STRATEGIES FOR MANAGING ENVIRONMENTAL PROBLEMS AND WATER TREATMENT IN MINING

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ABSTRACT

Managing environmental problems in mining, in particular regarding mine water, requires complex design and the implementation of integrated strategies, such as Integrated Water Management, Passive Biological Water Treatment and Environmental Impact Assessment Studies for active mines.

Integrated Water Management is defined as the planning, regulation and management of water use throughout the life cycle of mines. Starting with the draw-down of groundwater level before exploitation, it is concerned with on-going water drainage due to the cleaning of process water and other waste water as well as the management of groundwater recharge following the end of exploitation. Integrated water management systems provide substantial contributions to non-aggressive and sustainable use of water. Accordingly, it also contributes to environmental protection. Based on their experience in the mining industry, the authors exemplarily describe the treatment of sulphate-polluted process water from a copper mine in Chile by usage of passive biological systems. Aiming at the fulfilment of the Irrigation Quality Standard enforced in Chile, in the project, which is at a pilot scale level, polluted process water streams are collected in a basin and discharged to a plantation of trees. In Germany, these treatment processes, however, run on a full technical scale in order to reduce sulphate, uranium, and other pollutants.

Drawing on the example the example of Tsumeb smelter complex in Namibia, the authors discuss tasks and challenges of Environmental Impact Assessments (EIA) of complex polluted mining sites. The EIA-procedure ensures that the environmental implications of mining activities are being taken into account before making decisions for further developments of a mine life cycle. This process involves complex site analysis, the evaluation of all impacts on the environment, public consultations as well as stakeholder involvement of all parties concerned.

1. ENVIRONMENTAL PROBLEMS CAUSED BY MINING

Mining and associated activities have quantitative as well as qualitative impacts on the water regime and water quality in and around the complexes. Water-pollution problems, caused by mining, include acid mine drainage, metal contamination and increased sediment levels in streams. Sources can include active or abandoned surface and underground mines, processing plants, waste-disposal areas, haulage roads or tailing ponds. Mine drainage is a potentially severe pollution hazard, which can affect surrounding soil, groundwater, and surface water. The emission of metals can lead to contaminated soils, surface water, groundwater, and air, and so contribute to health and environmental effects. In order to avoid impacts on the surface and groundwater, comprehensive knowledge of the water regime is essential for effective and sustainable water management. The reduction of discharges of pollutants into surface water bodies is one of the most essential tasks to reduce impacts on environmental components.

The following case studies are provided to illustrate water management issues and measures taken to reduce pollution in water and environmental impacts of mining:

Case study 1 – Water management in the coal mining region Lausitz, Germany

Case study 2 – Treatment of mine drainages using a Constructed Wetland on the Lo Aguirre Mine, Chile

Case study 3 – Environmental risk assessment on the open pit Tsumeb, Namibia

1. WATER MANAGEMENT IN THE COAL MINING REGION LAUSITZ, GERMANY

Introduction

The concept of Integrated Water Management comprises the practice of making decisions and taking actions while considering multiple viewpoints of how water should be managed. These decisions and actions relate to situations, such as river basin planning, organisation of task forces, planning of new capital facilities, controlling reservoir releases, regulating floodplains and developing new laws and regulations. The need for multiple viewpoints is caused by the competition for water and by complex institutional constraints. Decision making processes usually take long and involve many participants.

Mining activities cause high impacts on the environment and, in this context, on the water in the mining area. Morphological (e.g. tailings, waste and rock dumps) and hydrogeological impacts on ground and surface water are of particular importance and must be managed to meet water quality standards and water quantity needs. In order to consider all viewpoints from water management agencies, government and non-government stakeholder groups in different geographic regions, as well as with regard to the different knowledge disciplines they represent, all stakeholder groups need to be involved in the Integrated Water Management planning process.

There are three main aspects to be investigated:

- quality and quantity of ground and surface water,
- interactions of water with land and environment,
- inter-relationships between water and social and economic development.

Hence, adopting the Integrated Water Management approach requires a constant discussion of all aspects mentioned above, with all stakeholders concerned and at each step in the mine cycle.

Water Management in Mining Processes

In the majority of cases, mining processes affect water and, consequently, cause high impacts and influences on the environment. Not only hydrogeological impacts on ground and surface water in mining areas and river catchments or geotechnical and morphological disturbances such as Tailings Storage Facilities TSF) are to be reflected on here, but also Waste Rock and Rock and Waste Dumps, with all their known consequences, such as geostability, erosion, dust on environmental compartments and a wide range of socio-economic questions.

In order to cope with all potential impacts and influences, it is necessary to know as much as possible about them and their dependencies. In this context, the Integrated Water Management in mining is concerned with the interplay between politics, economy and society, regarding the various aspects of water use, influenced by mining processes. Optimal strategies are always site-specific and must take aspects, such as geology, topography, hydrology, mining method and cost effectiveness into account. Amongst others, the objectives of water management comprise:

- prediction of short- and long-term effects,
- better understanding of geologic and hydrogeologic conditions,
- determination of an optimal design for water draw-down,
- control of on-going water drainage (esp. regarding AMD),
- treatment of process water and other waste water,
- achievement of a specified water quality at every time,
- reduction of the impacts on groundwater,
- minimisation of long-term impacts on the environment surrounding the site.

For the optimisation of water management and as a foundation for decision support analysis, numerical site models are appropriate. Modelling often plays a primary role in the investigations required to predict potential long-term impacts on the environment. A model could be the fundamental basis for any further qualitative assessments and decisions, both in functional-scientific and political fields.

During the implementation of the investigations, several complex scientific- technological, social and economical tasks had to be taken into consideration. These include activities, such as

- identification and assessment of pollution sources (mining, agriculture, sewage discharges),
- evaluation of appropriate models for optimal management of water resources,

- identification of water flows and flood plains,
- set-up of one or more hydrological and mass transport models,
- simulation and prognosis of future developments of water quantities and water chemistry,
- selection and testing of appropriate models for optimised management of water resources,
- definition and assignment of responsibilities,
- development of laws and regulations.

Case Study: Lake Area in the Former Coal Mining Region Lausitz, Germany

In the former coal mining region Lausitz (part of the German state of Saxony), several former pits are currently being planned to convert into lakes. This development is expected to be finished in 2018, making the Lausitz region, with a designated area of approximately 3,000 km², one of the largest lake regions in Europe (see Figure 1).

Figure 1. Overview Lausitz Lake Chain Region (Picture source: LMBV GmbH)

The process of filling the pits with rising groundwater and surface water flows is assisted by extensive numerical modelling studies. In this context, and in an area of around 1,200 km², G.U.B. Ingenieur AG is conducting a durable and steadily working numerical model in order to predict as well as control the water levels. Hydrogeological modelling is also being used for the decision support on scenarios for the recovery of groundwater levels or the optimisation of the process water management in active open pits.

One of the main challenges during the filling process after mining is the risk of Acid Mine Drainage (AMD). Against this background, substantial efforts for the water quality of the future lakes. Not only will an Integrated Water Management be appropriate to handle the situation, but it will also gain in importance. Potential water management strategies for reducing acid generation include the following issues:

- active mining operations can incorporate diversions to route surface drainage away from pyretic material or route through alkaline material,
- deposition and rough-grading of spoil material in order to prevent ponding and subsequent infiltration,
- prompt removal of pit water for lessening the amount and severity of acid generated,
- isolation of polluted pit water from non-contaminated sources (no co-mingling) for reducing the quantity of water requiring treatment,
- usage of constructed under-drain systems for routing water away from contact with acid forming material.

2. TREATMENT OF MINE DRAINAGES BY USE OF A CONSTRUCTED WETLAND ON THE LO AGUIRRE MINE, CHILE

Introduction

The formation of sulphate-polluted mine water poses a problem at the former coal mining regions in Germany as well as at a large number of other mine sites worldwide. The phenomenon described, mainly occurs when pyrite-containing geological layers and disposed overburden come in contact with percolating water and oxygen. During the processing of 1 ton of ore containing 1 % pyrite sulphur, 30 kg of sulphuric acid are obtained as waste material. The decomposition of pyrite is causing high loads of dissolved sulphate and iron ions as well as high acidity in the seepage and corresponding surface water. Due to the long period during which mine water treatment may be necessary, sustainable passive remediation technologies with low operational costs are regarded to have significant economical advantages. Conventional technologies, mainly based on chemical precipitation processes, need high technical and material input, resulting in high amounts of residues.

Approaches for the biological reduction of sulphate to sulphide by special micro-organisms (Desulphuricants) in laboratory scale are referred to in the enclosed bibliography [references 1, 2, 3, 4, 5]. Focused on the development of an overall biotechnical process for the cost-efficient and sustainable treatment of sulphate-polluted water and in order to transfer the first promising results, mentioned above, into a practical application investigations, aiming at improvements of the treatment of mine water by Constructed Wetlands, were undertaken. In a first step, the parameters for an optimum reduction of sulphate had to be determined and combined with strategies for the immobilisation of resulting sulphide in technical scale model systems.

In a second phase, the results of the preliminary investigations were applied to pilot plants on mine sites to verify the developed techniques under real circumstances. The individual process stages had to be adapted to the site specific conditions like sulphate load in the inflow, pH-value and the amount of total suspended solids. Through establishing an efficient passive biological water treatment, the sulphate concentration and acidity in the mine water had to be decreased to accomplish water quality standards for preventing health risks and environmental hazards.

Preliminary Investigations

Approaches for biological sulphate reduction using desulphurising bacteria, are described in the enclosed bibliography [references 1, 2, 3, 4, 5]. Under anaerobic conditions and the presence of molasses (carbon source) and ammonium (nitrogen source), sulphate is reduced microbially to sulphide.

The preliminary investigation set-ups were realised through the application of an upward flow of model water (2,000 mg/l SO_4) through columns with a capacity of 4.8 liters and the horizontal flow of model water through boxes with a capacity of 90 liters (figure 2). The columns as well as the boxes were filled with silicate gravel to provide a surface for the growth of sulphate-reducing bacteria. According to the obligate requirement of anaerobic conditions, the columns and boxes were sealed to avoid the immission of atmospheric oxygen into the described arrangements. The inflow and outflow were realised by the attachment of tubes. At the beginning of the experiments, the systems were inoculated with digested sludge originated from a sewage treatment plant to supply the process initially with sulphate-reducing bacteria.

The model water used for the experiments had a concentration of 2,000 mg/l sulphate. Before accessing the bioreactor installation, 600 µmol/l of ammonium and 2.6 g/l of molasses were added as a nitrogen and carbon source in order to provide the bacteria with the required nutrients. The hydraulic retention time was 7.6 days.

Figure 2. experimental set-up – left: columns (volume 4.8 l), right: box (volume 90 l)

The results obtained from the experiments confirm that sulphate can be reduced by anaerobic microbial transformation processes. During the experiment three distinct phases could be observed (see figure 3).

1st : (duration: 20 days) bacterial adaptation phase / lag-phase with small oscillations but no decrease of sulphate concentration

2nd : (duration: 15 days) log-phase with increasing rates of sulphate removal

3rd : (manually stopped after 50 days) steady phase with a constant rate of sulphate removal between 80 and 90 %

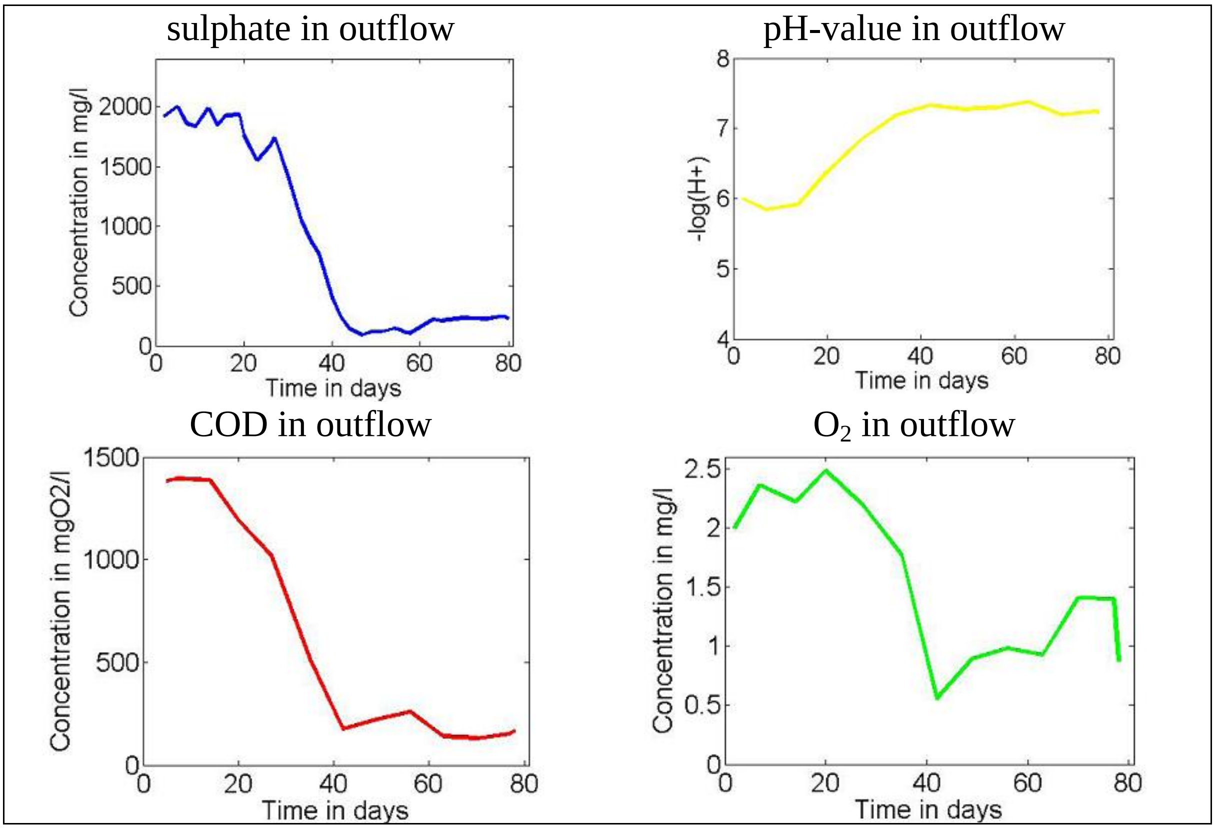

Figure 3. results of the microbial sulphate reduction in the preliminary investigations

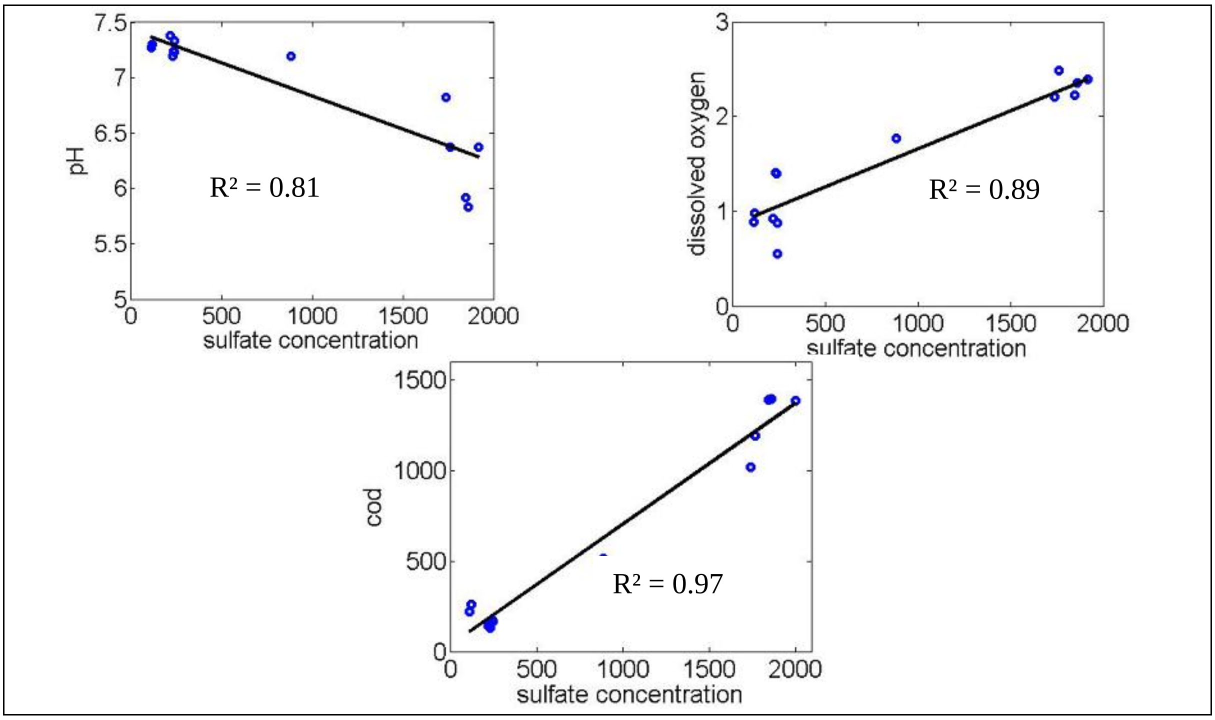

Figure 4. regression lines and coefficients for the correlations between sulphate concentration and pH-value, dissolved oxygen concentration and chemical oxygen demand (COD)

During the experiment, the sulphate concentration, the pH-value, the chemical oxygen demand (COD) and the concentration of dissolved oxygen in the outflow water were measured regularly. At the beginning of the experiment, a pH-value of 6 was observed in the outflow caused by chemical interactions between the gravel and the liquid phase. The significant relation obtained for the parameters sulphate concentration and pH-value in the outflow (see figure 4) indicates that the bacterial sulphate reduction is indeed responsible for an increase in alkalinity and a decrease in acidity.

By the addition of 2.6 g/l molasses (60-70 % carbohydrates) to the model water, the COD is raised considerably to nearly 1,500 mg/l O_2. As soon as an increment of sulphate removal can be observed, the COD in the outflow is lowered by the consumption of the sulphate-reducing bacteria to the final constant concentration of 140 mg/l O_2 (figure 3).

The concentration of dissolved oxygen is decreasing while the removal of sulphate is increasing. This indicates that aerobic bacteria in the inoculated sewage sludge are consuming oxygen and thus lowering its concentration. This process initialises and improves the required anaerobic medium for sulphate-reducing bacteria, which are subsequently metabolising sulphate more effectively.

From the anaerobic sulphate-reducing processes, sulphate was partially transformed into sulphide. Depending on pH, the produced sulphide is mostly available as hydrogen sulphide. Hydrogen sulphide has a toxic effect. In order to avoid its emission after passing through the sulphate reducing step, the treated water was drained through an iron granulate drainage to precipitate the sulphide as low soluble iron sulphide. The effectiveness of this technique has been proven and the sulphide concentration could be lowered by 90 %, from 400 mg/l sulphide down to 40 mg/l. Figure 5 shows the summarised simplified process of sulphate reduction and sulphide precipitation.

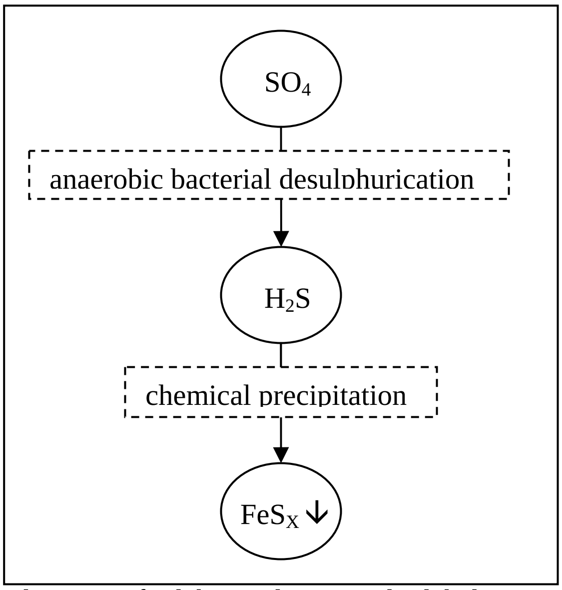

Figure 5. summarised process of sulphate reduction and sulphide precipitation (simplified)

The preliminary investigations displayed that an efficient decrease of sulphate concentration can be obtained by anaerobic microbiological processes. After an establishing phase of approximately 30 days, a continuous decrease of sulphate concentration of up to 90 % was observed (figure 3). The sulphate concentration was thus reduced from 2,000 mg/l to 200 mg/l. The sulphate-reducing processes could be successfully transferred from 4.8-litre-systems to 90-litre-systems. The concentration of the produced hydrogen sulphide could be lowered down to 10 % by the precipitation as iron sulphide by draining through granulated iron. The promising results, gained in the model systems, were utilised to determine the parameters of the design and operation of a pilot plant.

Pilot Plant at the Lo Aguirre Mine in Chile

The Lo Aguirre mine is situated 15 km west of Santiago de Chile. On this site, the first Chilean copper extraction plant was installed and operated. In former times, up to 14,000 t copper per year had been extracted. The total area of the site is about 45 ha. At present, the mine is closed and the rock piles are being capped using a clay and a topsoil layer (figure 6). The leachate from the rock piles (53,000 m³/a) is partially discharged to sealed basins using open channels. Another part is used for irrigation of plantations, which causes negative environmental impacts because of the high sulphate concentration and the low pH-value of the untreated water.

Figure 6. rock pile at Lo Aguirre site during mine closure (left) and basins for collection and evaporation of leachate (right)

For the dimensioning of a full scale plant for the treatment of leachate at the Lo Aguirre mine site, a pilot plant was constructed and taken into operation (figure 7). The technological concepts for the design and operation of this passive biological treatment plant were based on the extensive investigations described before. The parameters of the Constructed Wetland are adapted to the site specific conditions. It contains three treatment stages and is operated with a flow rate of 100 l/d. The developed technology is based on the microbial sulphate reduction in an anaerobic medium (see chapter “Preliminary investigations”). The sulphate removing process is mainly limited by pH-value, concentration of dissolved oxygen and the availability of a carbon source. Beside high loads of sulphate (>9,000 mg/l SO4), the mine water discharges contain a high iron concentration and are characterised by a low pH-value (<5). To avoid a clogging of the gravel used as filter material in the Constructed Wetland, the iron has to be removed and the pH-value needs to be increased (first treatment stage). For this purpose an aeration cascade and a limestone drainage are used.

At the second treatment stage the microbial sulphate reduction is accomplished in an anaerobic Constructed Wetland. For the efficient biological transformation of sulphate, a readily available carbon and nitrogen source (molasses and ammonium) are added to the treated water before it is passed into the system. From the anaerobic sulphate-reducing process, sulphate is transformed into hydrogen sulphide. At the third treatment stage, the treated water is drained through iron granulate. At this stage the high potential of iron to fix the hydrogen sulphide is used. By the final precipitation of low soluble iron sulphide, the sulphur compounds in the mine water are substantially eliminated from the water cycle.

Figure 7. pilot plant for the passive biological treatment of sulphate loaded leachate using a Constructed Wetland at the Lo Aguirre mine

The monitoring phase is still ongoing. The first monitoring data obtained until now is showing the following promising results:

- the pH-value is raised from 4.5 to 6.7
- the sulphate concentration is reduced by one third from around 9,000 down to 6,000 mg/l

The pilot plant is running in its actual configuration and monitored since the beginning of June 2009. Due to the still short operation period the sulphate-reducing process is still in its log phase as described in the chapter “Preliminary investigations”. Thus it is expected that the effectiveness of the sulphate removal will be increasing during the next few weeks, so that the preliminary results of up to 90 % sulphate reduction can be reached. The final results are assumed to be available by the end of September 2009. For the duration of the ongoing project the treatment parameters are further optimised to secure a maximum and constant sulphate reduction. The objective is to reach the Chilean Irrigation Quality Standards.

Once the pilot plant has proven the effective and constant removal of sulphate as seen in the preliminary experiments and an ongoing reduction of acidity, the gained results of this pilot plant will lead to the planning and design of a full scale wetland at this site. The full scale wetland will be a construction of several excavated pits with earth damns in order to contain the described treatment stages with their different reactive materials. They will be sealed with a plastic layer and will be connected by water pipes. The dimensioning of the wetland will depend especially on the effectiveness of sulphate reduction and thus on the required retention time to reach a sulphate concentration of <250 mg/l SO_4 in the outflow.

3. ENVIRONMENTAL IMPACT ASSESSMENT (EIA) ON THE OPEN PIT TSUMEB, NAMIBIA

Introduction

While performing an Environmental Impact Assessment (EIA) of a completely polluted mining site, all of the environmental implications of mining activities have to be taken into account before making decisions for further developments. This process involves a complex site analysis, the evaluation of all effects on the environment, public consultations as well as stakeholder involvement of all parties concerned.

Tsumeb smelter complex in Namibia is one of the worlds most famous mine sites as it is a prolific and poly-metallic deposit. Mining, in an open pit with a depth of up to 1,500 m, began in 1907 by the exploitation of copper, lead and zinc. After the end of active open pit mining in Tsumeb in 1996, serious environmental problems arose. The hydrological and hydrogeological situation started taking developments that endangered the drinking water supply in the whole region. As the mine site is located in a karst formation, the ground water is characterized by caverns. Due to the arid climate of Namibia and due to less rainfall, but high evaporation, water is a valuable asset and the resulting conflict potential, therefore, very high. EIA must therefore be aware of the problems regarding water an prioritise the issue. In addition, since the quarters around Tsumeb are increasingly regarded to become Namibia's growth areas, a stable ecological environment will we an essential foundation for any economic development.

The EIA was conducted in 3 Phases. Following a first and complex site analysis in a scoping phase, which comprised the evaluation of the current status and included the involvement of public interests, the second phase was characterized by intensive special investigations of underground as well as the specific situation at selected locations that were considered to be more sensitive for future development. The third phase of the EIA finally ended in an Environmental Management Plan that addressed the impacts of a future-related set of environmental specifications that will be included in decision making and, ultimately, enforced by relevant stakeholders on site.

Results

In terms of water, the EIA on the open pit Tsumeb provided evidence of the environmental impacts that the smelter complex had spread over an area greater than 1,000 km². During rainy season, harmful metals and arsenic components were largely washed out from tailings and storage facilities with the drainage system. However, the available data for groundwater did not show high anthropogenic influences. However, this fact could not be predicted for the time after the completion of dewatering measures. Although, altogether, the impacts on groundwater were considered to be not harmful, those on surface water were regarded to be more serious. [6] Regarding water-related impacts, the Environmental Management Plan recommends the establishment of a long term monitoring, both within the smelter complex and in adjacent areas. This refers in particular to tailing materials and rising groundwater. In summary, the EIA on the Tsumeb open pit expresses with certainty that, at present, the issue of water does definitely not give cause for concern at the Tsumeb smelter complex. But, to sustain this fact for the future, too, will remain a challenge and assignment of vital importance.

4. CONCLUSIONS

During mining and after mine closure, water management must remain an integrated task for the prevention of environmental risks. Hydrogeological modelling is the base for water management policies, such as the reduction of acid mine water discharge. Convenient strategies might be:

- routing of surface drainage away from pyretic material or route trough alkaline materials
- prevention of ponding and subsequent infiltration on spoil material deposition
- prompt removal of pit water to reduce the amount and severity of acid generation
- separation of non-contaminated and contaminated water flows to reduce the quantity of water which have to be treated.

In many cases, contaminated mine water needs to be treated after the ending of mining activities for decades. Consequently, passive technologies, providing low maintenance and operational costs, will become more and more important in the sector of remediation technologies. An effective pilot plant of a Constructed Wetland has been implemented in Chile to treat leachate from a copper mine, thus widely contributing to the relief of the environment at this site.

In conclusion, it can be established that long-time monitoring as well as the results from standardised investigations and environmental assessments can give considerable certainty to stakeholders that mining activities will not permanently and negatively influence water, the source of life.

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