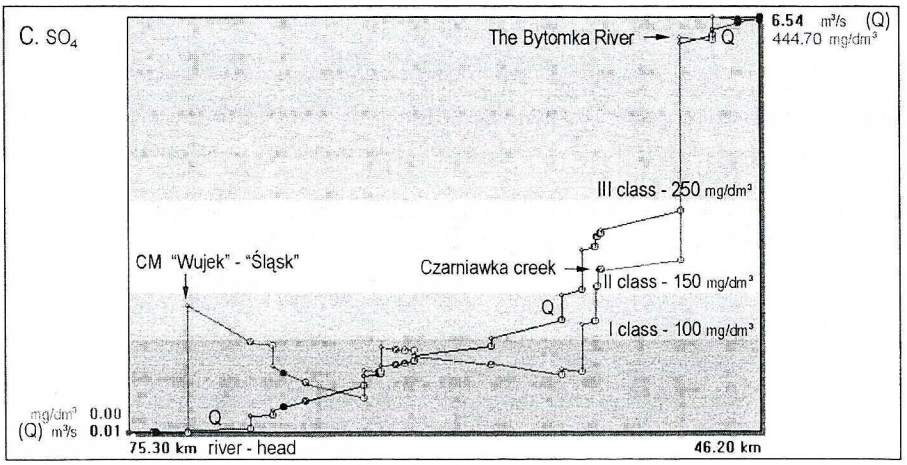


Fig. 3. The Kłodnica River, hydrochemical profiles: scenario A – BOD (Fig. A); scenario B – chlorides (Fig. B); and sulphates (Fig. C)

Nowadays the river pollution with biodegradable compounds (BOD) up to the mouth of the Bielszowicki creek remains at the level of the IV class of water quality (Fig. 1a). After directing the mining waters outside the Kłodnica catchment the average flows below Katowice would decrease by about 0.03 m^3/s (4.6%) and below Halemba coal mine by about 0.14 m^3/s (11%). However, the water flow reduction would not remarkably decrease the river capcity of BOD pollutants acceptance below Katowice even if the effectiveness of the wastewater treatment plant in Katowice-Panewniki does not improve and water and wastewater management in the catchment of the Bielszowicki creek is not re-organized, which was assumed in the scenario A.

The scenario C would be the best solution for improving the water quality in the Kłodnica River (Fig. 4).

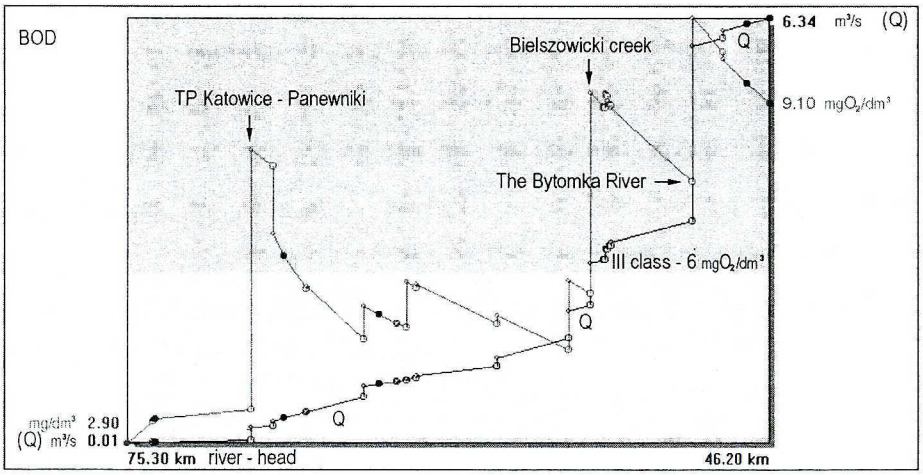


Fig. 4. The Kłodnica River, hydrochemical profiles: scenario C – BOD

The Bytomka River catchment

Scenario A – liquidation of collector outlets of untreated municipal wastewater and raising the effectiveness of the municipal wastewater treatment plant (impact on BOD).

The simulation was limited to determining the effectiveness of the existing plans and the on-going re-organization of the wastewater management in Zabrze, Bytom and Ruda Śląska. Nowadays, the whole Bytomka River, due to BOD, represents the IV class of water quality, except for a 2 km riverhead of the I and II class (Fig. 2a). After the implementation of the above-mentioned scenario BOD from the spring to the wastewater discharge point from the Orzegów wastewater treatment plant in Ruda Śląska would remain at the level of the II water quality class. Only at a several hundred meter stretch, below the mouth of the Żernicki creek the pollution would exceed the level of the III class (Fig. 5). The simulation results were used for the analysis of the effects of the scenario which assumed directing the saline mining waters outside the catchment.

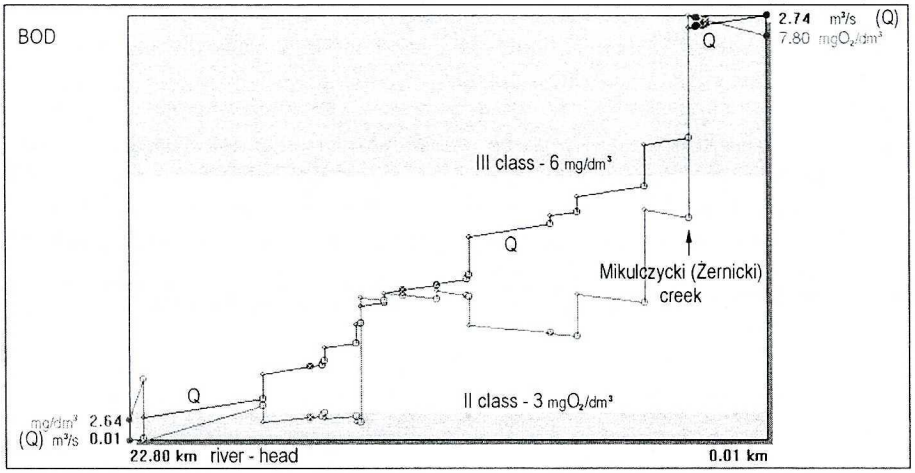


Fig. 5. The Bytomka River, hydrochemical profiles: scenario A – BOD

Scenario B – desalination of mining waters from Centrum coal mine and saline mining waters discharged by the central coal mine dewatering plant (Siemianowice Chorzów Region, Szombierki and Pstrowski) at least to the level of 500 mg/dm³ for chlorides and 300 mg/dm³ for sulphates (impact on the water salinity).

Currently the salinity significantly exceeds the permissible standards for chloride and sulphate salts (Fig. 2b and 2c). If the scenario were implemented the concentration of chloride salts below Bobrek coal mine would decrease to the level of the III water quality class and below the Mikulczycki (Żernicki) creek – to the level of the II class (Fig. 6).

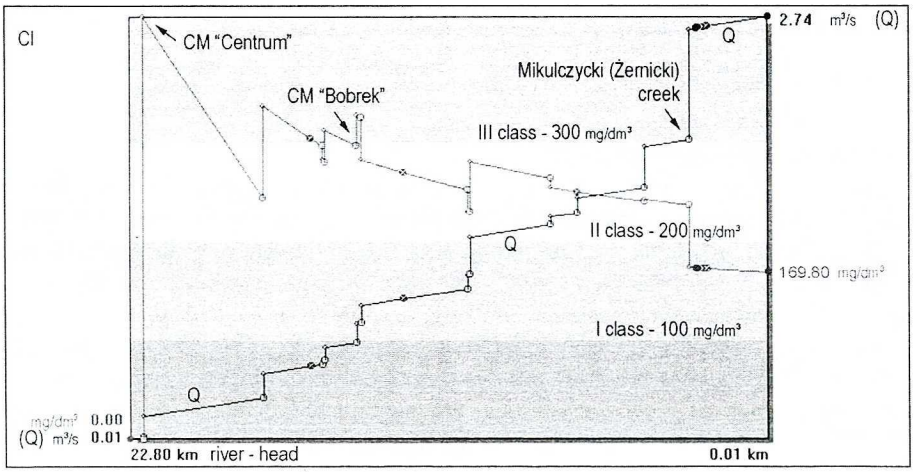


Fig. 6. The Bytomka River, hydrochemical profiles: scenario B – salinity; chlorides

In the case of sulphate salts, about 7 kilometers before the outlet to the Kłodnica River the salinity would decrease to the II level of the water quality class. After the inflow of the Mikulczycki (Żernicki) creek the Bytomka River would contain waters of the I water quality class (Fig. 7).

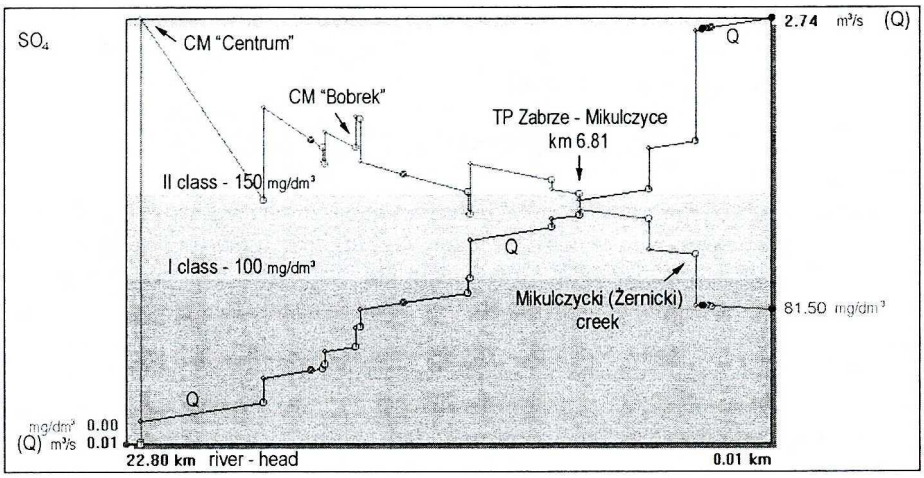


Fig. 7. The Bytomka River, hydrochemical profiles: scenario B – salinity; sulphates

Scenario C – directing all mining waters outside the Bytomka catchment after the re-organization of the municipal wastewater management – after the implementation of the scenario A (impact on BOD).

Directing mining waters outside the catchment could significantly reduce the river acceptance capacity of biodegradable pollutants (BOD). At the average annual flow of the Bytomka River at the mouth cross-section, amounting to 2.61 m^3/s, including wastewater 0.690 m^3/s, i.e. about 26% of the water flow fall on the mining waters and directing these waters outside the catchment could have a negative impact on the biodegradable compound pollution.

The carried out simulation showed that BOD value between the springs and the Orzegów wastewater treatment plant in Ruda Śląska would remain within the range of the III water quality class but below, towards the outflow to the Kłodnica River (except for some very short stretches), the pollution would exceed the permissible standards (Fig. 8).

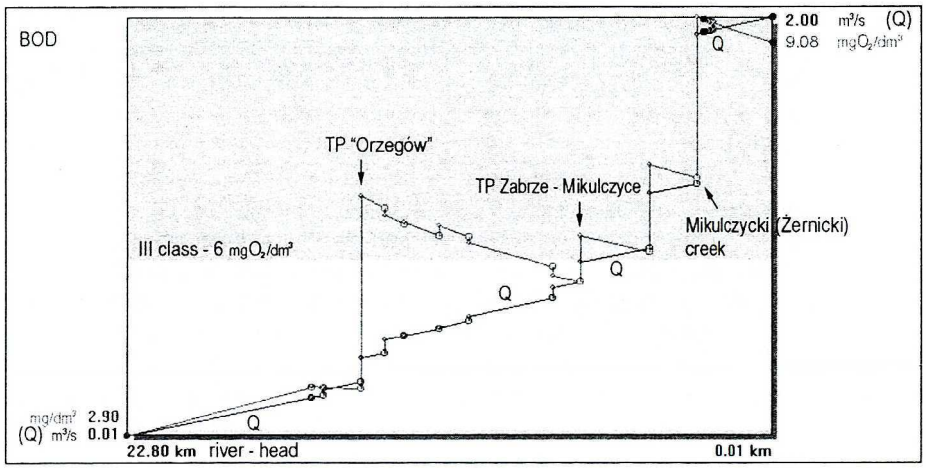


Fig. 8. The Bytomka River, hydrochemical profiles: scenario C – impact on BOD

Such a scenario, which proved correct for the Kłodnica River will not be applicable for the Bytomka River. In the case of low water flow, artificially raised by mining waters, the conditions will be more unfavorable.

SUMMARY AND CONCLUSIONS

In the analysis of solutions aimed at the protection of waters in the Kłodnica and Bytomka catchments from excessive loads of pollutants coming from point pollution sources the reduction of pollutant loads in the discharged municipal wastewater and directing salty mining waters outside the catchment were taken into consideration. The impact on the reduction of biodegradable compound concentrations, referred to as BOD coefficient, as well as chloride and sulphate ions contained in the discharged mining waters, was analyzed.

An integrated simulation model, verified for the Kłodnica and Bytomka rivers, was used.

Reduction of the salinity level of the running waters with salts contained in the mining waters is still one of the unsolved problems, mainly because of high construction costs and costs connected with the operation of the desalination system. Therefore, in the analysis of various solutions the application of the relatively cheapest solution, which is directing salty waters outside the catchment, was also taken into account. In the case of rivers with low natural flow, which receive other pollutants, in the flow of which significant share of mining waters can be observed, such a solution may have a negative impact on water quality.

The carried out simulations show that the following solutions, optimum for obtaining at least the III water quality class can be implemented:

to reduce the biodegradable compound pollution (BOD):

- in the Kłodnica River catchment – raising the effectiveness of the wastewater treatment plant in Katowice-Panewniki to achieve a BOD value of 6 mg O_2/dm^3 in the effluent and re-organizing the wastewater management in the catchment of the Bielszowicki creek so that water quality expressed as BOD at its outflow to the Kłodnica River would be at least at the level of 8 mg O_2/dm^3, which would mean that the average effectiveness of municipal wastewater treatment plants was achieved. Assuming even such a minimum wastewater treatment level in the Bielszowicki creek catchment will allow to maintain the III water quality class in the Kłodnica River up to the Bytomka River (due to BOD);
- in the Bytomka River catchment – liquidation of the collector outlets of the untreated municipal wastewater with a simultaneous raising of the effectiveness of the municipal wastewater treatment plants. This partially refers to the already undertaken actions. Nowadays the whole Bytomka River, due to BOD, represents the IV class of water quality (except for a 2 km riverhead of the I and II class). After the implementation of the scenario B BOD on the stretch from the spring to the discharge point of the Orzegów wastewater treatment plant in Ruda Śląska will remain at the level of the II water quality class. Only on a very short stretch, below the mouth of the Mikulczycki (Żernicki) creek the pollution would exceed the III water quality class;

to reduce salinity with chloride and sulphate ions:

- in the Kłodnica River catchment – directing all saline mining waters from Wujek Ruch Śląsk and Halemba coal mines outside the catchment. This would result in decreasing the average flows below Katowice by about 0.03 m^3/s (4.6%), and below the Halemba coal mine by about 0.14 m^3/s (11%). The obtained reduction of the water flow in the river would not have any significant impact on the level of the biodegradable compounds pollution (BOD) below Katowice even if the effectiveness of the wastewater treatment plant in Katowice-Panewniki did not improve and the water and wastewater management in the Bielszowicki creek catchment were not re-organized. The implementation of this scenario would improve water quality of the Kłodnica River due to the elimination of the abnormal, anthropogenic level of its salinity;
- in the Bytomka River catchment – desalination of mining waters at least to the level of 500 mg/dm^3 for chlorides and 300 mg/dm^3 for sulphates. If these conditions were fulfilled below the Bobrek coal mine the concentration of chloride salts would decrease to the III water quality class and below the Mikulczycki (Żernicki) creek – to the II class. In the case of sulphate salts 7 km before the inflow to the Kłodnica River the salinity would decrease to the II water quality class. After the inflow of the Mikulczycki (Żernicki) creek the Bytomka River would have the I class of water quality. This is an expensive solution but directing the salty mining waters outside the catchment, applicable in the case of the Kłodnica River, would not prove suitable for the Bytomka River. At the average annual flow of the Bytomka River, which at the mouth cross-section amounts to 2.61 m^3/s, including wastewater, 0.690 m^3/s, i.e. about 26% of this flow falls on the mining waters. After directing the waters outside the catchment the pollution caused by biodegradable compounds (BOD) would remain at the level of the III water quality class up to the wastewater discharge point at the Orzegów wastewater treatment plant in Ruda Śląska, but below, up to the outlet to the Kłodnica River, the pollution (except very short stretches) would exceed the permissible values. In the case of low water flows, nowadays artificially raised by mining waters, the pollution of the Bytomka River would be higher.

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SKUTKI WYBRANYCH SCENARIUSZY GOSPODAROWANIA ŚCIEKAMI W ZLEWNI NA JAKOŚĆ WÓD RZEKI

Dla większości wód płynących głównym źródłem zanieczyszczenia są źródła punktowe. Znając zdolności wód do samooczyszczania się można poprzez odpowiednie sterowanie wprowadzanymi zanieczyszczeniami wpływać na jakość wód. W pracy skupiono się na wskazaniu rozwiązań wprowadzania zanieczyszczeń do wód Kłodnicy i Bytomki, które pozwolą na osiągnięcie jakości ich wód przynajmniej w granicach III klasy jakości wód powierzchniowych. Przeprowadzono symulacyjne obliczenia dla różnych scenariuszy gospodarowania ściekami i wskazano rozwiązania korzystne dla środowiska wodnego. Analizowano tylko efekty środowiskowe wyrażające się poprawą jakości wód. Nie brano pod uwagę aspektu ekonomicznego działań niezbędnych do osiągnięcia nakreślonego celu. Wzięto pod uwagę zasolenie związane z wprowadzanymi wodami kopalnianymi oraz zanieczyszczenia biorozkładalne, oznaczane wskaźnikiem BZT_5, związane głównie ze ściekami komunalnymi. Symulację wykonano wykorzystując program komputerowy Zintegrowany Model Rzeka – ZMR. Dla ochrony przed ponadnormatywnym zasoleniem rozwiązaniem optymalnym w bezpośredniej zlewni Kłodnicy byłoby skierowanie wód kopalnianych poza jej zlewnię, a dla rzeki Bytomki – ich odsalanie. Dla ochrony przed zanieczyszczeniami biorozkładalnymi jedynym rozwiązaniem byłoby zaostrzenie kryterium efektywności oczyszczania ścieków komunalnych.