Mine Closure Wiki – Databank for Mine Closure

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Abstract

Mine closure is an essential part in the development of eco-efficient, sustainable mining. When mines close they leave behind open spaces (ground workings) and piles of mineral waste materials which may deteriorate the environment in the long-term, if not closed properly. Extensive knowledge on suitable closure technologies and related research methods as well as on site-specific factors affecting selection of proper closure technologies are required for successful closure. To reach the best results, planning of mine closure should be started as early as possible - ideally during the feasibility study phase, before any mining operations begin.

To provide guidance on mine closure and to reduce negative environmental, societal and economic impacts of closure, Geological Survey of Finland (GTK) and Technical Research Centre of Finland (VTT) developed Mine Closure Wiki – a wiki-based technology resource on mine closure. The objective of the Wiki is to promote the selection of technical methods for the closure and to facilitate smoother closure planning and permitting.

The Mine Closure Wiki includes the best practices and legislation pertinent to closure, systematic evaluations of the key closure methods and technologies, and benchmarked case studies on the performance of closure technologies. The Wiki is an open internet resource intended as an every-day tool for mining operators, authorities, consultants and researchers for planning, permitting, executing, and monitoring of mine closure. The Mine Closure Wiki was published in October 2015.

Key words: Mine closure, technology resource, mine closure process, water treatment, water management, waste management, monitoring

Introduction

Mining of metals and other commodities provides a basis for the needs of today's modern society. As the mineral resources are nonrenewable and the mining always changes the environment in its vicinity, mining need to be carried out in a sustainable way. Unlike for most other industrial activities, the timing of mine closure is typically known already when the mining activities are commenced and the planning for the mine closure can also be started. As such, mine closure is an essential part of an eco-efficient, sustainable mining project. After mine closure, open spaces (ground workings) and piles of mineral waste materials are left behind, and they may deteriorate surrounding environment in the long-term, if a mine site is not closed properly. Possible post-mining environmental impacts of mine excavations and waste facilities include, for example, changes in water quality and effects on aquatic biota as a result of low quality mine drainage. To close a mine successfully, extensive knowledge on suitable closure technologies and on site-specific factors affecting selection of proper closure technologies is needed. To reach the best results, planning of mine closure should be started as early as possible - ideally during the feasibility study phase, before any mining operations begin.

In Finland, mining history dates back to the 16th century (Puustinen 2003). Since then, there has been more than 1000 mines exploiting metal ores (Cu, Ni, Zn, Co, Cr, Fe, V; ~ 400 mines), industrial minerals (apatite, talc, quartz, feldspar, wollastonite; ~ 300 mines) and limestones (~ 300 quarries). The period of modern mining has been considered to have started in 1911, when the first flotation plant in the whole

Europe was established at the Orijärvi mine site in Southern Finland. The large-scale mining began in Finland somewhat later, in the beginning of the 1930s with the launch of exploitation of the Outokumpu multimetal ore deposit in Eastern Finland (Puustinen 2003). Today, the number of mines operating in Finland sums up to 30 of which eight exploit metal ore deposits and twenty two industrial minerals or limestones (GTK 2016). In addition, there is a continuous interest on the unexploited deposits in Finland which can be seen in the vast number of areas claimed for mineral exploration by the Finnish and international companies throughout the country (GTK 2016). Several of the currently exploited deposits are to be exhausted within the near future and many of the new mines are expected to be relatively short-lived with the comparatively restricted mineral resources and modern efficient mining methods. Consequently, it is foreseen that during the next decade there will be a number of mines requiring closure. The environmental legislation pertinent to mining in Finland has largely changed during the last decade and mine closure aspects have gained more importance. As a result, the current and future mining operators, permitting authorities, and consulting companies urgently need consistent information on mine closure to close mines successfully without extra burden to the environment.

This paper describes a databank of mine closure, the Mine Closure Wiki, which was developed to provide guidance on mine closure planning, execution, and monitoring to help to avoid negative impacts of mine closure on environment and society. Institutions world-wide have previously provided guidance on mine closure (e.g. Heikkinen et al. 2008, ICMM 2008, DMP 2015). The now presented Mine Closure Wiki is intended to be the first easily updatable technology resource in the Wiki environment with the ambitious aim to cover all aspects of mine closure.

Development and content of the Mine Closure Wiki

The Mine Closure Wiki was developed during Tekes funded Green Mining project "Closedure", which was made in cooperation with the Geological Survey of Finland (GTK) and Technical Research Centre of Finland (VTT). It is an open internet resource freely available for all interested parties at the GTK Wiki platform: http://mineclosure.gtk.fi. It provides data on mine closure process, research methods pertinent to closure, closure technologies and their performance, and mine closure monitoring procedures. The development of the Mine Closure Wiki is based on the earlier Mine Closure Handbook (Heikkinen et al. 2008) that required updating.

The structure of the Mine Closure Wiki is presented in Figure 1. The key themes of mine closure in the Wiki are mine closure process, waste facilities and waste management, water management and treatment, and post-closure monitoring. Mine closure process covers aspects such as concepts for mine closure, general objectives of mine closure, stakeholder engagement, closure planning, legal requirements for mine closure and management of soil contamination. Water management, water treatment, wastes and waste facilities and monitoring sections all contain subsections for closure objectives, closure technologies, case studies evaluating the performance of closure technologies, and research and development carried out on the key issues during the Closedure project. In the monitoring section, check-lists are provided for chemical and physical stability of parameters that should be observed to ensure performance of selected closure technologies and to meet the objectives of closure. A description of the Closedure project and its content is also presented in the Wiki.

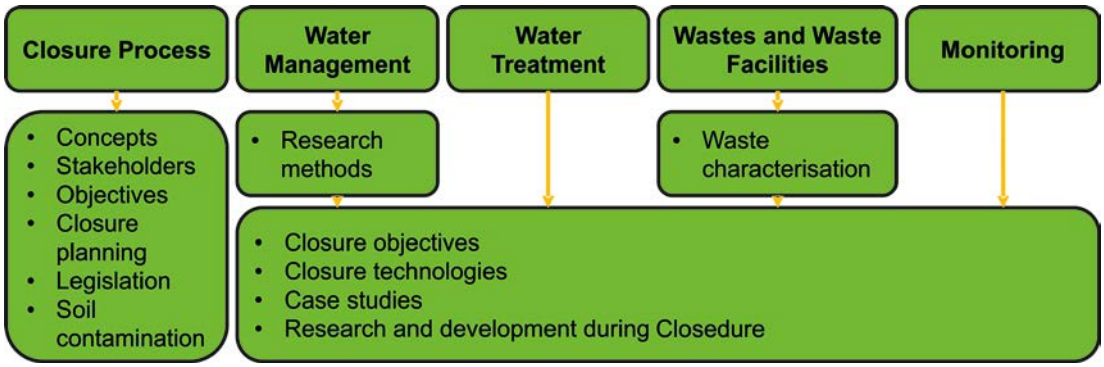

Figure 1 *Structure of the Mine Closure Wiki.*

Data for the Mine Closure Wiki was collected using three different templates to ensure consistency of the information included in the Wiki. These were templates for methods descriptions, technology evaluations, and descriptions of existing cases. The template for technology evaluations is presented as an example in Table 1.

Table 1 *Template for the technology evaluations.*

Title	Content
Introduction	
Description of the technology	Overall description of the technology, development stage, links to cases
Appropriate applications	Suitability, advantages and disadvantages of the technology
Performance	Capacity, maintenance needs, environmental cost aspects; proven and documented applications, successes and failures
Design requirements	Site specific data needs; Requirements for the materials and appliances; Management of potential discharges; Monitoring/control needs
References	

Wiki articles were written by approximately 30 researchers from different fields of mine closure from GTK and VTT. All the articles published at the Wiki went through an internal review by the project leaders and a language check if needed. Currently, the Wiki comprises ca. 200 articles on the key closure issues. In the following chapters, brief summaries of the contents and main approaches of each key theme are presented.

Mine Closure Process

While most of the content in the Mine Closure Wiki concentrates on the technical methods that can be employed when closing various processes and facilities at the end of mining, the Closure Process section looks into managing mine closure throughout the life of the mining project. This is a major task because the process has to be started early in the project and sustained throughout the operations even though the eventual goal may be in the distant future. Mine closure also involves most of the departments in the mining organization and many of the subcontractors that all need to work in sync and be aware of the goals of closure.

External and internal stakeholders are in a key role in mine closure. External stakeholders need to be informed of mine closure and they can contribute their views, local knowledge, concerns, and expectations regarding mine closure and post closure life in the region. This not only helps in minimizing risks but also sustaining the benefits of the mining project after closure. Considerable literature is available on stakeholder identification and engagement and these are referred to in the Wiki. The role of environmental impact assessment (EIA) is emphasized here, because the timing and objectives of closure planning and EIA are similar. The result of the stakeholder consultations should be a balanced, realistic, and achievable closure outcome that makes the planned post closure uses of the site possible.

Defining optimized closure objectives is a key element in mine closure planning (fig 2). The objectives guide all mine closure planning and also help in defining the exact scope of the closure for e.g. financial considerations. The objectives are designed to minimize the risks related to closure while at the same time maximizing the opportunities related to post closure life and communities in the region.

The Closure Management Plan (CMP) is the main vehicle to achieve the closure objectives and manage the process. It is a continuously updated set of documents that contains all the individual action plans and accumulates the results of the already completed actions. Continuous reduction of uncertainties and continuous closure of facilities is central to modern closure management. In addition, the mine must be 'operated for closure' so as not to compromise the closure objectives but rather contribute to them in all designs and daily operations. This requires that all internal stakeholders are constantly aware of the essentials of the CMP and take the closure objectives into account in their decision making.

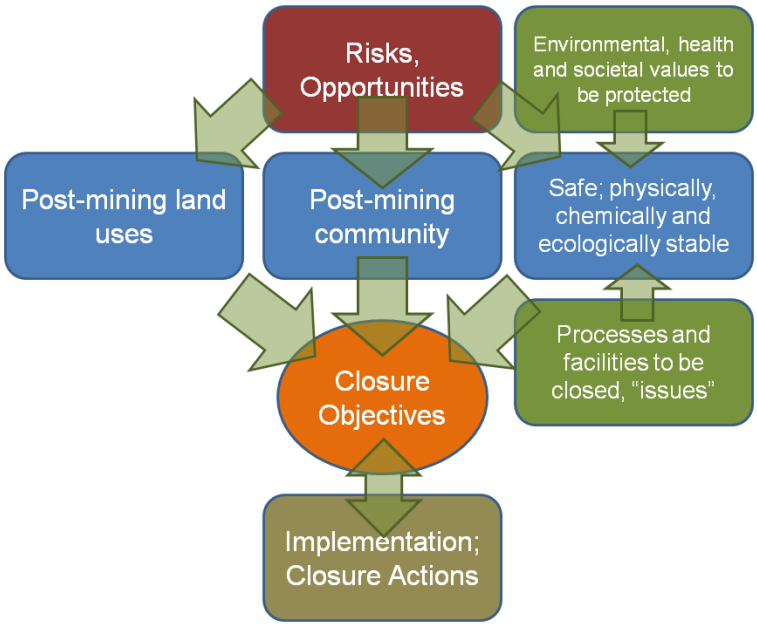

Figure 2 *Factors to consider when defining mine closure objectives to simultaneously minimize risks and maximize sustainable benefits.*

In the Mine Closure Wiki, all the above aspects of mine closure process together with legal requirements for closure and management of soil contamination are discussed.

Water Management

Mining affects water quality at a mine site, but also alters hydrological and topographical characteristics of the site, which has further influence on the surface water and ground water quantities and runoff, soil moisture, and evapotranspiration. The degraded water quality and altered runoff conditions may pose a significant risk to water resources and aquatic environments. Therefore, all waters entering, exiting and circulating at a closed mine site need to be managed to reach an acceptable water management status. To reduce costly water treatment and possible problems caused by, for example, heavy rains or other high discharge events at a closed mine site, it is also important to keep the unaffected surface runoff and groundwater separated from the possibly polluted waters and divert them past the mining operations. Overall, an environmentally sound post-closure water management plan is needed to prevent any adverse effects on the environment.

Water management designs should consider the mine closure already during the active mining phase. Using a pro-active approach throughout the operation phase and planning the water management to meet also the post closure standards, such as gravity driven runoff, erosion resistant water management structures, water treatment, and regulatory compliance, provides an ecologically, economically and socially durable solution (DWAF 2008). The water management structures should be designed resilient to physical and chemical erosion to ensure long life span and low maintenance costs. (Younger et al. 2002, Wolkersdorfer 2008). The planning of the post-closure mine water management requires participation of a multi-disciplinary team of professionals and authorities. In post-closure water management research, the hydrogeochemical behaviour and hydrodynamic development are the most essential aspects along with a thorough hydrological and hydrogeological understanding. (DWAF 2008)

The water management technologies evaluated in the Mine Closure Wiki include, for example, diversion ditches and channels, dams, mine flooding, and protection pumping. In addition, the Wiki describes various methods essential in water management, such as flow rate measurements, hydrogeological characterization methods, isotopic studies, and post-closure modelling methods including, for example, water balance modelling and flow modelling.

Water treatment

Due to the diversity of ore deposits, every mine site and its waters are unique and, therefore, also the water treatment objectives are site-specific for each mine site. There is an extensive group of variables

which affect on the quantity and quality of mine water even within a single mine and a sound understanding of the hydrogeology and hydrodynamics of each mine is crucial also for water treatment. Furthermore, also local environmental, climatic and socio-economic conditions and requirements affect the decisions on the post-closure treatment of mine site waters. Thus, there is not a single solution for water treatment in mining. (Taylor et al. 2007, Wolkersdorfer 2008).

Treatment techniques used at a mine depends on the water chemistry, the severity of the contamination, contaminants, flow rate, water volume, and the objectives of the treatment (e.g. water quality standards, use of water after treatment). The general objectives of post-closure water treatment typically include:

- Restoration of water quality to a level that does not present any long-term risks to the environment or human health,
- Long-term functioning of the technique and stability of the treatment products/residues,
- Integration with other water management measures (including management of tailings areas),
- Sufficient capacity for peak floods and adaptation to seasonal fluctuations,
- Accordance with the regulative requirements (legislation, environmental and other permits).

Mine water treatment technologies are usually divided into active and passive methods. Active treatment technologies require the input of energy and chemicals, whereas passive treatment methods are based on natural chemical and biological reactions without or little nutrient and energy addition. Since the passive treatment technologies cannot usually be adjusted according to the changes in water quality and flow rates, they are used to treat mine waters with low acidity and low flow rates. The advantage of active treatment technologies is that it can be engineered to accommodate essentially any acidity and flow rates of mine waters. Furthermore, the active technologies can be adjusted instantaneously in response to the changes in water quality and flow rates. However, all this adjusting usually requires frequent maintenance and regular labour inputs. In contrast, passive technologies are self-sustaining processes, they require only infrequent maintenance and function well without or little human interference when established. Thus passive treatment technologies are commonly used at closed mine sites. (Younger et al. 2002, Taylor et al. 2005, Wolkersdorfer 2008). The suitability of passive and active water treatment systems is based on influent water characteristics, mainly acidity, pH ranges and flow rate (tab 2). Mine Closure Wiki presents both active and passive water treatment technologies suitable for mine water treatment.

Table 2 *Acidity and pH ranges and flow rates for passive and active treatment methods (modified from Taylor et al. 2005)*

Treatment technique	Average acidity range (mg $CaCO_3$/l)	Average acidity load (kg $CaCO_3$/day)	Average flow rate (l/s)	Average pH range	Max attainable pH
Active	1.0–10,000	1.0–50,000	No limit	No limit	14
Passive	1.0–800	1.0–150	<50	>2	7.5–8

Wastes and waste facilities

Management of mining wastes, especially tailings and waste rocks is one of the major challenges during mining activities and mine closure. In the worst case, mismanagement of wastes leads to detrimental impacts on the surrounding water bodies and soils due to the generation and transport of low quality mine drainage. The ultimate objectives in sustainable mining are to decrease the amount of waste that requires final disposal, to increase material efficiency and to decrease their environmental impacts (fig. 3). Mining wastes can often be used, for example, in earth construction at the mine site or elsewhere, in landscaping or as a backfill of mine voids. Some mining wastes may even be utilized as a raw material, for instance, for cement or bricks. As the environmental impacts and also the raw material potential of wastes largely depend on the geology and mineralogy of the mined deposit, mineralogical and chemical characterization of wastes is essential. However, in many cases geotechnical or environmental characteristics of wastes prevent their further use and long-term disposal is required.

Comprehensive waste characterization is needed to design adequate waste management systems for wastes for long-term disposal. Characterization typically includes evaluation of both the geotechnical and environmental behaviour of wastes. Based on the characterization, selection of sufficient basal and dam structures for facilities is carried out. During the production phase, waste management includes various waste disposal techniques such as blending and layering, raising of dams, use as a backfill in mining voids and treatment of water effluents of the wastes. In mine closure, negative environmental impacts from mine wastes are typically prevented by different cover structures, landscaping the waste facilities and, in many cases, by treating the effluents. It is important to note that the planning of closure of facilities should already be considered during the design phase of the waste facilities, because decisions made during the design or operation will ultimately impact the options available in closure. In Figure 3, a flow sheet for overall management of mining wastes is presented.

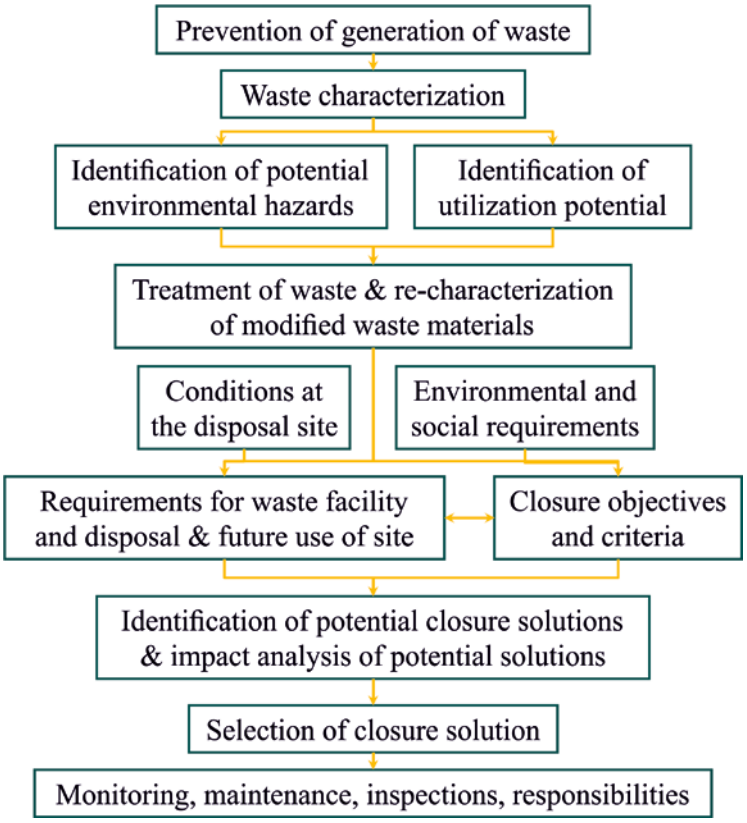

Figure 3 *Management of mining wastes throughout the life-cycle of mining operations.*

Mine Closure Wiki provides thorough evaluation of different methods applied in the mine waste characterization including methods measuring overall chemical and mineralogical contents of wastes to identify potential harmful substances and their occurrence in wastes, potential of wastes to produce acid mine drainage, and leachability of contaminating agents from wastes. In addition, methods used in determining physical and geotechnical properties of wastes are included.

The closure technologies for wastes and waste facilities have been divided into two groups in the Mine Closure Wiki: to those applied already before or during operations, and those used in the actual closure phase. The evaluated technologies include, for example, various basal structures for waste facilities, technologies to reduce acid production potential of wastes (e.g. desulphurization, layering), cover structures (dry cover, water cover), backfill technologies, and passivation methods.

Monitoring

Monitoring is needed after mine closure to ensure that all the chosen closure technologies perform as intended and in accordance with the closure objectives and criteria. Through monitoring it should be possible to demonstrate that the mine site is safe and poses no environmental or health risks. Furthermore, monitoring should be used as a proactive tool to identify potential defects in the rehabilitation process or structural failure, and to facilitate a rapid response in a case of failure. Structures

remaining at the site after closure and requiring monitoring include, for example, underground workings, open pit, waste rock and overburden piles, tailings facilities, and the remediated industrial area.

In many cases, extensive monitoring is needed to reach the above mentioned goals, and monitoring may include various methods to ensure physical, chemical, biological and socio-economic stability of a closed mine site. Chosen methods and parameters are site-specific and depend on the structures and activities remaining at the site, and the nature, type and size of the mining. Duration of the monitoring also depends on the nature and size of the operations and may continue for decades after mine closure. In Finland, and in many other countries, a post-closure monitoring plan accompanying a mine closure plan is submitted to the environmental authorities for approval before actual mine closure activities can begin. Typical questions for drafting post-closure monitoring include:

- what is to be monitored (which impacts and variables)
- how is monitoring implemented (sampling, analytical techniques, installation of monitoring network)
- what is the frequency and duration of monitoring (schedules and timing of sampling intervals)
- who is responsible for monitoring (who will undertake monitoring and ensure compliance)
- how is the record keeping arranged (Heikkinen et al. 2008).

Table 3 presents examples of features to be monitored and typical inspections in post-closure monitoring. The Mine Closure Wiki provides guidance on suitable monitoring methods and sampling techniques, including methods used in geotechnical and water quality monitoring.

Table 3 *Examples of targets and typical inspections carried out in post-closure monitoring (modified after Heikkinen et al. 2008)*

Typical features to be monitored	Typical inspections in post-closure monitoring
• condition of structures preventing inappropriate access • physical and chemical stability of waste facilities and embankments – and performance of potential cover structures • rate and quality of mine workings flooding • performance of water treatment systems • success of revegetation programs	• visual inspections of embankments and waste facilities • quality and volume of drainage from waste facilities • quality of downstream aquifers and water bodies • revegetation rates, biodiversity and density

Who can benefit from the Mine Closure Wiki?

The Mine Closure Wiki is intended as an every-day tool for mining operators, authorities, consultants and researchers for the planning, permitting, executing and monitoring of mine closure. The Wiki is freely available for everybody for reading and acquisition of information but commenting of the articles requires registration. Contributions on the Wiki are invited from mine closure experts throughout the world, especially on the latest, updated information on the available closure technologies and their performance and case studies presenting the applications of various technologies. For registrations and contributions, inquiries can be sent to: mineclosure@gtk.fi.

Management of the Mine Closure Wiki

The Mine Closure Wiki is managed and updated by the Industrial Environments and Recycling unit of the Geological Survey of Finland. Updates will be made as a part of the basic task of GTK and during current and upcoming research projects. Comments and proposals for the development of the content of the Wiki can be addressed to: mineclosure@gtk.fi.

Conclusions

Mine Closure Wiki (http://mineclosure.gtk.fi) was developed in the Finnish Closedure project by GTK and VTT to provide guidance and support for mine closure for mining operators, environmental authorities, consultants and researches working with mine closure issues. The primary objective of the project was to establish an open internet resource of mine closure that is freely available to all interested

parties. The Mine Closure Wiki currently holds approximately 200 articles covering different aspects of mine closure, such as the mine closure process, water management and treatment, management of wastes, and monitoring of performance of closure solutions. Evaluations of methods and main closure technologies are provided from these main themes supplemented with case examples of the performance of key technologies. The Mine Closure Wiki is managed and updated by the GTK and contributions are invited from mine closure experts throughout the world.

Acknowledgements

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References

DPM (2015) Guidelines for Preparing Mine Closure Plans, Department of Mines and Petroleum, Environmental Protection Authority, Government of Western Australia, 96 p.

DWAF (2008) Best Practice Guideline - H1: Integrated Mine Water Management -- December 2008, Department of Water Affairs and Forestry, Republic of South Africa. 52 p.

GTK (2015) Mine Closure Wiki, Closedure, Geological Survey of Finland. http://mineclosure.gtk.fi/. Accessed 3rd November 2015

GTK (2016) Mineral Deposits and Exploration. Database accessible at: http://gtkdata.gtk.fi/mdae/index.html. Accessed 26th April 2016

Hedin RS, Nairn RW, Kleinmann RLP (1994) Passive treatment of coal mine drainage, US Bureau of Mines Information Circular 9389 (2nd Ed.), Pittsburg, 35 p.

Heikkinen PM (Ed.), Noras P (Ed.), Salminen R (Ed.), 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, Komppa V (2008) Mine Closure Handbook, Geological Survey of Finland, Special Publications, Espoo, 169 p.

ICMM (2008) Planning for Integrated Mine Closure: Toolkit, International Council on Mining & Metals, London, UK, 84 p.

Puustinen K (2003) Suomen kaivosteollisuus ja mineraalisten raaka-aineiden tuotanto vuosina 1530–2001, historiallinen katsaus erityisesti tuotantolukujen valossa. 578 s. Geologian tutkimuskeskus, arkistoraportti, M 10.1/2003/3. (in Finnish)

Skousen J, Sextone A & Ziemkiewicz PF (2000) Acid mine drainage control and treatment. In: Barnhisel RI, Darmody RG, Daniels WL (Eds), Reclamation of drastically disturbed lands, Monograph Number 41, American Society of Agronomy, Madison, pp. 131-168

Taylor J, Pape S, Murphy N (2005) A Summary of Passive and Active Treatment Technologies for Acid and Metalliferous Drainage (AMD), Proceedings of the fifth Australian Workshop on acid drainage 29th-31st August 2005, Fremantle, Australia, pp. 151-200

Younger PL, Banwart SA, Hedin, RS (2002) Mine water – Hydrology, Pollution, Remediation, Environmental pollution, Volume 5, Kluwer Academic Publisher, The Netherlands, 464 p.

Wolkersdorfer C (2008) Water Management at Abandoned Flooded Underground Mines, Fundamentals, Tracer Tests, Modelling, Water Treatment, Springer, 465 p.