Chapter 7

Dimensions of water management in the extractive industries

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7.1 INTRODUCTION

The aim of this chapter is to provide the readers with limited technical knowledge about the field of mining with an overview of the dimensions of water management in mining. It describes the range of water management tasks required and provides information on how water management challenges can be addressed.

Mining is the extraction of raw materials from the Earth's crust by construction of surface openings (open pits, shafts, adits, inclines), the extraction of raw materials from the host rock by means of treatment plants, the dumping of residues in waste rock heaps or tailings ponds, the drainage and lowering of groundwater in large areas and all related transport activities. Mining activities require the management of water resources in the surface and underground watersheds. Commonly, mine site rehabilitation is also considered a mining activity, which includes the revitalization of mining areas after the extraction of raw materials. Technical measures for this are the groundwater rebound after switching off the pumps (mine flooding), the closure and dismantling of the mining facilities, the covering of heaps and tailings facilities and the reclamation of the land used for mining and their landscaping.

Water management plays a substantial role in all phases of mining and in all types of mining activities (Grünewald, 2001; Tiwary, 2001; Wolkersdorfer *et al.*, 2020). During the exploration phase, extensive hydrogeological studies must be carried out to allow comprehensive planning for

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the subsequent mine drainage including flood protection, water supply and disposal, disposal of liquid processing residues as well as to initiate the respective water management approval procedures within the overall permitting procedure framework for the mining site. As a rule, a hydrological-hydrogeological site model is created using the results of the site exploration, which provides information on the hydraulic properties of the subsoil in order to predict future dewatering scenarios (Rapantova *et al.*, 2007).

In addition to the geotechnical and hydrogeological site exploration of the extraction site, the water management activities during the exploration and site preparation include the planning and implementation of processes for (1) lowering the groundwater level, (2) disposing of groundwater and wastewater, and (3) planning of development of facilities for processing wastes from the site. Both liquid and solid residues need to be addressed (Dold, 2008; Fields, 2003; Pepper *et al.*, 2014; Younger & Wolkersdorfer, 2004). While solid residues are deposited on waste rock dumps, processing residues are dumped into sedimentation basins called tailings ponds. Depending on the rock composition and target raw mineral, these tailings ponds may contain potentially toxic substances that are used to process the rocks to extract the target minerals. For example, in the case of gold mining, cyanide is used as a solvent; in the case of uranium mining, acid or alkaline solutions are used. The pollutant-containing suspension is deposited into the tailings ponds, so that the sediment can settle and thus forms a sediment layer with an excess water level. Furthermore, flood protection measures must be planned for all mining facilities.

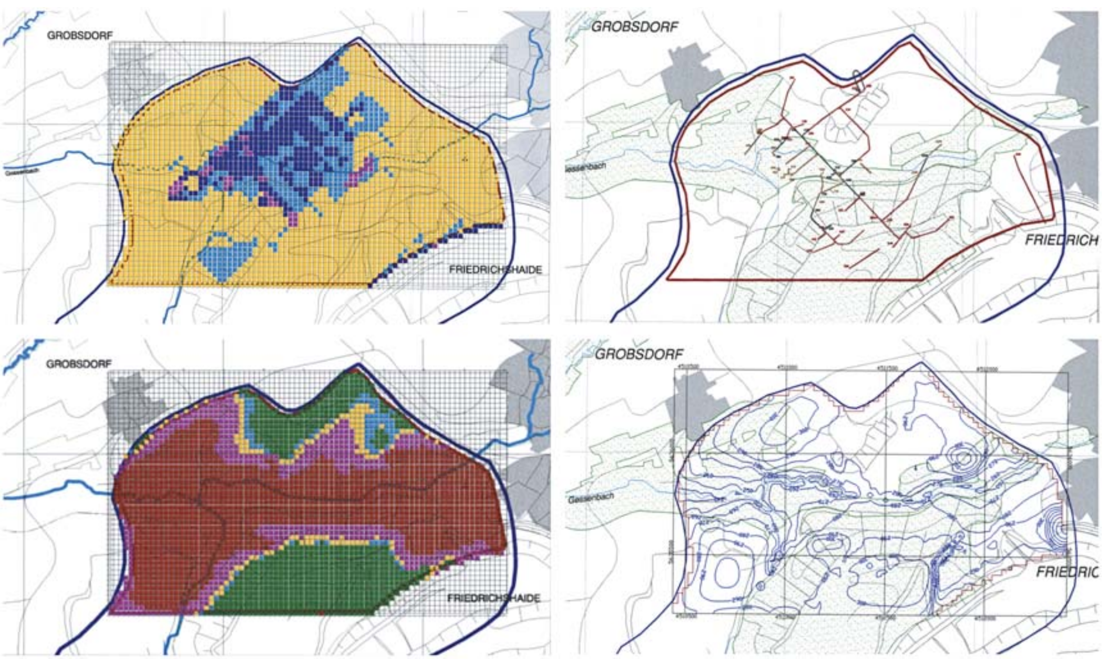

Figure 7.1 Exemplified preparation of extraction by site exploration; top left: rock permeability with consideration of tectonics, top right: map with the routes implemented in the model, bottom left: calculated groundwater corridor distances, bottom right: groundwater balance plans as the basis for the scenario calculation.

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Thorough water management preparation during the exploration and site preparation phases is key for successful water management during the extraction phase (Dold, 2008). For planning the water management of the extraction site, methodical baseline data collection is carried out, to determine the water balance (natural and anthropogenic groundwater recharge, marginal inflows, groundwater abstraction), geological setting (drilling data, geological maps), hydrogeological situation (hydraulic parameters in coarse rock and bedrock) and the planned mining (mining crack, the location where the ore will be extracted). These data are used to build the hydrogeological and hydraulic model for the mine site (Figure 7.1).

Basic preparation steps for commissioning of a mine can be quite extensive (Figure 7.2), and the dimension of water management in mining is illustrated by numerous photos hereafter.

7.2 WATER MANAGEMENT DURING MINE OPERATION

During the extraction of raw materials, liquid and solid waste (such as treatment residues, wastewater) is generated for which disposal facilities must be planned. In some cases, the mining residues might be toxic if the treatment has been carried out with chemicals. For economic reasons, these disposal facilities are close to the mining activities and must be equipped with appropriate safeguards against potential environmental emissions. The planning of waste disposal facilities for liquid waste concerns industrial landfills (tailings ponds) and solid waste rock dumps (Ritcey, 1989). In addition, water treatment plants might be necessary, in particular when mine water with elevated concentrations of potentially toxic elements or acidity is formed during the excavation of the deposit. Usually, this occurs when geogenic iron (di)-sulphides (pyrite, marcasite, pyrrhotite) are oxidized by water and oxygen; in this case, sulphuric acid reacts with the host rocks, forming Acid Mine Drainage (AMD) (Blowes *et al.*, 2014; Evangelou & Zhang, 1995; Wolkersdorfer, 2008). Water management activities during the extraction process include groundwater and mine water management, the operation of the water supply and disposal, the disposal of liquid processing residues in tailings dams (Figures 7.3 and 7.4) and mine flooding protection.

The planning of tailings dams has to be carried out according to the recommendations of the International Commission on Large Dams (ICOLD), which issues bulletins on dam safety management. ICOLD is an international non-governmental organization aiming to share professional information and knowledge of the design, construction, maintenance, and effects of large dams (any dam above 15 m in height), and leads in setting standards and guidelines to ensure that dams are built and operated. ICOLD presently has 30 Technical Committees, which issue bulletins with 'state of the art' recommendations for engineers to ensure long-term geotechnical and environmental stability for tailings pond dams (Bowles *et al.*, 2007). Depending on the dimension of the mining site and extension of the processing activities, tailings ponds can cover as much as several hectares and be several tens of meters deep. They contain the processing sludge that is undergoing sedimentation and thus gets separated into a solid and a liquid phase, which is called pore water or interstitial water and, usually, is contaminated with the processing residues.

The term mine water describes all water that circulates in the mine, comes into contact with the underground or open pit host rocks or raw material. It does not include the processing water, and it is not necessarily polluted. Usually, mine water with the highest environmental relevance is AMD, which is mine water with a pH below 5.6. It forms when iron (di)-sulphides in the rock are oxidized and not enough buffering minerals exist. The acidic environment in the mine water provides optimal conditions for the solution of metals and metalloids from the surrounding rock. As a result, acid mine water is usually highly mineralized. If it is not treated and is not prevented from spreading, large amounts of acid

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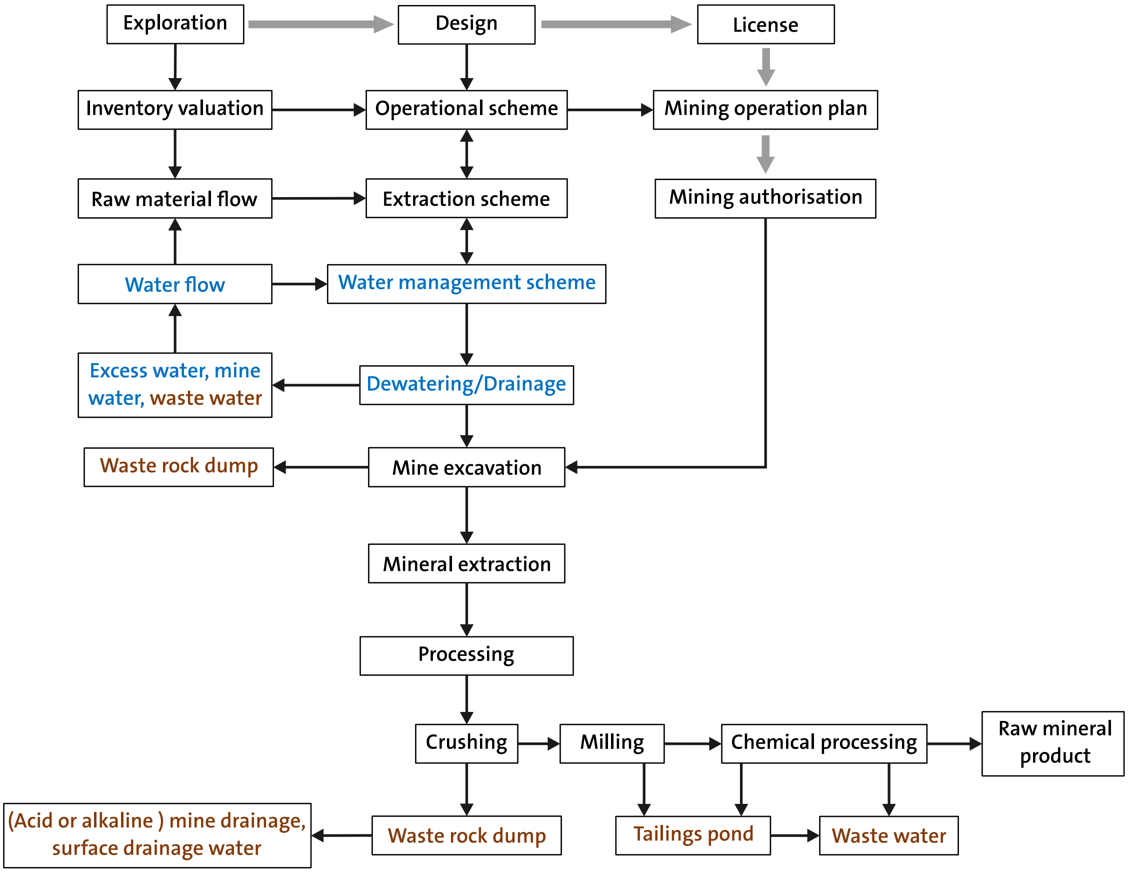

Figure 7.2 Exemplified scheme of mine design and mining process. (*Key*. Black font: activities related to mine preparation and operation; blue font: water-related flows and activities; brown font: waste-related flows or activities)

Figure 7.3 Example of an operating mine tailings pond in South Africa (left) and Chile (right). (Photographs: *left, Petra Schneider; right, Christian Wolkersdorfer*)

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Figure 7.4 Example of the dimension of an operating mine tailings pond in South Africa. (Photographs: *Petra Schneider*)

mine water can flow into nearby rivers or pollute the groundwater, as can be seen in many regions of the world like South Africa and Spain. (Olías *et al.*, 2004; Sarmiento *et al.*, 2009) (Figure 7.5).

AMD represents a major challenge in mining practice, because (1) it is heavily polluted and (2) there are mining sites where it is produced in large quantities. A classic method for treating AMD is liming (i.e. neutralization by means of calcium carbonate, calcium oxide, calcium hydroxide or sodium hydroxide). This method of treatment results in potentially dangerous residues that must be disposed of appropriately. Currently, there is no industrial-scale method for obtaining economic benefit from mine water; as a result, treatment and disposal still represent the best option available for handling of mine water. The level of toxicity of the material flushed into tailings ponds may also be affected by treatment that has occurred in the mining process. Metal and energy minerals are often treated with chemicals; the highly polluted wastewater resulting from this treatment process is flushed into tailings ponds as well.

Aggregate mining typically has less effects on water quality, as this type of mining is carried out without chemicals, and the target raw materials rarely contain pyrite or marcasite. Nonetheless, aggregates mining also requires sound water management, with a focus on water supply (such as dust control and sanitation) and flood control. Aggregate quarries operators usually maintain a sedimentation basin for rain and flood

Figure 7.5 Examples of Acid Mine Drainage (AMD) from South Africa (left) Rio Tinto mine, Spain (right). (Photographs: *left, Christian Wolkersdorfer; right, Petra Schneider*)

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Figure 7.6 Example of an aggregates mine and the respective extraction and processing installations in the Sevilla region, Spain (left) and increased sedimentation due to aggregates mining in the Nakku Khola River, Kathmandu Valley, Nepal. (Photographs: *left, Petra Schneider; right, Christian Wolkersdorfer*)

retention, but also for the provision of service and extinguishing water (Figure 7.6). Another type of aggregates mining that has a substantial effect on watersheds is sand dredging from rivers. Shortage of sand to support urban construction is a pressing problem in many areas, such as South East Asia; unsustainable sand mining is often accompanied by massive geotechnical and ecological hazards (Kondolf, 1997).

7.3 WATER MANAGEMENT DURING MINE CLOSURE AND REHABILITATION

When the economically viable potential of the raw material is exhausted, mining rehabilitation should begin. Most mining sites that require landscape rehabilitation are large (Figure 7.7). Usually, the use of the area for mining has had a substantial effect on the regional water balance system, as water regulating vegetation may have been removed and natural watersheds drained. The stage of mine closure and rehabilitation provides an

Figure 7.7 Dimensions of mining: active lignite mining site Jänschwalde (Germany, left); former iron mining area Río Tinto (Spain, right). (Photographs: *Petra Schneider*)

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Figure 7.8 Example of a flooded open cast mine in the Lusatian area of Germany. The embankments are equipped with stabilising materials. (Photographs: *Petra Schneider*)

opportunity to restore ecosystems and aquifers (Heikkinen *et al.*, 2008; McHaina, 2001; McKenna, 2002; Sheoran *et al.*, 2010; Slingerland & Wilson, 2015), though rehabilitation of most mining sites requires decades of restoration work (Sheoran *et al.*, 2010; Slingerland & Wilson, 2015).

In order to insure that funding will be available for the rehabilitation of mining sites, financial reserves must be built up during the operational phase. In addition to mine closure and dismantling of the facilities, backfilling and flooding of the mines may be required. In this case, groundwater recovery management is necessary, probably including water treatment. In most instances, the first step in the reclamation of the mining affected environment is to drain the pore water from the tailings and to cover the waste and tailings storage facilities. Polluted pore water is treated in a wastewater treatment plant.

Open pits, particularly those resulting from lignite mining, will often be flooded. In the frame of mine site rehabilitation, flooding refers to the cut-off of the drainage systems in order to allow the natural surface and groundwater to enter the mine through shafts and adits or to fill an open cast excavation (Melchers *et al.*, 2019). Mine flooding is a rehabilitation activity that can take several years or even decades. Large volumes of water are necessary that would then be unavailable for other purposes during the flooding period (Figure 7.8). Flooding measures are closely connected to other geotechnical measures that are necessary (e.g. the stabilisation of the embankments of the future lakes). In addition, a chemical stabilisation might be required in case AMD is generated during the flooding process (Johnson & Hallberg, 2005).

Water management during closure and rehabilitation work in the extractive industry typically requires groundwater retention (Figure 7.9, left) as well as the construction of water diversion channels (Figure 7.9, right). This is especially true, when several mines on a mining site are undergoing rehabilitation at the same time, as in the case of the 'Lusatian Lakeland' in Germany (Figure 7.10). In this area, water was diverted to flood open cast mines, developing these lakes into a tourist area. The diversion channels used to flood the mines were also used to support recreational use of small boats by tourists (Lintz *et al.*, 2012).

Tailings pond rehabilitation is a challenge during the whole mine closure process, as the fine sediments are not always settled after mining ceases due to strong pore water pressures. To ensure long term safety of tailings ponds, a methodology using verticals drains has been developed (Wismut GmbH, 2019). Usually, the supernatant water is pumped off to take off free pore water from the surface. Pore water from the

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Figure 7.9 Rehabilitation of lignite mines: the case of Lusatia (Germany). Left: groundwater management, right: flooding water channel to fill an open cast mine chain. (Photographs: *Petra Schneider*)

remaining sedimentation layers is drained off through vertical drains. Holes are drilled into the processing sludge (typically 3 m deep) to introduce vertical drains. Stabilisation of the complete system is performed through a geogrid, underlain by geofabric and drain mats (Figure 7.11). In general, the layered system is covered with 1 to 2 m of mineral soil or waste rock material to force tailings consolidation.

Both the extracted pore water and the supernatant water usually need treatment (Wismut GmbH, 2019). In principle, the approaches used entail mechanical, chemical or biological methods or a combination of these (Wolkersdorfer, 2008). Due to the size of the sites and the lengthy time required for the mine water treatment, the extractive industry often employs passive water treatment methods which are based on a combination of aeration and biological treatment e.g. with microorganisms (Baker & Banfield, 2003; Espana *et al.*, 2005; Gazea *et al.*, 1996; Kleinmann *et al.*, 1981; Martínez *et al.*, 2019; Neculita *et al.*, 2007). These mine water treatment methods are designed to occur in open basins (e.g. constructed

Figure 7.10 Flooding water channels for transport of water during the rehabilitation process. After rehabilitation, these channels serve as waterway for small touristic boats. (Photographs: *Petra Schneider*)

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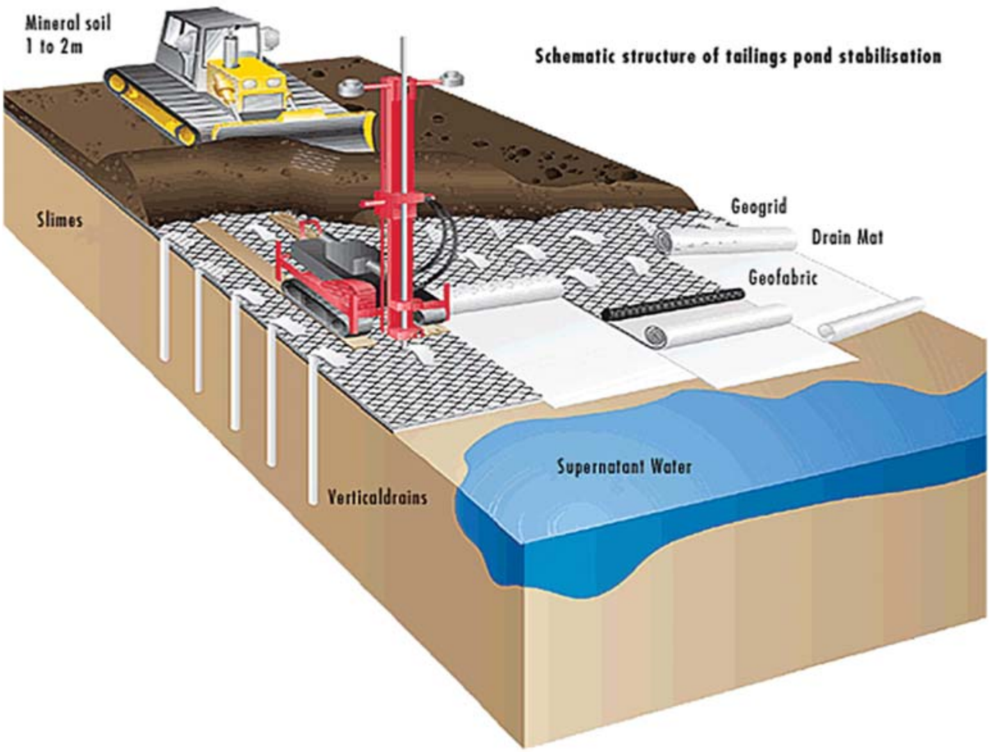

Figure 7.11 Stabilisation technology for tailings ponds: vertical drains in combination with a stabilisation package made of geofabric, drain mats, and geogrid. The system is covered with 1 to 2 m thick mineral soil or waste rock material to force consolidation. (*Modified from Wismut GmbH, 2019*)

wetlands) and are located at the bottom of the mine water outlet (Figure 7.12). Further chemical treatment options for metals include the use of reactive materials (Schneider *et al.*, 2001).

Typically, the remaining waste rock dumps must be rehabilitated as well. In practice, the remediation approach depends on the pollution potential. While sites with lower pollutant potential are often not surface sealed (Ludwig *et al.*, 2003) and, as a preferred solution, are often left to be remediated by natural plant succession (Sweigard *et al.*, 2017), waste rock dumps with higher pollutant potential or in close proximity to protected areas usually need to be covered (Ludwig *et al.*, 2003). A further after-use for biomass production might also be taken into consideration for sites with a small pollution potential that are left to natural plant succession (Bungart *et al.*, 2000). For sites that require a mineral sealing, this sealing may involve a hydraulic barrier (mineral sealing layer with a permeability coefficient of $<1 \times 10^{-9}$ m/s and a thickness of about 50 cm), or pure mineral layers, which form a gas and dust barrier and serve as root space for plants. A special mitigation solution for waste rock dumps with a very high pollutant potential can be reactive horizontal barriers (Schneider *et al.*, 2002).

Aggregates mining quarries are usually reused (Oswald *et al.*, 2018) with different approaches, including industrial heritage tourism (Edwards *et al.*, 1996). After appropriate geotechnical safeguarding, potential uses for reuse of quarries include swimming, fishing, as semi-natural habitat; or as a soil deposit or waste landfill.

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Figure 7.12 Example of a passive mine water treatment system in South Africa (left), and the Río Tinto area, Spain (right). (Photographs: *Petra Schneider*)

7.4 ENVIRONMENTAL IMPACTS OF MINING ACTIVITIES

By nature, mining usually causes substantial environmental damage; sometimes this damage is irreversible. In addition to damaging nature and the landscape, mining often affects both the quantity and quality of the water in the catchment area. Water resources are subject to competing usage claims as a result of mining activities. Strict control on the amount of water withdrawn for mining should be enforced by a water management authority. The municipal community is also often faced with major challenges from mining in its environment, as mining unleashes emissions such as dust and noise, in addition to the damage to nature and landscape. The licensing procedure for mining should require environmental impact assessment in the preparation phase, as well as an environmental management plan in the operation phase. In some countries, legislation requires an environmental and social impact assessment.

Assessment of the effects of past mining and treatment activities on the environment is critical for defining the precise requirements of the rehabilitation work that will be needed at the conclusion of the project, in order to justify the spending of funds for this purpose and to monitor the success of the rehabilitation measures. As a result of the long-term nature of the monitoring programs, an optimized approach is required for monitoring equipment and procedures, as well as for the frequency, dimension and accuracy of the monitoring network installed during or after the rehabilitation work. A financial plan and an institutional framework are also required for implementing the monitoring plan.

7.5 SOCIAL IMPACTS OF MINING ACTIVITIES

In many regions of the world, extraction of resources through mining is a way to greatly enhance the economic performance of a region. Plans to mine often create a polarizing effect on the local population. On the one hand, the economic benefits that the region can derive from active mining are seen when the mining operator takes its social responsibility. However, this also presupposes that its corresponding benefit sharing takes place with the municipalities concerned and their inhabitants. Implemented in this way, mining activities can bring about a societal upswing associated with job creation and increasing prosperity. There are numerous examples on a global scale for this. On the other hand, resistance to mining activities is increasing in many regions, as has been the case in recent years, for example in Romania and Ecuador. At the forefront of resistance to mining activities is an awareness of the need to

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protect natural resources and biodiversity, coupled with a recognition that mining has not always been done in a manner that protects either nature or communities. For these reasons, mining activities should reflect a consensus decision between all protected goods and stakeholders, and should only advance when a social license to operate has been secured.

The Lusatian mining area in East Germany provides a well-defined example of the social effects of mining and its closure in a region. While 30 opencast mines in Lusatia were used for lignite mining during the socialist German Democratic Republic (GDR) era and employed 75,000 people, there are currently four active open pits left where people find work (Welzow-Süd, Jänschwalde, Nochten, Reichwalde). However, many workers are engaged in mining rehabilitation to give the region a new face and a future. Twelve open pits have been flooded in the Federal States of Brandenburg and Saxony since the political change in East Germany, forming a total water surface of about 8,000 ha. However, it should not be forgotten that since 1924, 80 villages were dismantled because of lignite mining (Förster, 1995); local memorials remind future generations of these modifications (Figure 7.13, left). In order to keep the mines dry, it was necessary to drain the groundwater down to depths of up to 150 m. As a result, streams and wetlands dried out, which now are partially irrigated. In addition, the soil structure changed, resulting in extensive land settlements (sometimes up to distances of 15 to 20 km in the Lusatian region). The use of land in the Lusatian lignite mining areas resulted in a total deficit of around 13 km^3 of groundwater in 1990. Today, the deficit amounts to around 6 km^3.

In Lusatia, an ambitious project has been developed with the Lusatian Lake District to give the region a new future after the remediation has been completed. One example is Lake Geierswald (Figure 7.13 right), a former lignite open pit that has been flooded since 1973, which now has a size of 653 ha and a depth of up to 34 m (Lausitzer Seenland, GmbH, 2019). However, the ability to link such visions for the future with plans for new mining ventures presuppose that during the active mining period, the mining operator will provide financial reserves to finance the refurbishment costs and to ensure that these are not transferred to the taxpayer. Most countries with active mining have such regulations in their mining laws to ensure this funding. In practice, however, these regulations are not always enforced.

The need to assess and mitigate the economic and social consequences of mine closure results in the conclusion that the involvement of the local service and material suppliers may be critical in terms of

Figure 7.13 Period after mining: memorial for a village that was removed for lignite mining in Lusatia, Germany (left), floating houses on a flooded open cast lignite mine for touristic purposes at Lake Geierswald, Germany. (Photographs: *Petra Schneider*)

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obtaining the approval of the community and other local and national related authorities for carrying out the rehabilitation works. Consequently, the remediation concept from each site needs to be correlated as much as possible with these issues. The remediation strategy for a site also needs to consider feasible post-mining use scenarios that could be supported by remediation investments.

7.6 ROLE OF FINANCIAL GUARANTEES

Financial guarantee is defined as the obligation and responsibility of the natural or legal entities carrying out mining operations under an exploration license or permit, to supply the financial funds required for the environment rehabilitation. For the European member states, Directive 2006/21/EC of the European Commission (EC) on the management of waste from the extractive industries (EWD) (EU Parliament, 2006) provides 'measures, procedures and guidance to prevent or reduce as far as possible any adverse effects on the environment and any resultant risks on human health' from the management of extractive waste. This Directive obliges the competent authority to 'require a financial guarantee, prior to the commencement of any operations involving the accumulation or deposit of extractive waste in a waste facility'. The EWD requires the Member States to ensure that the operator draws up an extractive waste management plan (EWMP). This EWMP includes a 'proposed plan for closure, including rehabilitation, after-closure procedures and monitoring'. Beside the Directive 2006/21/EC, a main regulatory frame is given through the Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 'on environmental liability with regard to the prevention and remedying of environmental damage' (EU Parliament, 2004). In general, 'a financial guarantee is a promise to assume responsibility for another entity's financial obligation if that entity is unable to meet its obligation' (Chaudhari, 2017). Directive 2006/21/EC recognises the 'importance of guaranteeing that the taxpayer is not left with the financial burden of environmental clean-up and rehabilitation of mining liabilities, as has often been the case in the past and thus, requires a financial guarantee to be lodged by the mine operator prior to the commencement of deposition operations in the waste facility' (MonTec, 2008).

7.7 CONCLUSIONS AND OUTLOOK

Mining activities cause large-scale and often irreversible interventions in nature and landscape, but are also required to ensure the provision of mineral resources. Water management plays a substantial role during exploration, development, mining and mining rehabilitation.

While the active mining phase involves hydrogeological site exploration, as well as planning and implementation of groundwater lowering, water supply and disposal, the construction of waste disposal facilities and flood protection in the rehabilitation phase with demolition of the mining facilities is in the focus of the activities. This involves the backfilling of cavities and flooding of the mines, the management of the groundwater recharge with the associated water drainage and treatment, as well as the sealing of waste rock dumps and tailings ponds including their rehabilitation.

Regardless of whether mining is in the active or decommissioning phase, the dimension and challenges of these tasks are usually enormous. Large quantities of rock and water have to be moved, and existing land uses have to be abandoned. This results in competing usage claims, and often, a high cost to residents when mining is officially approved. Often the water demands of other water users are subordinated to those of the mining industry. The priorities of residents and the long-term health of the local ecosystem should play a substantial role when mining projects are considered, licensed, and monitored.

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REFERENCES

Baker B. J. and Banfield J. F. (2003). Microbial communities in acid mine drainage. *FEMS Microbiology Ecology*, **44**(2), 139–152.

Blowes D. W., Ptacek C. J., Jambor J. L., Weisener C. G., Paktunc D., Gould W. D. and Johnson D. B. (2014). The Geochemistry of Acid Mine Drainage. In: Treatise on Geochemistry, H. D. Turekian and K. K. Holland (eds.), Elsevier, Oxford, pp. 131–190.

Bowles D. S., Giuliani F. L., Hartford D. N. D., Janssen J. P. F. M., McGrath S., Poupart M., Stewart D. and Zielinsk P. A. (2007). ICOLD bulletin on dam safety management. Proceedings NZSOLD-ANCOLD 2007 Conference – Dams – Securing Water for Our Future, Queenstown, 1–9.

Bungart R., Bens O. and Hüttl R. F. (2000). Production of bioenergy in post-mining landscapes in Lusatia: Perspectives and challenges for alternative landuse systems. *Ecological Engineering*, **16**, 5–16.

Chaudhari C. A. S. (2017). A Guide to Risk Based Internal Audit System in Banks. Notion Press, Chennai.

Dold B. (2008). Sustainability in metal mining: from exploration, over processing to mine waste management. *Reviews in Environmental Science and Bio/Technology Volume*, **7**(4), 275–285.

Edwards J. A., Llurdes I. and Coit J. C. (1996). Mines and quarries: Industrial heritage tourism. *Annals of Tourism Research*, **23**, 341–363.

Espana J. S., Pamo E. L., Santofimia E., Aduvire O., Reyes J. and Barettino D. (2005). Acid mine drainage in the Iberian Pyrite Belt (Odiel river watershed, Huelva, SW Spain): geochemistry, mineralogy and environmental implications. *Applied Geochemistry*, **20**(7), 1320–1356.

EU Parliament. (2004). Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage.

EU Parliament. (2006). Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC – Statement by the European Parliament, the Council and the Commission.

Evangelou V. P. and Zhang Y. L. (1995). A review: pyrite oxidation mechanisms and acid mine drainage prevention. *Critical Reviews in Environmental Science and Technology*, **25**(2), 141–199.

Fields S. (2003). The earth's open wounds: Abandoned and orphaned mines. *Environmental Health Perspectives*, **111**, A154–A161.

Förster F. (1995). Verschwundene Dörfer. Die Ortsabbrüche des Lausitzer Braunkohlenreviers bis 1993. *Schriften des Sorbischen Instituts*, Bautzen, 8.

Gazea B., Adam K. and Kontopoulos A. (1996). A review of passive systems for the treatment of acid mine drainage. *Minerals Engineering*, **9**(1), 23–42.

Grünewald U. (2001). Water resources management in river catchments influenced by lignite mining. *Ecological Engineering*, **17**(2–3), 143–152.

Heikkinen P. M., Noras P., Salminen R., Mroueh U. M., Vahanne P., Wahlström M., Kaartinen T., Juvankoski M., Vestola E., Mäkelä E., Leino T., Kosonen M., Hatakka T., Jarva J., Kauppila T., Leveinen J., Lintinen P., Suomela P., Pöyry H., Vallius P., Nevalainen J., Tolla, P. and Komppa, V. (2008) Mine Closure Handbook, Geological Survey of Finland, Espoo.

Johnson D. B. and Hallberg K. B. (2005) Acid mine drainage remediation options – a review. *Science of the Total Environment*, **338**, 3–14.

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Kleinmann R. L. P., Crerar D. A. and Pacelli R. R. (1981). Biogeochemistry of acid mine drainage and a method to control acid formation. *Minerals Engineering*, **33**(3), 300–305.

Kondolf G. M. (1997). PROFILE: hungry water: effects of dams and gravel mining on river channels. *Environmental Management*, **21**(4), 533–551.

Lausitzer Seenland GmbH. (2019). Geierswalder See, https://www.lausitzerseenland.de/de/die-seen/artikel-geierswalder-see.html (accessed 15 September 2019).

Lintz G., Wirth P. and Harfst J. (2012). Regional structural change and resilience: from lignite mining to tourism in the Lusatian Lakeland. *Raumforschung und Raumordnung*, **70**, 363–375. doi: 10.1007/s13147-012-0175-x

Ludwig J. A., Hindley N. and Barnett G. (2003). Indicators for monitoring minesite rehabilitation: trends on waste-rock dumps, northern Australia. *Ecological Indicators*, **3**(3), 143–153.

Martínez N.M., Basallote M.D., Meyer A., Cánovas C.R., Macías F. and Schneider P. (2019). Life cycle assessment of a passive remediation system for acid mine drainage: Towards more sustainable mining activity, *Journal of Cleaner Production*, **211**, 1100–1111. doi: 10.1016/j.jclepro.2018.11.224

McHaina D. M. (2001). Environmental planning considerations for the decommissioning, closure and reclamation of a mine site. *International Journal of Surface Mining, Reclamation and Environment*, **15**, 163–176.

McKenna G. (2002). Sustainable Mine Reclamation and Landscape Engineering. Ph.D. Dissertation, University of Alberta, Edmonton, SK, Canada.

Melchers C., Westermann S. and Reker B. (2019). Evaluierung von Grubenwasseranstiegsprozessen. *Berichte zum Nachbergbau*, **1**, 1–130, Deutsches Bergbau-Museum Bochum, Bochum.

MonTec GmbH. (2008). Guidelines on Financial Guarantees and Inspections for Mining Waste Facilities – Final Report for European Commission – DG Environment. Report Nr. 2007/S 49-059670.

Neculita C. M., Zagury G. J. and Bussière B. (2007). Passive treatment of acid mine drainage in bioreactors using sulfate-reducing bacteria. *Journal of Environmental Quality*, **36**(1), 1–16.

Olías M., Nieto J.M., Sarmiento A.M., Cerón J.C. and Cánovas C.R. (2004). Seasonal water quality variations in a river affected by acid mine drainage: the Odiel River (South West Spain). *Science of the Total Environment*, **333**(1–3), 267–281.

Oswald K.-D., Schneider P. and Riedel W. (2018). Technical solutions for mining and processing of aggregates and the mining sites after-use: A Cleaner Production Guideline for Vietnam, Results of the project MAREX: Management of Mineral Resource Extraction in Hoa Binh Province – a Contribution to Sustainable Development in Vietnam (2015–2018); Issue 3, IÖR Eigenverlag Dresden.

Pepper M., Roche C. P. and Mudd G.M. (2014). Mining legacies – Understanding life-of-mine across time and space. Proceedings of the Life-of-Mine Conference 2014, Brisbane, Australia, 16–18 July 2014, 1449–1466.

Rapantova N., Grmela A., Vojtek D., Halir J. and Michalek B. (2007). Ground water flow modelling applications in mining hydrogeology. *Mine Water and the Environment*, **26**(4), 264–270.

Ritcey G. M. (1989). Tailings Management – Problems and Solutions in the Mining Industry. Elsevier, Amsterdam.

Sarmiento A. M., Nieto J. M., Olías M. and Cánovas C. R. (2009). Hydrochemical characteristics and seasonal influence on the pollution by acid mine drainage in the Odiel river Basin (SW Spain). *Applied Geochemistry*, **24**(4), 697–714.

Schneider P., Neitzel P. L., Osenbrück K., Noubacteb C., Merkel B. J. and Hurst S. (2001) In-situ treatment of radioactive mine water using reactive materials – Results of laboratory and field experiments in uranium ore mines in Germany. *Acta hydrochimica et hydrobiologica*, **29**(2–3), 129–138, doi: 10/ff64fb

Schneider P., Osenbrück K., Neitzel P. L. and Nindel K. (2002). In-situ mitigation of effluents from acid waste rock dumps using reactive surface barriers – a feasibility study. *Mine Water and the Environment*, **21**(1), 36–44.

Sheoran V., Sheoran A. S. and Poonia P. (2010). Soil reclamation of abandoned mine land by revegetation: A review. *International Journal of Soil, Sediment and Water*, **3**(2), Article 13.

Slingerland N. and Wilson G. W. (2015). End Land Use as a Guide for Integrated Mine Planning and Closure Design. Mine Closure, Vancouver, BC, Canada. Available online: https://www.researchgate.net/profile/Neeltje_Slingerland/publication/304626811_End_land_use_as_a_guide_for_integrated_mine_planning_and_closure_design/links/57c5b69f08ae0a6b0dc8d31f.pdf (accessed 15 September 2019).

Sweigard R., Burger J., Zipper C., Skousen J., Barton C. and Angel P. (2017). Low compaction grading to enhance reforestation success on coal surface mines. In: The Forestry Reclamation Approach: guide to successful

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reforestation of mined lands, M. B. Adams, (eds.) Gen. Tech. Rep. NRS-169. US Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, 4-1–4-8.

Tiwary R. K. (2001). Environmental impact of coal mining on water regime and its management. *Water Air and Soil Pollution*, **132**(1–2), 185–199.

Wismut GmbH (2019). Stabilisation of tailings management areas (TMA). Available online: https://www.wismut.de/en/tailings_pond_remediation.php. (accessed 15 September 2019).

Wolkersdorfer C. (2008). Water Management at Abandoned Flooded Underground Mines – Fundamentals, Tracer Tests, Modelling, Water Treatment. Springer, Heidelberg.

Wolkersdorfer C., Nordstrom D. K., Beckie R., Cicerone D. S., Elliot T., Edraki M., Valente T. M., França S. C. A., Kumar P., Oyarzún Lucero R. A. and Soler A. I. G. (2020). Guidance for the integrated use of hydrological, geochemical, and isotopic tools in mining operations. *Mine Water and the Environment*, **39**(2), 204–228, doi: 10.1007/s10230-020-00666-x

Younger P. L. and Wolkersdorfer C. (2004). Mining impacts on the fresh water environment: technical and managerial guidelines for catchment scale management. *Mine Water and the Environment*, **23**, s2–s80, doi: 10.1007/s10230-004-0028-0

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