Environmental risk mitigation resulting from implementation of mine water treatment technologies developed within project MANAGER

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Abstract

Contamination of surface water by the mine water discharges is one of several problematic environmental issues related to coal mining. The discharges of mine water have a significant impact on water quality and aquatic ecosystem. Mine water released to the river ecosystem may increase salinity, temperature and concentration of heavy metals. Therefore, water management including implementation of solutions allowing to minimize the environmental impact of mining operations plays an increasingly important role. Assessment of environmental risk mitigation resulting from application of possible treatment solution should be a part of the technology selection process depending on existing environmental problem.

Approach based on the treatment technologies efficiency and water quality standards was applied to estimate the potential environmental risk reduction. The performed analysis showed that implementation of treatment technologies have a positive impact on the aquatic environment by removing a significant loads of pollutants, thereby supporting the prevention of deterioration of aquatic ecosystems exposed to contaminants from mining water. Performed process of technologies assessment in terms of risk mitigation confirmed that due to selectivity for specific type of contaminants, different flexibility to concentration changes and limitations the process of solution selection should be performed individually for selected specific case conditions. During this process besides the technology parameters physico-chemical parameters of discharged mine water and river as well as river flow rate should be taken into account.

Key words: mine water, treatment technologies, environmental risk, aquatic ecosystem

Introduction

Activity of hard coal mining is associated with pumping mine water to the surface and then discharges to nearby watercourses. Impact of the mining on surface water was undertaken within many papers (Absalon and Matysik 2007; Dogaru et al. 2009; Office of Environment and Heritage NSW 2012). Water discharged from both operating and abandoned mines causes degradation of water quality and introduces alteration of aquatic habitat. Mine water from European coalfields is often characterized by high salinity and temperature (Belmer et al. 2014). Substances present in discharged mine water such as heavy metals, radioactive isotopes, sulphate and chloride (Bondaruk et al. 2016; Canedo-Arguelles et al. 2013; Janson et al. 2009; Chałupnik and Wysocka 2009; Younger and Wolkersdorfer 2004) may have an significant impact on water quality and in consequence may damage or alert the structure of biological communities in aquatic ecosystem (Besser et al. 2007). One of the most important document, in the field of water resources management and protection is the Water Framework Directive (WFD). According to the Article 4.1 the general aim is to achieve in all surface bodies good status by 2015 as well as introduce the principle which allow to prevent any further status deterioration (European Communities, 2009).

Therefore, water management including implementation of solution such as treatment technologies allowing to minimize the environmental impact of mining operations plays an increasingly important role. Assessment of environmental risk mitigation resulting from application of possible treatment solution should be a part of the technology selection process depending on existing environmental problem. MANAGER project (full title: Management of mine water discharges to mitigate environmental risks for post-mining period) implemented within Research Fund for Coal and Steel was aimed at development and evaluation of treatment technologies in terms of risk reduction for aquatic ecosystem. Among technologies developed within the project were semi-passive and active solutions focused on treatment of different hazardous substances occurring in mine water discharge.

Within this paper results of the analysis of environmental risk mitigation performed based on treatment efficiency and comparison to EQS (Environmental Quality Standard) set out by Directive 2013/39/EU are presented. The results of laboratory analysis to estimate the pollutant load reduction for zinc, nickel, cadmium, copper, lead, mercury, iron, manganese, magnesium, barium were used. Annual Average Environmental Quality Standards (AA-EQS) values for heavy metals from priority list - nickel, cadmium and lead were applied to calculate the required dilution degree of treated mine water. Analysis was performed to assess how implementation of treatment technology may mitigate the environmental risk posed by discharge of mine water including metals. The implemented approach may become an important part of management practices reducing the environmental impact of mining operations.

Methods

The analysis of environmental risk mitigation was performed for selected technologies developed and tested in MANAGER project which are dedicated to treat mine water from metals such as Zn, Ni, Cd, Cu, Pb, Hg, Fe, Mn, Mg, Ba. Based on the collected information concerning physico-chemical parameters characterizing mine water in Europe coalfields the matrix of artificial mine water was developed within the project MANAGER by DMT GmbH & Co. KG (Table 1). This matrix includes five type of artificial mine water with different characteristics was used in order to create comparable conditions of treatment efficiency analysis in laboratory scale.

Table 1 *Artificial mine water matrix*

Parameters	Type1 Groundwater	Type2 Low salinity	Type3 Intermediate salinity, flooding	Type4 High salinity, sulfate	Type5 High salinity, barium
pH	7,00	7,00	7,00	7,00	7,00
Sodium Na (mg/l)	170	1 380	8 300	30 170	26 850
Potassium K (mg/l)	20	80	180	250	330
Calcium Ca (mg/l)	200	400	1 000	1 000	2 800
Magnesium Mg (mg/l)	85	250	450	1 000	1 000
Iron Fe (mg/l)	4,317	10,793	43,173	129,520	129,520
Manganese Mn	1,882	4,706	18,823	56,470	56,470
Zinc Zn (mg/l)	0,236	0,590	2,361	7,082	7,082
Lead Pb (mg/l)	0,047	0,118	0,473	1,418	1,418
Cadmium Cd (mg/l)	0,004	0,009	0,038	0,113	0,113
Chromium Cr (mg/l)	0,000	0,000	0,000	0,000	0,000
Copper Cu (mg/l)	0,012	0,029	0,117	0,352	0,352
Nickel Ni (mg/l)	0,013	0,031	0,126	0,377	0,377
Mercury Hg (mg/l)	0,000	0,000	0,001	0,002	0,002
Barium Ba (mg/l)	0	0	0	0	400
Strontium Sr (mg/l)	0	0	30	0	333
Sum of cations (mg/l)	475	2110	10020	32420	31713
Hydroxid (OH) (mg/l)	0	0	0	0	0
Chloride Cl (mg/l)	185	2 500	15 000	50 000	50 000
Sulfate SO_4 (mg/l)	400	1 000	1 400	1 800	0
Nitrate NO_3 (mg/l)	5	0	0	5	0
Bromide Br (mg/l)	0	5	20	60	60
HCO_3 (mg/l)	600	650	200	200	110
Sum of anions (mg/l)	1190	4150	16600	52005	50110
Sum of salts (mg/l)	1 665	6 260	26 620	84 425	81 823
Ion balance (mg/l)		3,8	4,3	3,2	1,0

Parameters	Type1 Groundwater	Type2 Low salinity	Type3 Intermediate salinity, flooding	Type4 High salinity, sulfate	Type5 High salinity, barium
Dissolved salt calc. (mg/l)	1 665	6 265	26 640	84 485	81 883
Total hardness calc (mg/l)	285	650	1 450	2 000	3 800
Electr. conductivity calc	2 440	9 110	37 398	106 531	103 777

Assessment of the environmental risk mitigation included in the first step the calculation of percentage of pollutant load reduction and in the second the step comparison to recommended AA-EQS for Ni, Cd, and Pb. Within this paper technologies for metal removal were investigated. The estimation of environmental risk mitigation was performed for the following treatment technologies:

- Active technology based on precipitation process using a sodium sulphide Na_2S as a reagent - tested by DMT GmbH & Co. KG,
- Active technology based on precipitation process using a sodium hydroxide NaOH as a reagent - tested by DMT GmbH & Co. KG,
- Active technology based on precipitation process using a calcium hydroxide $Ca(OH)_2$ as a reagent - tested by DMT GmbH & Co. KG,
- Active treatment by sparging with hydrogen sulphide (H_2S) gas generated using an off-line sulphidogenic bioreactor – tested by Coal Authority,
- Semi-passive synthetic zeolite technology – developed and tested by CERTH,
- Semi-passive algae bio-technology – developed and tested by University of Almeria,
- Passive compost systems – tested by Coal Authority.

To perform the analysis data concerning concentration of specific contaminants present in mine water before and after implementation of treatment technologies was used. The percentage of pollutant load reduction was calculated comparing the concentration at the entrance and at the exit of the technology for each type of artificial mine water (Figure 1, Figure 2, Figure 3, Figure 4, Figure 5). The basis for the initial concentrations before treatment was matrix for five mine water types (Table 1). Due to differences between treatment technologies resulting from their specifics such as removal only of certain type of pollution the common list of metals allowing calculation of percentage of pollutant load reduction was created. Concentration of Zn, Ni, Cd, Cu, Pb, Hg, Fe, Mn, Mg, Ba in mine water samples were used to estimate the environmental risk mitigation resulting from loads reduction.

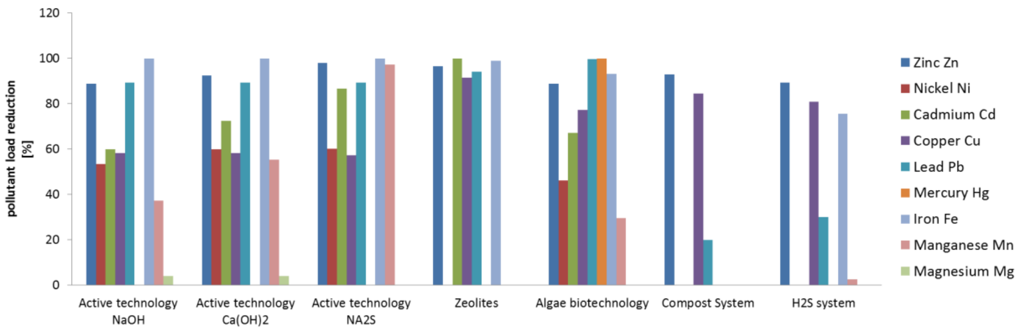

***Figure 1** Percentage of metal load reduction by treatment technologies (artificial mine water type 1)*

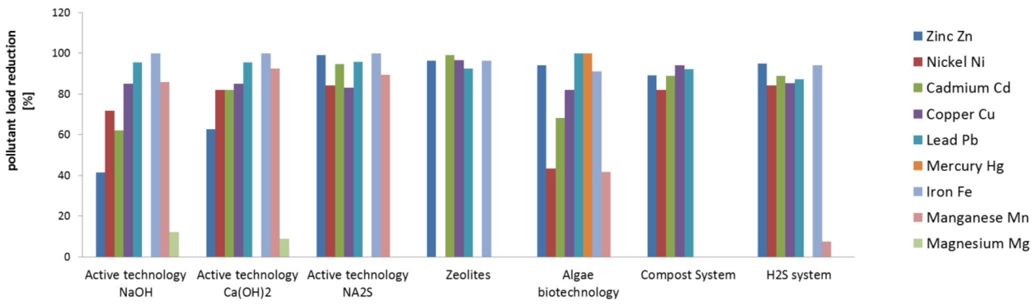

***Figure 2** Percentage of metal load reduction by treatment technologies (artificial mine water type 2)*

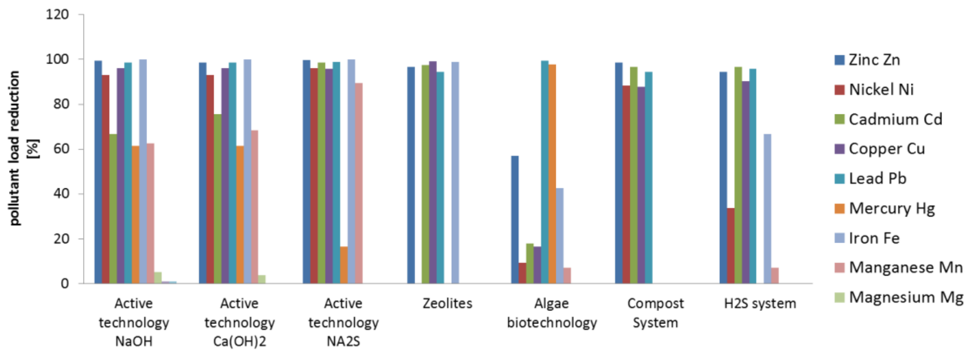

Figure 3 *Percentage of metal load reduction by treatment technologies (artificial mine water type 3)*

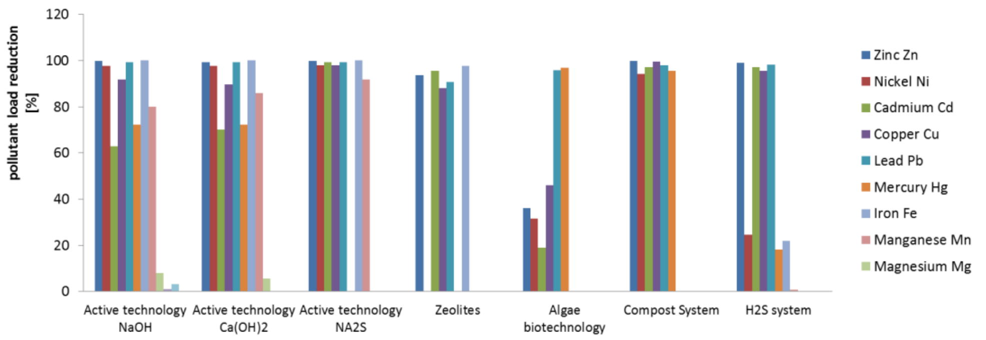

Figure 4 *Percentage of metal load reduction by treatment technologies (artificial mine water type 4)*

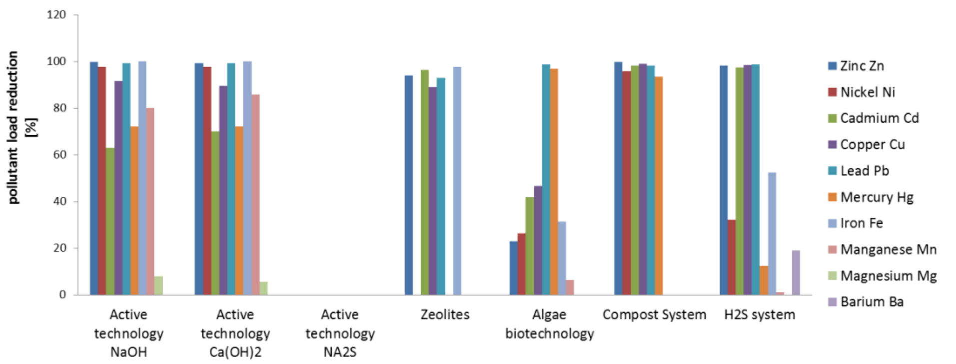

Figure 5 *Percentage of metal load reduction by treatment technologies (artificial mine water type 5)*

The achieved results showed that the range of treated pollutants is different depending on the technology and mine water type. The most wide range of treated pollutants characterizing active technologies (using NaOH, Na_2S, $Ca(OH)_2$ as a reagent) regardless mine water types, however the pollutant load reduction was most effective in case of the 3rd, 4th and 5th mine water type. The active technologies are particularly effective to treat mine water from Fe, Pb, Ni, Zn. The active technology using Na_2S as a reagent to precipitation process is not applicable for 5 mine water type. Zeolites technology is specific only for selected pollutants: Zn, Cd, Cu, Pb, Mn and the pollution load reduction in case of all mine water types was in most cases nearly 100%. Algae biotechnology reduced the metals concentration most effectively in 1st and 2nd mine water type. Algae biotechnology is dedicated to mine water contaminated mainly by Fe and Mn (around 100 % for all mine water type). The compost system can be also implemented to treat mine waters from heavy metals such as Zn, Ni, Cd, Cu, Pb and Hg but the highest effectiveness of treatment was observed in case of high salinity waters (type 4 and 5). The active treatment by sparging with hydrogen sulphide (H_2S) allow effectively for reduction of heavy metals such as Pb, Cu, Zn and Cd. However this technology is not dedicated for chemical parameters characteristic for 1st type of mine water.

Within the second step of environmental risk mitigation analysis the concentration of priority substances present in the outflow from treatment technologies were compared with environmental quality standards of priority substances set out in Directive 2013/39/EU (Table 2).

Table 2 *Environmental quality standards in the field of water policy (Directive 2013/39/EU amending 2000/60/EC and 2008/105/EC) used in the environmental risk assessment*

Parameters	AA-EQS [uq/l]	MAC-EQS [uq/l]
Nickel Ni	4	34
Cadmium Cd	0,08-0,25	0,45 - 1,5
Lead Pb	1,2	14
Mercury Hg		0,07

Subsequently, the annual average concentrations AA-EQS of selected priority substances (Ni, Cd, Pb) were used to estimate required degree of dilution (fold of dilution resulting from level exceedance of AA-EQS). The required degree of dilution of treated mine water by zero concentration river ensuring achievement of water quality standards was calculated. The achieved results are presented from Figure 6 to Figure 10.

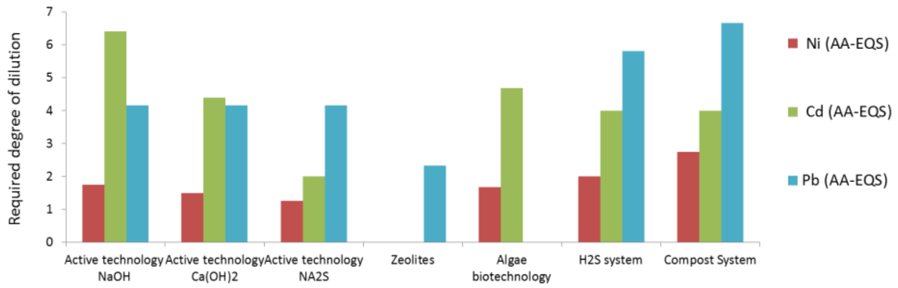

Figure 6 *Required degree of dilution of mine water after treatment in order to achieve the required water quality standards for mine water type 1*

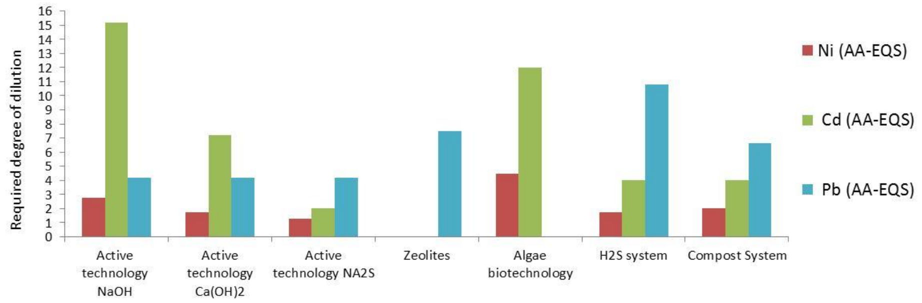

Figure 7 *Required degree of dilution of mine water after treatment in order to achieve the required water quality standards for mine water type 2*

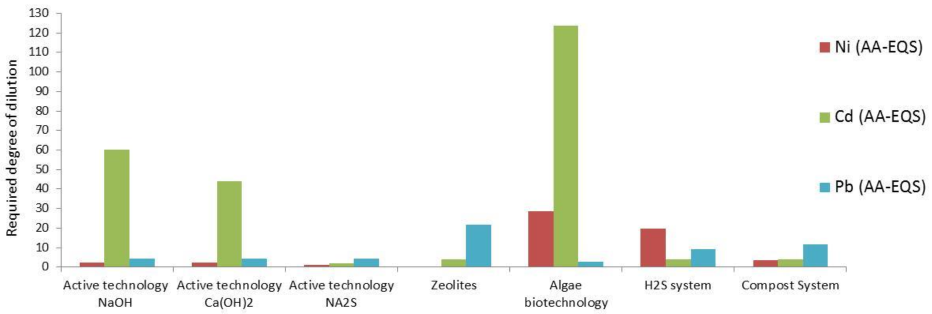

Figure 8 *Required degree of dilution of mine water after treatment in order to achieve the required water quality standards for mine water type 3*

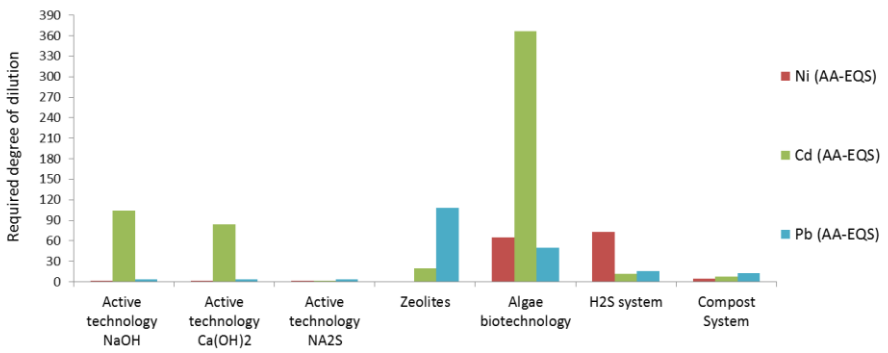

Figure 9 *Required degree of dilution of mine water after treatment in order to achieve the required water quality standards for mine water type 4*

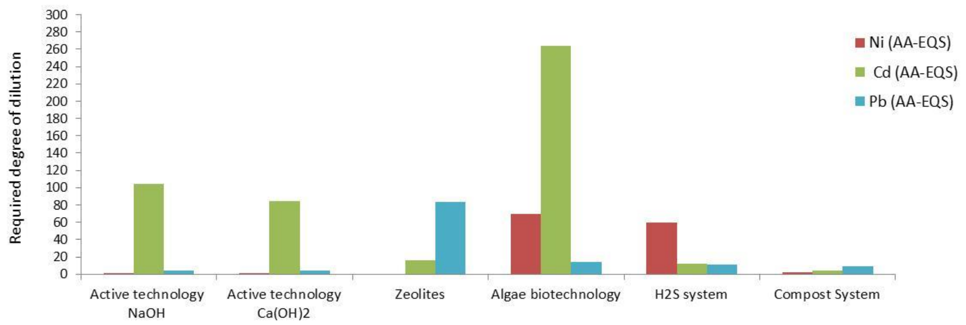

Figure 10 *Required degree of dilution of mine water after treatment in order to achieve the required water quality standards for mine water type 5*

The results showed that despite the high treatment efficiency required environmental quality standards are difficult to achieve and the further reduction of pollutant is required. Due to the dilution effect the river flow as an important factor should be taken into account during the technology selection process. In terms of environmental risk reduction caused by Cd, Ni and Pb, each technology has its limitations and the effectiveness was dependent on chemical composition of water. Comparing technology for different types of water showed that active technologies are more flexible in relation to changes in the concentration of contaminants.

In case of active technologies (using reagents NaOH, $Ca(OH)_2$), the relatively low degree of dilution of Pb and Ni is required for 3rd,4th,5th type of artificial mine water, however the concentration of Cd significantly exceeded the required limits. Environmental risk is effectively reduce by active technology using Na_2S in case of 3rd and 4th mine water type (Figure 8, Figure 9). However, this type of technology is not dedicated to treatment the water with parameters characteristic for 5th type of artificial mine water. The zeolite technology is very effective to reduce the risk caused by Ni and Cd, however to meet the environmental limit for Pb the further dilution is required. Algae-biotechnology allow to gain the required environmental quality standard for Pb in experiment performed for 1st and 2nd type of artificial mine water. The algae biotechnology is more selective regarding the treatment of different types of contaminants. In case of technology using for treatment hydrogen sulphide (H_2S) the risk was effectively mitigated and relatively stable regardless the changing water parameters, however the Ni concentration required higher dilution to meet AA-EQS value. The results concerning passive treatment based on compost system, showed that required dilution degree maintained at the similar level for all types of artificial mine water.

Discussion & Conclusions

The environmental risk is posed by discharged mine water due to the fact that they include elevated concentrations of metals and metalloids (Johnson and Hallberg 2005). Therefore, the implementation of treatment methods mitigating the risk and allowing to meet the set out environmental quality standards plays increasingly important role in mine water management systems. The performed analysis showed that comparison of the technologies between each other in terms of environmental risk mitigation is a complex and multidimensional process. The achieved results confirmed that active treatment technologies are more chemically flexible than passive systems (Taylor et al. 2005) and may effectively remove wide range of pollutants. Moreover appropriately designed active technologies may be less limited by operational parameters but this results in relatively high operating costs (Degens 2009). While active treatment technologies need power and input of (bio)chemicals to operate, the passive technologies require low energy input and smaller maintenance costs (Younger et al. 2002).

However, well-constructed passive technologies, carefully selected for occurring environmental problem and specific conditions, can be an effective ecological treatment systems successfully mitigating the environmental risk. The coal mining community is becoming increasingly interested in passive solutions which constitutes less expensive alternative to more costly active treatment technologies (Watzlaf et al. 2004). Additionally, if it is required the active and passive solutions may be combined to meet the existing environmental standards. As many experts indicated the treatment systems usually consists of multiple steps involving to the treatment process more than one technology (US EPA 2014). Consequently, the achieved results presented within this paper should not be interpreted unambiguously due to differences between technologies specifications. The performed analysis showed that treatment technologies may prevent further water body status deterioration, however during the assessment process each technology should be considered individually depending on site specific local conditions and type of mine water (Younger 2000).

The approach to assess and select suitable solution for environmental risk mitigation should involve estimation of pollutant load reduction as well as a required dilution degree. To perform complex assessment the process should start from collection of data about exceedances occurring in mine water and receiving river. The assessment of the technology risk mitigation should estimate not only improvement of parameters in mine water discharge but also the impact on the water body. Accordingly, the flow rate of the receiving river is an important factor due to dilution effect which can decide on the applicability of the selected technologies. In order to estimate the final concentration of contaminants and assess the risk mitigation resulting from technology implementation, parameters such as water chemical composition of discharge and river as well as technology and river flow rate should be considered.

The environmental risk mitigation is an important factor in decision making process in selection of the treatment technology. For this reason the assessment of environmental risk mitigation resulting from application of possible treatment methods should be a part of the technology selection process depending on existing environmental problem. However, in addition to environmental aspects factors such as available size of land, system longevity, maintenance requirements, flow rate, site accessibility, availability of power sources; economic aspects (capital and operation costs); climate impacts on system efficiency should be also important elements of technology selection (US EPA, 2014). Therefore in the further step the cost benefit analysis including estimation of potential costs and benefits resulting from treatment technologies implementation is required.

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