ENVIRONMENTAL TECHNIQUES
FOR THE EXTRACTIVE INDUSTRIES

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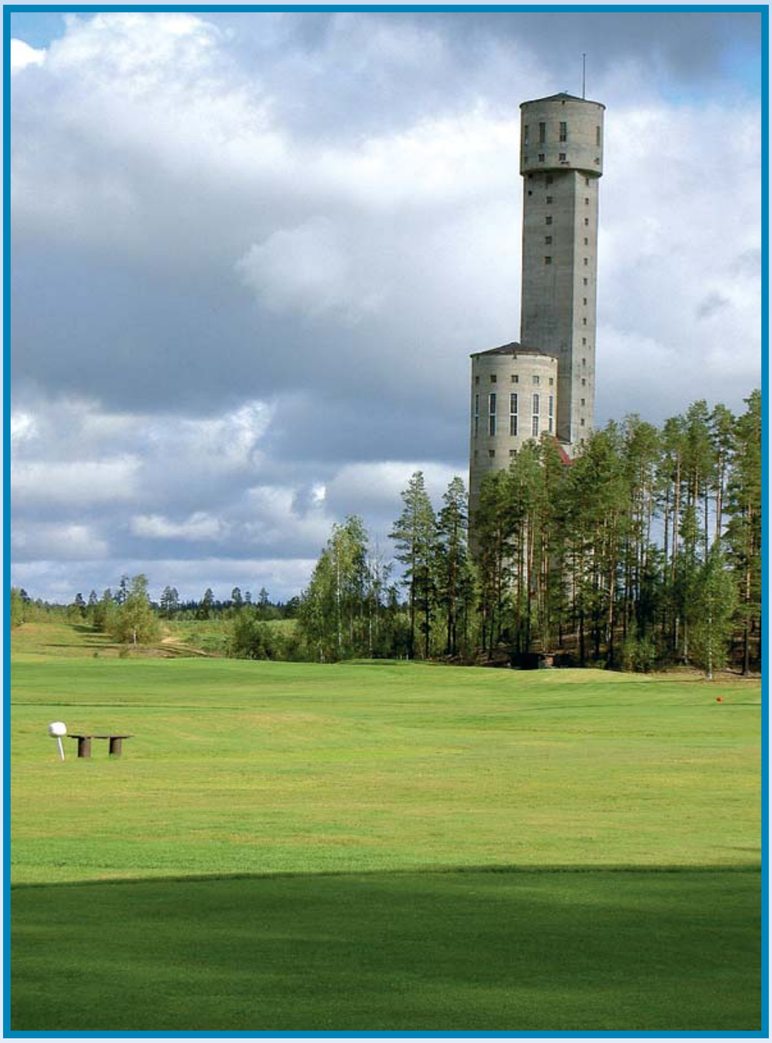

MINE CLOSURE HANDBOOK

TEKES OUTOKUMPU JAAKKO PÖYRY INFRA Maa ja Vesi Tieliikelaitos GTK VTT

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Mine Closure Handbook
Environmental Techniques for the Extractive Industries

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Cover photo: Listed pit head frame of the Keretti mine and tailings area landscaped into golf course in Outokumpu, Finland. (Photo: P. Heikkinen).

Vammalan Kirjapaino Oy 2008

MINE CLOSURE HANDBOOK

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FOREWORD

This handbook has been prepared during the TEKES-funded project 'Environmental Techniques for the Extractive Industries' (in Finnish, 'Kaivostoiminnan ympäristötekniikka'), which was undertaken as a joint research project between industry and various agencies during the years 2003-2005. The project was coordinated by Outokumpu Oyj with supporting industry partners being Tieliikelaitos (TLL, the Finnish Roads Enterprise) and Maa ja Vesi Oy (M&V Oy, Soil and Environment Ltd, which has since been incorporated into Pöyry Environment Oy). Public sector agencies participating in the project were Geologian tutkimuskeskus (GTK, Geological Survey of Finland) and Valtion teknillinen tutkimuskeskus (VTT, Technical Research Centre of Finland).

Preparation of this handbook was one of the central objectives of the Environmental Techniques for the Extractive Industries project. Background research for the handbook included comprehensive reviews of relevant literature and analysis of various issues relating to the mine closure process, including Finnish and international legislation and best practice procedures, risk assessment, procedures for evaluating the long-term behaviour of tailings and waste rocks; hydrological and geochemical modelling; and post-closure monitoring strategies. The Hitura nickel mine at Nivala in western Finland was chosen as a case study for demonstrating planning and implementation of environmental management and closure programs. Investigations were carried out by four separate working groups, under the guidance of their respective group leaders; an outline of these research activities is documented in Appendix 15, while research reports are archived and available from the relevant participating organization.

Responsibility for production of the handbook rested with a working group coordinated by Pentti Noras (Deputy Director/International Services, GTK) and comprising Päivi M. Heikkinen (Environmental geologist, GTK), Ulla-Maija Mroueh (Senior Research Scientist, VTT), Pekka Vallius (Production manager, TLL/Salvor Oy), Reijo Salminen (Research Professor, GTK), Erkki Ikäheimo (Vice President, M&V Oy), Eero Soininen (Resident Manager/Mine Reclamation, Outokumpu Oyj) and Veikko Komppa (Professor, VTT). Individual sections of the handbook were written by Päivi M. Heikkinen, Jussi Leveinen (Senior Research Scientist), Pentti Noras, Tarja Hatakka (Geologist), Jaana Jarva (Geologist), Tommi Kauppila (Senior Research Scientist), Petri Lintinen (Senior Research Scientist) and Pekka Suomela (Lawyer), GTK; Ulla-Maija Mroueh, Pasi Vahanne (Senior Research Scientist), Margareta Wahlström (Senior Research Scientist), Tommi Kaartinen (Research Scientist), Elina Vestola (Research Scientist), Markku Juvankoski (Research Scientist) and Esa Mäkelä (Team Leader), VTT; Tiina Leino (Manager of Environmental Legal Issues), Outokumpu Oyj; Heimo Pöyry (General Manager), Outokumpu Mining Oy; Mirja Kosonen (Vice President), Maa ja Vesi Oy; Jukka Nevalainen (Production Manager) and Pekka Vallius, Salvor Oy and Panu Tolla (Geotechnical Services Manager), Tieliikelaitos. Editorial responsibilities were shared by Päivi Heikkinen (GTK), Pentti Noras (GTK) and Reijo Salminen (GTK). The handbook was translated into English jointly by MSc Peter Sorjonen-Ward and a translation company The English Centre.

The project was supervised by a steering committee which included representatives from each of the participating organizations, chaired by Veikko Komppa (VTT); other members were Matti Koponen (Senior Vice President/Corporate Environmental Affairs), who on retirement was succeeded by Eero Soininen, Outokumpu Oyj; Pekka Vallius, Salvor Oy; Erkki Ikäheimo, Maa ja Vesi Oy; Reijo Salminen, Pentti Noras and Päivi Heikkinen, GTK and also Esa Mäkelä and Ulla-Maija Mroueh, VTT. Comments and feedback on the content of the handbook were also invited from relevant permitting authorities, including the Ministry of Trade and Industry (KTM), the Safety Technology Authority of Finland (Tukes), and Environmental Permit Authorities, as well as from environmental authorities (Ministry of the Environment, 'YM', and Finnish Environment Institute, 'SYKE'), mining industry stakeholders (including members of the Association of Finnish Extractive Resources Industry, 'Kaivannaisteollisuusyhdistys') and other specialists in the field. A meeting with relevant authorities was also arranged during the drafting process, to solicit ideas and responses concerning handbook content and preparation strategy.

The handbook was first introduced to interested stakeholders at a seminar on environmental management for the mining industry organized by the Lapland Regional Environment Centre (7.–8.4.2005), and subsequently at a training course convened by the Finnish Environment Institute (SYKE) on dam safety issues (27.9.2005) and at a meeting organized by the Association of Finnish Extractive Resources Industry (Kaivannaisteollisuusyhdistys) (19.10.2005).

Without the initiative and enthusiastic encouragement provided by the late PhD Matti Koponen, in his capacity as Senior Vice President of Corporate Environmental Affairs for Outokumpu Oyj, neither the TEKES project, nor ultimately, this handbook would have proceeded beyond the planning stage.

Figure 1. Hitura Ni-Cu mine, Nivala, Finland. Open pit is in the foreground, with waste rock and overburden stockpiles and concentrator plant behind. Tailings impoundment and settling ponds are visible in the background.

ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectrophotometer
ALD	Anoxic limestone drain
AMD	Acid mine drainage
AP	Acid production potential
ARD	Acid rock drainage
BAT	Best available techniques
BOD	Biological oxygen demand
BREF	BAT reference document
COD	Chemical oxygen demand
DETR	Department of the Environment, Transport and the Regions
DME	Department of Minerals and Energy, Republic of South-Africa
DTLR	London Department for Transport, Local Government and the Regions
EC	European Commission
EIA	Environmental Impact Assessment
EIPPC	European Integrated Pollution Prevention and Control
EM	Electromagnetic
EMAS	The Eco-Management and Audit Scheme
EPA	U.S. Environmental protection agency
EPER	European Pollutant Emission Register
ERT	Electrical resistivity tomography
EEA	European Economic Area
EU	The European Union
F	Safety factor
FMEA	Failure Mode and Effects Analysis
GPS	Global positioning system
GTK	Geological Survey of Finland
HAZOP	Hazard and Operability Study
ICP-AES/MS	Inductively Coupled Plasma Atomic Emission Spectrometer / Mass Spectrometer
ISO	International Organization for Standardization
KHO	The Supreme Administrative Court
KTM	Ministry of Trade and Industry
L/S-ratio	Liquid-Solid ratio
MCA	Multi-Criteria Analysis
MEND	Mine Environmental Neutral Drainage (A Canadian research project)
MMSD	Mining, Minerals, and Sustainable Development -Project
NDir	Directive of European Commission
NP	Neutralization potential
NNP	Net neutralization potential (NP-AP)
OLD	Open limestone drain
PAH	Polyaromatic hydrocarbons
PIMA	Polluted soils
PIRAMID	Passive in-situ remediation of acidic mine / industrial drainage (EU-project, www.piramid.org)
RAPS	Reducing and alkalinity producing system
SGY	Finnish Geotechnical Association
SYKE	The Finnish Environment Institute
TEKES	Finnish Funding Agency for Technology and Innovation
TEM	Ministry of Employment and the Economy
TUKES	Safety Technology Authority of Finland
UNEP	United Nations Environmental Program
VTT	Technical Research Centre of Finland
WHO	World Health Organization
YM	Ministry of the Environment

1. INTRODUCTION

1.1 OBJECTIVES AND SCOPE OF THIS HANDBOOK

The purpose of this handbook is to provide mine operators, regulatory authorities and industry consultants with guidelines relating to planning and implementation of mine closure strategies. Closure as defined here covers a range of activities and procedures, relating to and following the point at which production finally ceases permanently, from decommissioning of plant and relinquishment of title, through to implementation and ongoing monitoring of site rehabilitation programs. In some circumstances, temporary closure may occur due to external factors, such as unfavourable commodity prices, or through change of ownership. In these situations it is expected that production will be resumed at some stage and there is generally no need to initiate formal, large-scale closure procedures. Therefore, mines placed under temporary care and maintenance, are beyond the scope of this handbook.

There is no single law or decree that specifically deals with all obligations relating to the mine closure process. Rather, there are a number of acts and regulations, which control mining operations and closure. For some activities, legislation defines objectives and provides an operational framework, while in practice, decisions are typically made using a combination of best practice and previous experience. The handbook includes general guidelines and principles for mine closure, and presents suggestions for closure procedures and methodologies that are based on Finnish and EU legislation, with the aim of establishing and promoting a uniform best practice code for the entire mine closure process.

Although the purpose of the handbook is to provide general guidelines, each case needs to be assessed on an individual basis, taking into consideration such diverse factors as mineralogy and chemical composition of the ore, mining method, nature of surrounding environment and land use priorities, the scale of mining operations and the type of enrichment and processing used. As a general principle however, the primary stated objective of successful mine closure is to ensure that the form mine site is restored to a condition where it no longer represents any kind of environmental, health or safety risk. To achieve this objective, it is also desirable that closure planning is seen as an integral part of the mining process from its inception.

The handbook is structured such that the introductory section provides a background to the mining process, including the overall life-cycle perspective and environmental context of mining, together with a brief review of the diversity and significance of mining activities in Finland. Then an overview of general objectives and principles relating to concept of mine closure will follow with a more detailed discussion of legal and environmental issues. Nevertheless, the intention is not to provide an exhaustive guide to the entire legislative framework, but to provide the relevant regulations for mine closure. Chapters 4 and 5 describe procedures for planning closure strategies and various approaches to assessment of risk and environmental impact, together with illustrative examples of practical research methods available for assessment, monitoring and remediation. Chapter 6 progresses from assessment through to actual implementation of the closure process, describing technical solutions and risk management procedures. Finally, there is a description of necessary ongoing monitoring requirements that continue after mining has ceased, and some issues related to ensuring provision of sufficient financial resources for meeting closure obligations. Additional information and examples are presented in the Appendices, including a comprehensive summary of environmental regulations and responses required by the mine operator, as well as a general proposal for design of the closure plan.

The handbook also contains a glossary of relevant terminology, based on the EC Reference Document for Best Available Techniques for Management of Tailings and Waste Rock in Mining Activities (EC 2004), and a supplementary explanatory guide to the application of relevant terms in their Finnish context by Himmi & Sutinen (2005).

The handbook is intended primarily to provide closure guidelines to mine operators in Finland, either at existing mines, or for projects entering the production phase. The guidelines have been formulated in particular for metallic and industrial mineral deposits, but will also be relevant to the appropriate extent to commercial quarrying of dimension stone – primarily soapstone and marble (quarrying is regulated by Mining Act 503/1965) – and to restoration programs at previously closed mine sites, as well as for a variety of mining activities outside Finland. However, the handbook has intentionally excluded closure and remediation strategies in relation to mining of radioactive materials or to quarrying related to production of natural stone or crushed rock aggregate, regulated by Land Extraction Act (555/1981). A guide to site rehabilitation following quarrying natural stone, in accordance with Land Extraction Act, has previously been compiled and published (Alapassi *et al.* 2001).

The handbook was originally published in Finnish in 2005. Thereafter, some changes in the environmental legislation, for example concerning the contaminated soils, have come into effect. During the translation process, the most relevant changes were updated in this English version of the handbook.

The handbook provides general guidelines for mine closure planning. Decisions on closure strategy should always be ultimately based on a case-specific assessment, taking into consideration the full diversity of characteristics and requirements at each mine site.

1.2 OPERATING ENVIRONMENT AND NATURE OF THE MINING INDUSTRY

The following sections briefly outline the various phases of a mining operation, from exploration through to decommissioning and the potential environmental impacts of each of these activities. In addition, the nature of mining is considered in the context of sustainable development, followed by an overview and an assessment of the significance of the mining industry in Finland.

1.2.1 An overview of mining activities and the mining life-cycle

Mining activity refers to the extraction and enrichment or refinement of metallic ores, coal and industrial mineral deposits. In Finland, the range of commodities exploited by the mining industry, fall under the operational jurisdiction of the Mining Act (503/1965). These commodities are grouped into four categories: 1) metallic ores, 2) industrial minerals, 3) gemstones, and 4) marble and soapstone (Table 1). It should thus be noted that marble and soapstone are the only natural stone commodities that are covered by the Mining Act. Quarrying of other dimension stones and crushed rock aggregate requires permitting and compliance under the distinct Land Extraction Act (555/1981).

The mining life-cycle can be divided into three main stages, namely exploration, production and rehabilitation (Figure 2). The exploration phase commences with regional area selection to define the most prospective terrain, based to a large extent on previously available geological, geochemical and geophysical data, supplemented by reconnaissance investigations and surveys. Preliminary exploration at this stage requires normally an expression of interest alone (Mining Act 530/1965, Section 3). Decisions concerning more local targeting strategies are then made on the basis of these regional studies, at which stage it is customary to lodge a notice for a claim reservation at the register office of the appropriate local municipality, allowing more detailed investigations to be carried out over a period of twelve months. Under Section 7 of the Mining Act, this also confers a pre-emptive right in subsequently applying to the Ministry of Trade and Industry (KTM)[1] for an exploration claim, usually over a more restricted, carefully defined area. It should be noted here that an exploration claim application must be submitted within a year of tendering a notice of reservation (Mining Act, Section 7). The intent of the exploration claim is to provide an opportunity for better delineation of resource potential, or to make a preliminary estimate of potential reserves (Mining Act, Sections 4 and 8). This process may require very detailed investigations, involving ground geological and geophysical surveys,

[1] *Since January 1, 2008 merger of the Ministry of Trade and Industry (KTM) and Ministry of Labour took place. The name of the new entity is* ***Ministry of Employment and the Economy (TEM)****. The duties of the new ministry involve mining issues to the same extent as they were of the former KTM. The change took place after the final editing of the Handbook. Therefore, it should be considered as a correction to all of the following chapters and enclosures of the Handbook.*

a)

b)

c)

Figure 2. a) Diamond drilling during exploration, b) open-cut quarrying of metamorphosed limestone at the Ihalainen mine, Lappeenranta, Finland, and c) underground operations at the Hitura Ni-mine, Nivala, Finland.

sampling and trenching, drilling and trial mining and enrichment (Mining Act, Section 12). However, the exploration permit does not grant the right to exploit a mineral deposit identified during the exploration program. In some cases, the exploration process may continue for many years or even decades before either sufficient information is available, or circumstances are appropriate for commencement of planning a full-scale mining operation.

Table 1. Groups of commodities that fall under the jurisdiction of Finnish mining law (Mining Act 530/1965, Section 2).

	Mineral commodity*
1)	Li, Rb, Cs, Be, Mg, Sr, Ra, B, Al, Sc, Y, lanthanides, Ac, Th, U and other actinides, Ge, Sn, Pb, As, Sb, Bi, S, Se, Te, Cu, Ag, Au, Zn, Cd, Hg, Ga, In, Tl, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Re, Fe, Co, Ni, Pt and other platinum group elements
2)	Graphite, diamond, corundum, quartz, bauxite, olivine, kyanite, andalusite, sillimanite, garnet, wollastonite, asbestos, talc, pyrophyllite, muscovite, vermiculite, kaolin, feldspar, nepheline, leucite, scapolite, apatite, baryte, calcite, dolomite, magnesite, fluorite and cryolite
3)	Gemstones
4)	Marble and soapstone

* Of these commodities, exploration, exploitation and beneficiation with respect to iron, alumina, quartz and feldspar is only permitted if they occur as deposits within bedrock.

If the intention is to commence mining operation, then a formal written application for a mining concession must be made to the Ministry of Trade and Industry. When the application has been processed and recorded in the national mining register, the applicant is issued with a permit granting the rights to commercially exploit the resources defined in the concession area (Mining Act, Sections 21 and 40). After the mining concession has been legally recognized, further studies are usually undertaken, involving more detailed drilling and reserve calculations, to refine and validate earlier inferences; the decision to proceed with mining then depends on the outcome of these estimates. Before any activity can commence, however, appropriate operating permits, including building and environmental permits, are required, and the operator must also submit a general mine plan to the Safety Technology Authority of Finland ('TUKES').

Depending on the nature of the deposit, mining may be either as an open pit (Figure 2b), or else an underground operation (Figure 2c). Planning for an underground operation in particular needs to be very thorough and may require a number of years of preparation prior to production, for example if the main ore is at depth, and only accessible after construction a complex system of declines and tunnels and support facilities. This stage, as well as the main phase of production, produces variable amounts of waste rock, which needs to be dealt with somehow, usually by stockpiling some-

a)

b)

Figure 3. a) Waste rock pile at Siilinjärvi apatite mine, Finland, and b) tailings impoundment at Lahnaslampi talc mine, Sotkamo, Finland; tailings are spread as a slurry with a spigot distribution system.

where on the mine site (Figure 3a). However, various options exist for using waste rock during mining, for example by backfilling of stopes, galleries and tunnels, and providing structural support. Waste rock can also be used above ground, as required for earthworks at the mine site. Ore and any waste rock that cannot be mechanically separated are transported to the crushing mill, or in some instances to crushing facilities installed underground. The crushed ore can then be processed by concentration plant on site, or transported elsewhere for further processing and enrichment, although not all mineral commodities require further treatment or enrichment on site. At the concentrator, ore is generally crushed further to a sufficiently fine grain size to allow separation of desired commodities either by physical or chemical means, for example by gravity, magnetic or electrostatic methods, or by leaching or flotation. The final concentrate is transferred by conveyor belt to storage bins, before transport for further processing. Metallic concentrate for example, will be taken to a smelter, where desirable metals will be separated from unwanted material. Tailings (Figure 3b) generated during enrichment are transported, usually as a slurry to a tailings impoundment, or if in solid form, may be returned to the mine as backfill material, or used in earthworks, either on the mine site or elsewhere.

The duration of mining operations depends on the size and grade of the deposits and methods used, as well as prevailing commodity market prices. Although mining may occur over years or several decades, commodity price fluctuations might result in temporary breaks in production, or even lengthy periods of closure. However, when all economically recoverable ore has been mined, preparations for decommissioning and mine closure commence. The closure process not only deals with the cessation of technical operations, but also includes site rehabilitation, which involves both landscape restoration and prevention or mitigation of any potential environmental and safety risks. Closure may thus be viewed as an ongoing process, depending on local circumstances, with monitoring of rehabilitation potentially continuing for many years. Figure 4 presents a schematic summary of the mining life-cycle process, from exploration through to closure.

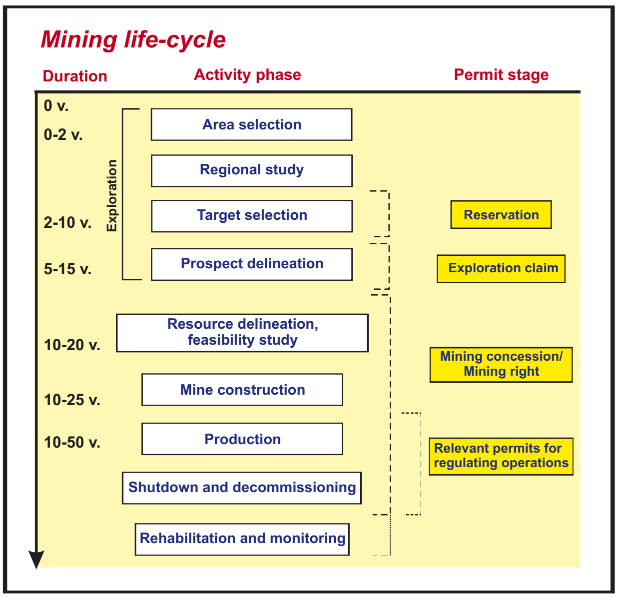


Figure 4. Mining process life-cycle; time scale at left is indicative of duration of various phases of activity.

1.2.2 Environmental impacts of mining activity

Mining operations inevitably cause changes in the surrounding environment, the extent of which depends upon the nature of the ore, mining and treatment methods and the size, geometry and location of the deposit. The most significant effect on the environment typically relates to the establishment and mining production phase; exploration and resource delineation generally have little or no impact, although blasting during trial mining may produce noise and dust and possibly influence the local surface water and groundwater levels or water quality. Implementation of a rehabilitation program after mining has ceased is intended to ensure safety and to minimize potential negative environmental impacts of the closed mine. Without such precautionary measures, it is possible that environmental effects could persist for tens of years after mine closure.

In Finland, mineral deposits can be grouped into four categories with respect to potential environmental impact, namely sulphide- and oxide metallic ores, industrial minerals and natural stones. The greatest potential impact is usually associated with the mining and processing of sulphide ores, for at all stages, from quarrying through crushing and stockpiling, sulphide grains exposed to the atmosphere and rainwater will tend to oxidize and weather (Figure 5). Oxidation of sulphides may promote the formation of acidic mine waters, which have the capacity to further leach metals and contaminate surface and groundwaters or soils, potentially resulting in restrictions in their use for domestic or recreational purposes. Deterioration of water quality and contamination of soil also constitute potential health risks to animals and humans. In contrast, mine-influenced waters associated with waste rock areas and tailings at mines in carbonate rocks tend to have relatively low metal abundances and circumneutral pH values, and consequently have only a minor effect on surrounding waters. The principal environmental effects in relation to mining of oxide ores and industrial minerals are in the form of dust derived from blasting in the mines and from tailings and waste rock facilities. Noise impact is the most prominent cause for concern during quarrying for natural stones (Aatos 2003).

Both underground and open pit mining and associated activities can significantly modify the landscape at the site and hence have a major impact on vegetation and local ecosystems, and also influence land use options and human activities, from recreational or aesthetic perspectives. One of the most significant effects on the landscape is the removal of extensive overburden related to commencement of mining in an open pit. Underground mining operations also require removal of material during the initial construction of declines, tunnels and shafts. Although some of this waste rock can be replaced as backfill during mining or utilized, in the same way as overburden, in various earthworks, a quantity of waste rock is stockpiled in proximity to the mine. In addition to waste rock piles, the mine environment is variably affected by the construction of mine infrastructure, including various buildings, crushing mill, roads and water pipelines and electric cables. If a concentrating plant is built at the site, then a substantial area will need to be allocated for constructing a tailings impoundment, as well as for the plant itself, and storage facilities for the concentrate. Further modifications to landscape can occur if it is necessary to divert surface waters in proximity to the mine. The overall effect on the landscape will depend ultimately on the size of the mining operations and to some extent on the geometric configuration of the deposit. For example, a compact, contiguous ore body will obviously leave a

Figure 5. Sulphide minerals in tailings oxidize when exposed to weathering, leading to precipitation of iron (oxy)hydroxides and imparting rusty brown colour (Aijala tailings area, Kisko, Finland).

smaller disturbance than a more dispersed, low-grade deposit consisting of several or more separate lodes or structurally disrupted ore bodies.

Quarrying, crushing and transport during mine production are all potential sources of excess noise, vibration and dust. Tailings and stockpiled concentrate may also cause dust problems (Figure 6). Dust may settle in surrounding surface waters, causing silt accumulation or chemical changes, not only to surface waters but also through subsequent infiltration into groundwater and soil, eventually representing a potential human health risk. Water and soil quality may also be adversely affected through stockpiling of waste rock and tailings at the mine, the handling and storage of chemicals and hazardous waste (for example used oil or processing chemicals), contamination by routine servicing and maintenance of machinery and equipment at workshops on the mine site, or through accidents and the residue from explosives used at the mine. The risk of groundwater contamination is likely to be greatest in situations where sulphide tailings and waste rock dumps are located over a highly permeable substrate and particularly if topographic relief results in a significant hydraulic head (see above).

Open pit and underground operations both require pumping to keep the mine free of water, which tends to lower the ambient water table and may, therefore, have an impact on water supply to any nearby households or communities that are reliant on groundwater. Water pumped out of the mine is commonly either used during the ore enrichment process or is discharged into the surrounding watershed, after removal of suspended matter in settling ponds. The original composition of these waters may be variably modified through mixing with water used for cooling or flushing during drilling, or which has percolated through backfill, or has been affected by other mining processes. In addition to contamination derived from interaction with ore and rock, these waters may contain chemical residues, including nitrogen compounds, from explosives and lubricants or processing and enrichment chemicals. Release of such waters into the surrounding watershed may reduce water quality downstream from the mine and have a negative impact on aquatic ecosystems. To prevent such occurrences, it is common practice to use a closed-cycle process to direct water from the settling ponds back into the processing circuit. Final discharge from the settling ponds is usually timed to coincide with heavy rainfall, when the capacity of the ponds may otherwise be exceeded, and increased flow rates during discharge will allow more effective dilution of any contaminant loading in the surrounding environment. If accumulation of supernatant water in the tailings impoundment is sufficient, then this water may also be pumped via settling ponds to be used in the closed-cycle enrichment process.

The tables in Appendix 1 are compilations of different types of mineral deposits and respective potential environmental consequences of their mining and processing activities. In addition, Section 4.1 deals with environmental aspects of mining operations in more detail, with respect to risk assessment procedures.

Figure 6. Generation of dust from tailings areas can be minimized by watering (as in picture) or spreading a lime slurry (Zinkgruvan Zn-Pb mine, Sweden).

1.2.3 Mining and sustainable development

Mineral commodities and products are required in almost all industrial and manufacturing processes, which are in turn essential to provision of services to society (Figure 7). Materials derived from mining are also required at some stage in the utilization of many natural resources that are classified as renewable or energy-neutral. However, if oil and natural gas are excluded, then the exploitation and beneficiation of mineral resources represents less than 1% of the total volume of natural resources utilized annually (Raw Materials Group 2005). A flow chart depicting mineral resources and products within a global economic and environmental context is shown in Figure 7.

Mineral resources cannot be classified as renewable at the time of extraction from host rocks, since this process, as well as downstream applications of mineral resources, contributes to resource depletion. However, if the efficient utilization of mineral resources is evaluated more broadly, and over a longer time frame, a somewhat different perspective emerges, for reasons such as the following:

- Material mined from mineral deposits is by nature permanent, so that appropriately stockpiled tailings and waste rocks are in principle accessible to further exploitation, potential over hundreds of years.
- Metallic elements occur in a wide range of minerals, not just those that are currently exploited, and therefore future beneficiation technologies may allow access to mineral deposits of different type or lower grade.
- The global abundance of a number of important metallic elements (notably Fe and metals used in Fe-alloys, Al and Mg) remains far in excess of society requirements.
- Rapid technological developments in exploration, processing and metallurgy mean that the mining industry is relatively more productive and energy efficient.
- Almost limitless opportunities exist for substitution of many metals by other material, for example machine components requiring high strength and temperature resilience can be manufactured from ceramics or polymers.
- Developments in engineering and material science allow increasing use of widely available mineral products in composite materials, more efficient use through miniaturization in the electronics industries, novel biotechnological applications and protecting from corrosion.
- There appears to be an upper limit for production of many mineral commodities, such that their market price exerts an influence on demand, making efficient recycling of materials and components a more economically viable option.
- General strategies to consume less, and consume more efficiently and responsibly are increasingly encouraged.

On the basis of such principles and in a view of the evident abundance of resources, the long-term sustainability of the minerals industry seems assured (Ericsson & Noras 2005).

The goal of sustainable development is to reconcile current requirements for socio-economic development with management of a stable global environment and thus ensure a balanced social and environmental legacy for future generations. While a robust and sustainable ecosystem can survive short-term and local environmental pressures during resource exploitation, the long-term goal must be minimal environmental impact and restoration of any imbalances, wherever possible. During mining operations for example, it is very difficult to avoid having some impact on the quality of the local environment. The very nature of mining also makes virtually impossible to perfectly restore the mine site to its previous state, but with careful landscaping and removal or stabilization of potential physical and chemical hazards, it is possible to establish a diverse and functional ecosystem and plan options for post-closure land use.

In terms of sustainability from a social perspective, mining operations can clearly be beneficial over the long-term in supporting skills and services, at least in proximity to the mine and potentially over a wider area as well. However, ensuring the future stability and well-being of a community (largely dependent upon mining) after operations cease, requires careful planning and evaluation of options well in advance of mine closure. With these caveats in mind, the overall effect of mining over the long-term may be argued as bringing a net benefit in terms of community stability and prosperity and thus satisfies many sustainable development criteria (Table 2). However, attainment of a sustainable solution still requires effective response to and management of these issues.

The downstream impact of the minerals industry on a global scale, both through direct consumption of manufactured goods and their further utilization within the services sector, is already considerable and continues to accelerate. Production and consumption of manufactured goods is a fundamental prerequisite for current social, cultural and domestic prosperity, yet there is an increasing awareness of the environmental impact and long-term sustainability of such growth. There are accordingly strong ethical as well as economic incentives for the minerals industry to demon-

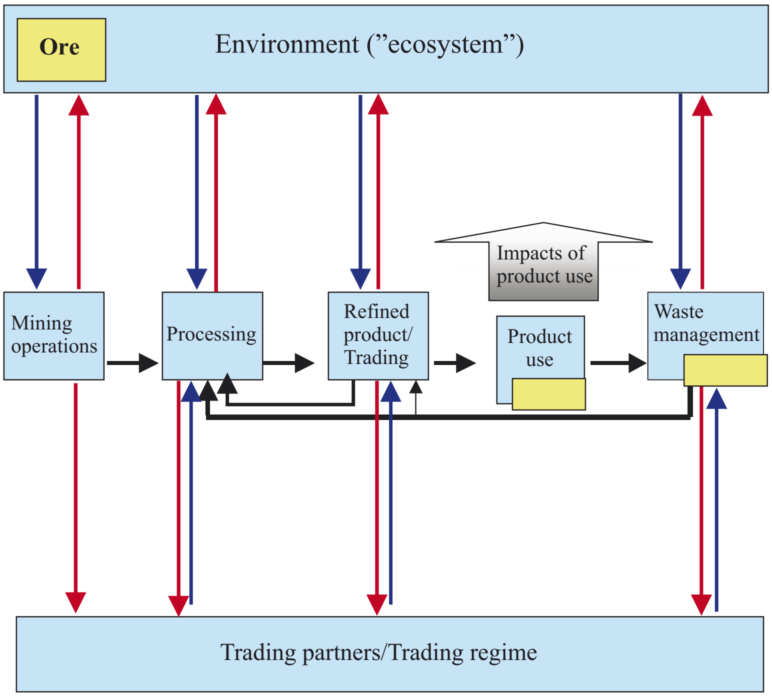


Figure 7. System of material flows and stocks. Stocks of unrefined and processed minerals industry resources (yellow box) and material flows (black arrows). Dark blue and red arrows track utilization of mineral resources, emissions and trade. Return-flow feedback loops ("new" and "old" scraps) are indicated by arrows directed from right to left. The impact of certain manufactured products and activities, notably vehicles and transport, though significant in many ways, is not included within the mineral resources flow analysis. Diagram is modified after Muller & Graedel (2003).

Table 2. Minerals industry and related derivative products, and their respective sustainability.

Phase in mineral commodities utilization	Social prosperity and well-being	Ecosystem functionality	Sustainability	Comments
Mining operations	• Improving (assuming responsible govern)	• Stable/Slight deterioration	• Sustainable • Almost sustainable	• Local, short-term sustainability issues • Risk management procedures ready for implementation
Product manufacture	• Improving	• Stable/Slight deterioration	• Sustainable • Almost sustainable	• Essential for economic growth: energy flows and recycling are important criteria
Consumption of goods and services	• Increasing • Decreasing (negative feedback loop with environmental quality)	• Stable • Significant deterioration	• Sustainable (exploitation balanced) • Unsustainable (over consumption)	• Essential to long-term social and cultural stability • Sustainable management is a global challenge

strate the implementation of socially accountable and ecologically sustainable practices, particularly given that 1) required technological solutions are to a large extent, already available, 2) a number of international regulations and treaties and codes of conduct are in place or under negotiation, and 3) additional expenditure for implementing reforms are generally modest. However, irrespective of the success and impact of such reforms in the resources sector, it is clear that as long as society promotes increased material consumption and global population continues to increase, economic growth is not sustainable from a long-term environmental perspective. The transition to an equitable global society less demanding of finite resources remains the greatest challenge facing humanity.

1.2.4 The mining industry in Finland – past and present

Finland has a long tradition of mining, with the earliest documented operations being the Ojamo iron mine at Lohja, apparently dating back to before 1530. Since then, more than a thousand metallic ore, industrial mineral, and carbonate rock deposits have been exploited. While Finland was administered as part of the Kingdom of Sweden, all mineral resources were property of the Swedish Crown, which also had exclusive mining rights, until 1723, when the first general mining legislation was formulated (Puustinen 2003). These early laws dealt with claim procedures and mining leases and procedures, and defined respective rights of landowners and the discoverer of an ore deposit. The Mining Act introduced in 1965 currently regulates exploration and mining activities in Finland. Since late Swedish rule, mining affairs were administered by the "Collegium of Mines", then under Russian administration by an office of the Finance Ministry (1816), then by a separate Board of Mines (1858), after which mining activities fell under the authority of a more general Board of Industries (1885). Finland became an independent sovereign state in 1917 and, from 1919, the mining industry was regulated and administered firstly by the Board of Trade and Industry, and subsequently by its successor, the current Ministry of Trade and Industry. Since 1994, when Finland joined the European Economic Area (EEA), it has been possible for foreign exploration and mining companies to operate in Finland.

In the period following the Second World War, the number of metallic mining operations in Finland was greatest in 1974, with a total of 22 separate deposits being mined, while the largest combined annual production, of 10.3 Mt was in 1979. Since 1980, the number of mines in operation and total production have both decreased rapidly. In contrast, there has been a significant increase in industrial mineral production over the last two decades, although there has been a general decrease in the number of deposits exploited. Carbonate rocks are an exception in that the number of mines and the production volumes have both continued to increase in recent decades, with 18 separated deposits being worked throughout the 1990's (Puustinen 1990). The maximum number of industrial mineral deposits being mined simultaneously was 26 in 1980. There is currently no production of iron ore in Finland, the last operations having closed in 1990.

Closure of operations for the more significant sulphide and oxide mines in Finland over time is as follows:

- 1950–1960: Orijärvi (Kisko), Makola (Nivala), Jussarö (Tammisaari),
- 1960–1970: Haveri (Viljakkala), Aijala (Kisko), Ylöjärvi, Kärväsvaara (Kemijärvi),
- 1970–1980: Korsnäs, Metsämonttu (Kisko), Kylmäkoski, Raajärvi (Kemijärvi),
- 1980–1990: Luikonlahti (Kaavi), Hällinmäki (Virtasalmi), Vuonos (Outokumpu), Hammaslahti (Pyhäselkä), Outokumpu, Kotalahti (Leppävirta), Otanmäki (Vuolijoki), Mustavaara (Taivalkoski), Rautuvaara (Kolari),
- 1990–2000: Ruostesuo (Kiuruvesi), Vihanti, Saattopora (Kittilä), Pahtavuoma (Kittilä), Pampalo (Ilomantsi), Telkkälä (Taipalsaari), Hälvälä (Kerimäki), Laukunkangas (Enonkoski), Stormi (Vammala), Hannukainen (Kolari), and
- 2000–2004: Mullikkoräme (Pyhäsalmi).

Two deposits in Finland are ranked as world-class in terms of tonnage and production, namely the carbonatite-hosted apatite deposit at Siilinjärvi and the chromite ores at Kemi. Other significant deposits in terms of European production have been the Outokumpu and Vuonos Cu-Co-Ni-Zn ores, the Pyhäsalmi and Vihanti Zn-Cu ores, the Lahnaslampi talc deposits, and the Ihalainen carbonate-wollastonite deposit. Cumulative total production from metallic mines in Finland between 1530–2001 is around 480 Mt, of which processed and refined ore accounts for 270 Mt. Cumulative production figures for industrial minerals are 267 Mt of ore mined with about 186 Mt of concentrate, while for carbonate rocks, respective values are in excess of 277 Mt mined, with nearly 240 Mt of processed ore (Puustinen 2003).

In terms of total production, the most significant metallic ore deposits have been Pyhäsalmi (36 Mt), Outokumpu (32 Mt), Vihanti (28 Mt), Kemi (27 Mt), Otanmäki (25 Mt), Hitura (13 Mt), and Mustavaara (13 Mt); the most important commodities in terms of concentrate have been sulphur, iron, chromium, copper, zinc, ilmenite and nickel. Using the same criteria, the Siilinjärvi apatite mine has been by far the largest producer of industrial minerals, with over 144 Mt of ore processed. Amongst carbonate mines, largest producers have been Parainen (79 Mt), Ihalainen (>45 Mt), and Tytyri (>34 Mt). The above production figures are based on available data for the years 1950–2001 (Puustinen 2003).

As of 2006, there were six metallic ore mines operating in Finland, 17 carbonate mines and 16 other industrial mineral operations, with a combined production of 20 Mt (Figure 8 and Table 3). The Kemi chromite mine and Siilinjärvi apatite mine together have accounted for a significant amount of total production particularly since 1980's.

Calculated earnings from the total amount of metallic ores mined in Finland, in present day terms, is in excess of 17 billion euro, of which copper has made the most valuable contribution (5,100 M€), followed by chromium (4,000 M€), zinc (3,800 M€), nickel (2,500 M€), iron (1,500 M€), and gold (300 M€). The cumulative equivalent calculated value of industrial mineral production is nearly 15 billion euro, of which the most significant commodities have been carbonate minerals (8,500 M€), talc (4,100 M€), and apatite (800 M€) (Puustinen 2003). These figures, nevertheless, represent only a fraction of the total contribution of the minerals industry to the economy, both domestically and outside Finland, if value-added activities from metals refining through manufacturing to provision of services are considered.

The mining industry currently represents around 2% of Finnish GNP and directly employs about 9,600 people representing 1.8% of the total workforce; of these, only 662 people are involved in the operation of metallic mines. However, an inherent and traditional characteristic of the minerals industry is the significant multiplier effect that the sector generates in terms of employment in the wider community, during value-added processing, manufacturing and services. Given this perspective, the minerals, mining and metals sector in Finland has a direct and indirect impact on employment of 211,000 people in Finland, or 39% of the workforce, and accounts for nearly 20% of manufacturing exports (Raw Materials Group 2002).

Figure 8. Metallic mines and industrial mineral deposits in Finland in 2006 (Source: Geological Survey of Finland).

Table 3. Metallic ore and industrial mineral mines (including carbonate mines), and natural stone operations falling under jurisdiction of the Mining Act in Finland, for the year 2006, showing commodities, annual production, and total ore output (GTK 2007).

Mine/quarry	Location (Municipality)	Metal or other commodity	Operator	Volume mined (t)	Total ore output (t)
Metallic ores					
Pyhäsalmi	Pyhäjärvi	Co, Zn, S, Ag, Au	Pyhäsalmi Mine Oy	1 457 203	1 371 823
Kemi	Keminmaa	Cr	Outokumpu Chrome Oy	1 394 153	1 166 985
Pahtavaara	Sodankylä	Au	Scan Mining Oy	610 300	497 400
Hitura	Nivala	Ni, Cu	Outokumpu Mining Oy	619 616	567 135
Orivesi	Orivesi	Au	Polar Mining Oy	86 835	1 880
Suurikuusikko	Kittilä	Au	Agnico-Eagle AB	772 333	0
Total: 6				***4 940 440***	***3 605 223***
Carbonate rocks					
Ankele	Pieksämäki	Dol	SMA Saxo Mineral Oy	54 116	52 917
Kalkkimaa	Tornio	Dol	SMA Saxo Mineral Oy	118 417	87 609
Rantamaa	Tornio	Dol	SMA Saxo Mineral Oy	743	743
Förby	Särkisalo	Lms	Karl Forsström Ab	112 721	112 721
Juuka quarry, Matara 2	Juuka	Dol, Lms	Juuan Dolomiittikalkki Oy	5 640	5 640
Paltamo quarry, Reetinniemi	Paltamo	Dol, Lms	Juuan Dolomiittikalkki Oy	29 660	29 660
Siikainen (Otamo)	Siikainen	Ca, Mg	Nordkalk Oyj Abp	103 420	79 300
Matkusjoki	Vampula	Ca, Mg	Nordkalk Oyj Abp	94 329	40 455
Punola	Vampula	Ca, Mg	Nordkalk Oyj Abp	112 963	34 093
Varmo (Ahola)	Kesälahti	Ca, Mg	Nordkalk Oyj Abp	1 000	1 000
Sipoo (Kalkkiranta)	Sipoo	Lms	Nordkalk Oyj Abp	91 110	91 110
Ruokojärvi	Kerimäki	Ca	Nordkalk Oyj Abp	192 000	185 000
Ihalainen	Lappeenranta	Lms, Dol	Nordkalk Oyj Abp	1 822 791	1 490 908
Vesterbacka	Vimpeli	Lms	Nordkalk Oyj Abp	6 334	5 528
Tytyri	Lohja	Lms	Nordkalk Oyj Abp	281 819	218 819
Skräbböle-Limberg	Parainen	Lms	Nordkalk Oyj Abp	2 243 652	1 639 402
Ryytimaa	Vimpeli	Lms	Nordkalk Oyj Abp	154 711	137 810
Total: 17				***5 425 426***	***4 275 715***
Other industrial minerals					
Ala-Aulis, Kyrkoberget	Kemiö	Fsp, Qz	SP Minerals Oy Ab	233 800	136 200
Kinahmi	Nilsiä	Qz	SP Minerals Oy Ab	208 263	201 271
Ristimaa	Tornio	Qz	SMA Saxo Mineral Oy	42 596	42 596
Siilinjärvi	Siilinjärvi	Apa	Kemphos	12 146 086	9 807 054
Uutela	Sotkamo	Tlc, Ni	Mondo Minerals Oy	197 424	33 459
Hyvärilä	Lemi	Al, Fe	Nordkalk Oyj Abp	43 378	21 353
Pehmytkivi	Polvijärvi	Tlc, Ni	Mondo Minerals Oy	2 897 800	602 165
Joutsenenlampi	Lapinlahti	Al	Paroc Oy Ab	217 245	163 739
Lehlampi	Mäntyharju	Oli	Paroc Oy Ab	73 404	73 404
Metsäsianniemi	Kiiminki	Mg, Al, Fe	Paroc Oy Ab	0	0
Sallittu	Suomusjärvi	Mg, Al, Fe	Paroc Oy Ab	16 038	0
Vanhasuo	Savitaipale	Mg, Al, Fe	Paroc Oy Ab	46 366	42 233
Ybbernäs	Parainen	Mg, Al	Paroc Oy Ab	0	0
Horsmanaho	Polvijärvi	Tlc, Ni	Mondo Minerals Oy	189 464	78 522
Lahnaslampi	Sotkamo	Tlc, Ni	Mondo Minerals Oy	2 633 203	523 044
Mieslahti	Paltamo	Tlc, Ni	Mondo Minerals Oy	53 947	32 710
Total: 16				***18 999 014***	***11 757 750***
Natural stone production under the Mining Act and others					
Nunnanlahti	Juuka	Soapstone	Nunnanlahden Uuni Oy	158 685	62 399
Kivikangas	Suomussalmi	Soapstone	Tulikivi Oyj	276 316	14 721
Koskela	Juuka	Soapstone	Tulikivi Oyj	564 621	54 246
Tulikivi	Juuka	Soapstone	Tulikivi Oyj	277 178	53 145
Karelia Mining (Kännätsalo)	Luumäki	Be	Karelia Beryl Oy	2 184	0
Lampivaara	Pelkosenniemi	Amethyst	Kaivosyhtiö Arctic Ametisti Oy	2 603	3
Total: 6				***1 281 587***	***184 514***
Combined total: 45				***30 646 467***	***19 823 202***

Lms = Limestone (calcite marble), Dol = Dolomite (dolomite marble), Wol = Wollastonite, Apa = Apatite, Tlc = Talc, Qz = Quartz, Fsp = Feldspar, Be = Beryl, Ol = Olivine

2. MINE CLOSURE

The following sections describe the concept of ”mine closure”, outlining the more general objectives and most essential factors to take into consideration when planning and implementing closure strategies, with emphasis on a best practice perspective. The final section of the chapter then deals with practical integration of the closure process within the overall life and context of the mining operation.

2.1 MINE CLOSURE – DEFINITIONS AND BASIC CONCEPTS

The concept of ”mine closure” as understood in this handbook refers to the final stages of mining activity, after production and processing have permanently ceased (decommissioning, relinquishment and rehabilitation planning) and any subsequent activities that are directly related to shutdown of the mine (site rehabilitation and ongoing monitoring). A distinction must be made between such permanent cessation of mining and temporary winding down of production, when the site is placed on care and maintenance, in the expectation that operations will resume. Mine closure is thus defined as the process, where mine production operations finally cease and the mine owner commences decommissioning the site infrastructure and relinquishes rights to the mining concession. A further corollary of this definition of closure is that the mining concession will not be transferred to another operator, which in practice usually means that the ore deposit has effectively been depleted. If, however, there is a significant amount of ore remaining to be recovered, the Ministry of Trade and Industry may stipulate that mine infrastructure is not to be dismantled or removed, but should remain in place, and may be used by a future operator, in case the mine is re-opened (Mining Act, Section 51). It is customary nowadays that the mine operator retains concession rights through the closure process, including during any site rehabilitation program.

Mine closure = Permanent cessation of mining operations and all subsequent activity related to decommissioning and site rehabilitation or monitoring.

The final outcome of the closure process is measured against a range of closure criteria and objectives that provide guidelines for negotiation between the operator and regulatory authorities concerning priority issues and performance indicators. Closure objectives are based foremost on compliance with statutory obligations, although they may also be defined to some extent by assessing the possible range of options available for closure, or by local circumstances and the need to reach agreement on specific issues with the surrounding community. The mine closure process is regulated in Finland by mining and environmental legislation as well as a number of EU and other specifications. These provide a detailed guide to required procedures during closure, including BAT (”Best Available Technique”) recommendations. The planning, implementation and monitoring of closure is increasingly aligned with best practice principles, through a combination of practical experience and industry recognition of the need to include quality assurance and environmental considerations within responsible corporate policy. As a result, the global mining industry has already reached a consensus concerning restoration of mining areas to a stable environmental state, physically, chemically, and ecologically, so as to minimize potential environmental and health risks (cf. Brodie *et al.* 1992, MMSD 2002a). Planning of closure strategies should be an integral part of the general mine planning process from its inception, with at the very least, closure assessment criteria being defined before the commencement of mining operations.

However, it is commonly difficult to anticipate and define all required remediation measures in advance, as the nature and scale of operations may in some cases depart from the original mine plan. Modifications to legislation may also take place during the operating life of an individual mine. Therefore, it is common practice that only qualitative goals are framed at the commencement of mining, and that closure objective and strategies are periodically reviewed and refined during the production phase. Nevertheless, a sufficiently detailed closure plan within the overall mine planning process is needed to ensure that adequate and accountable provision of resources for the closure program is made during the economic feasibility calculations. Table 4 summarizes examples of general mine closure objectives obtained from relevant published sources (Brodie *et al*. 1992, MMSD 2002a, EC 2004, Robertson & Shaw 2004). In addition to satisfying such general objectives, it is assumed that all legal and regulatory commitments will be met during closure. For example, Finnish mining law decrees in relation to mine closure that the mine site must be restored to a condition required by public safety (Mining Act, Section 51). A further objective, which should be added to the above, is to ensure that rehabilitation measures remain effective over the long-term and require minimal management or intervention. Examples of more specific objectives are presented in Chapter 2.2.

Effective planning and realization of closure objectives and measures need to be determined on the basis of local circumstances at the individual mine site. In some situations, for example at many industrial mineral operations, landscaping of tailings areas or waste rock areas and covering with topsoil, prior to revegetation, may be sufficient to meet closure requirements. On the other, other types of mining operations, particularly those involving sulphide ores, may require an extensive program of water treatment and ongoing monitoring to ensure that there is no release of contaminant into the surrounding environment. Establishing appropriate closure objective also requires that other factors are considered, such as local environmental attributes (e.g., soils, climate and biodiversity), the location of the mine (proximity to habitation, potential pressures on post-closure land use and water use issues), as well as technical matters such as methods used in quarrying and implementing closure. Attainment of closure objectives needs to be regularly monitored against accepted performance indicators, ensuring that the process is effective over the longer term. The mine closure process can only be considered complete when the closure objectives have been satisfactorily met, in accordance with such performance criteria.

Table 4. Examples of general closure objectives for mining activities (Brodie et al. 1992, MMSD 2002a, EC 2004, Robertson & Shaw 2004).

Criteria	Closure objectives
Physical stability	• All remaining anthropogenic structures are physically stable, sustainable to erosion and safe, and impose no risks to public health in long-term • Structures are performing the functions for which they were designed
Chemical stability	• All remaining anthropogenic structures are chemically stable and impose no risk to public health or environment throughout all phases of their life-cycle ◦ Closure is appropriate to the site-specific requirements in terms of the quality of surface water, groundwater and soils
Biological stability	• The biological environment a) is restored to a natural, balanced ecosystem typical of the area, or b) is left in such state so as to encourage and enable the natural rehabilitation of a biologically diverse, stable environment
Geographical and climatic influences	• Closure is appropriate to the demand and specifications of the location of the site in terms of climatic (e.g. rainfall, storm events, seasonal extremes) and geographic factors (e.g. proximity to human habitations, topography, accessibility of the mine)
Land use and aesthetics	• Rehabilitation is such that the ultimate land use is optimised • Closure optimises the opportunities for restoring the land and the upgrade of land use is considered whenever appropriate and/or economically feasible • Closure enables the productive and economical post-operational land use following the principles of sustainable development
Natural resources	• Closure aims at securing the amount and quality of the natural resources of the site
Financial consideration	• Adequate and appropriate readily available funds are allocated for the closure
Socio-economical issues	• Negative socio-economical impacts are minimized • Requirements of the local communities are taken into consideration to appropriate extent

2.2 OBJECTIVES AND PERFORMANCE CRITERIA FOR THE CLOSURE PROCESS

In the following sections, closure criteria and procedures are outlined with respect to general safety and environmental management issues, as well as social and economic considerations. Chapter 6 provides a more comprehensive treatment of closure objectives in relation to specific remedial and monitoring activities.

2.2.1 General safety criteria

Compliance with basic safety guidelines requires 1) that all structures (infrastructure, tailings and waste rock areas) remaining at the site are physically and chemically stable over the long-term, and 2) that any other legacy of mining operations, which might pose a safety risk (e.g. mine tunnels, steep slopes and embankments, decommissioned mining infrastructure and equipment), are either removed from the site, or rendered permanently inaccessible. Safety criteria are defined so as to ensure that risk mitigation procedures are sufficiently robust to cope with all conceivable geological and climatic contingencies. Therefore, closure strategies need to anticipate the likelihood of:

- extreme natural events (including intense rainfall, floods, storms, drought, wildfires, landslides and avalanches, and in some countries, volcanic eruptions and earthquakes);
- potential hazards of geological origin, such as erosion, collapse and subsidence and landslides
- environmental deterioration due to cumulative effects of successive floods or erosion over time;
- effects of climatic changes, such as variations in the frequency and intensity of extreme precipitation events and floods, and
- progressive deterioration in quality and loss of integrity of materials used in site management and remediation, including wooden, concrete and steel structures as well as clay liners and membranes and rock fill, as a consequence of weathering, or successive freezing and thawing, or microbial attack and degradation.

Planning and assessment of long-term stability measures is achieved through the use of various indices based on likely risks associated with particular features. Relevant risk categories for each specific structure or procedure can be defined according to their potential impact on both humans and the surrounding environment.

Examples of the kinds of indicator used for monitoring physical and chemical stability and safety risk (EC 2004) are as follows:

- slope stability of permanent retention barriers and embankments and waste dumps,
- safety index for specific use in embankment stability calculations,
- capacity of drainage systems (N times larger than greatest measured discharge),
- peak flood capacity of dams and embankments, drainage channels, settling ponds and water treatment facilities, and
- longevity and stability of building materials over time.

2.2.2 Closure and remediation objectives in relation to environmental quality

The closure process is essentially aimed at restoring the surrounding environment to a state, resembling as closely as possible that which existed prior to the commencement of mining, as measured by both chemical and biological parameters. An additional requirement is that the site is secure for any planned future land use. Therefore, it is necessary to ensure that neither discharge from the mine area, nor harmful substances remaining at the site soil, present any long-term risk to the environment or human health. A further objective is to ensure that environmental restoration is adequate to allow the establishment of a diverse and functional ecosystem in the area. Landscaping should also be carried out in a way that is appropriate for any future land use activities, planned for the area (Figure 9).

Figure 9. After closure, the mine site is landscaped in an attempt to integrate it with the surrounding environment. The former tailings dump at the Zinkgruvan mine in Sweden, which is located adjacent to a lake, has been covered and landscaped to form a golf course and recreation area.

Deterioration of surface waters and groundwater quality at mine sites can be the result of contamination from tailings and waste rock areas and also from heaps of concentrate (particularly at sulphide ore mines), storage of chemicals on site and from accidental spillage in the course of routine transport and maintenance at the mine (cf. Sections 1.2.2 and 4.1). To stabilize the site chemically, the first priority is to contain, or if possible, remove the source of contamination. In the case of contaminated soil or chemicals, the most cost-effective remedy is to physically remove the affected material (refer to Section 5.8). At sulphide mines however, where discharge of acidic and metal containing seepage waters from tailings may occur, remediation measures are usually more complicated, requiring either earthworks and drainage to channel impacted waters to an appropriate site for further treatment (refer to Section 6.2.1).

Assessment of quality of mine surface waters and groundwater is usually based on measurement of metal abundances at discharge and outflow sites, preferably before the water enters the surrounding watershed. Monitoring of surrounding groundwater and surface waters at specifically designated sites may also be carried out, including pH, electrical conductivity and alkalinity measurements in addition to metal concentrations (refer to Section 7.1). Possible contamination risks from tailings and waste rock areas can be anticipated by measuring a number of parameters, including acid generation potential, chemistry and mineralogy of the materials, and by conducting leaching tests at the laboratory for selected metals (refer to Section 5.4).

The ability to develop and maintain an ecologically functional environment suited to the requirements of animal life as well as humans can be assessed using indicators based on:

- soil chemistry,
- physical properties of the soil and regolith,
- availability and quality of surficial and groundwaters, and
- efficiency of water supply and drainage systems.

The possibility of climatic changes or extreme weather events also needs to be taken into consideration, as variations in physical and chemical parameters due to changing climatic conditions could potentially lead to an increase in metal solubility and transport in the mine environment.

Desirable attributes of the landscaped environment following site remediation include:

- general neatness,
- landforms in harmony with surroundings and, where possible, pre-mining landscape,
- revegetation programs appropriate to future land use options, and
- aesthetically pleasing and appropriate site for designated land use purpose.

2.2.3 Social and economic objectives in relation to mine closure

Specific and tangible social and economic objectives are more difficult to define within the context of mine closure than general safety and environmental issues. This is principally because there are no binding regulations covering legal obligations to society on behalf of the mining operator. However, the BAT reference document on management of mine tailings and waste rocks (EC 2004) does make general reference to the socio-economic implications of mine closure, with respect to impact on employment and the ongoing viability of business and commerce in the adjacent area. Therefore, minimization of potential adverse impacts on the local economy and consideration of long-term requirements of surrounding communities may be defined as general socio-economic objectives in relation to mine closure (EC 2004).

The mining process, throughout its various stages, generally provides considerable socio-economic benefits to surrounding communities, and potentially over an even wider area. Strategies, for ensuring that communities dependent on mining retain social stability and continue to prosper economically after closure, can be developed in consultation with the appropriate authorities and stakeholders. An outcome of the Mining, Minerals and Sustainable Development project (MMSD 2002b) was the formulation of a seven-point assessment process for evaluating the alignment of mining projects with sustainable development objectives. The seven categories addressed in this assessment process are shown schematically in Figure 10 and described in more detail in Appendix 2 and in a separate working report of the TEKES project "Environmental Techniques for the Extractive Industries" (Noras 2005a).

Criteria, against which the contribution of a mining project to regional sustainability can be assessed, include individual and community welfare, economic indicators, cultural heritage, environmental values, and evaluation of the total cost of the closure process. Stakeholder perspectives are considered by consultation with mining employees, businesses that are directly or indirectly involved with the mining process, and local residents and communities. The underlying aim of the process is to ensure effective consultation and negotiation as early as possible during planning the closure process, to ensure sustainable outcomes. Even

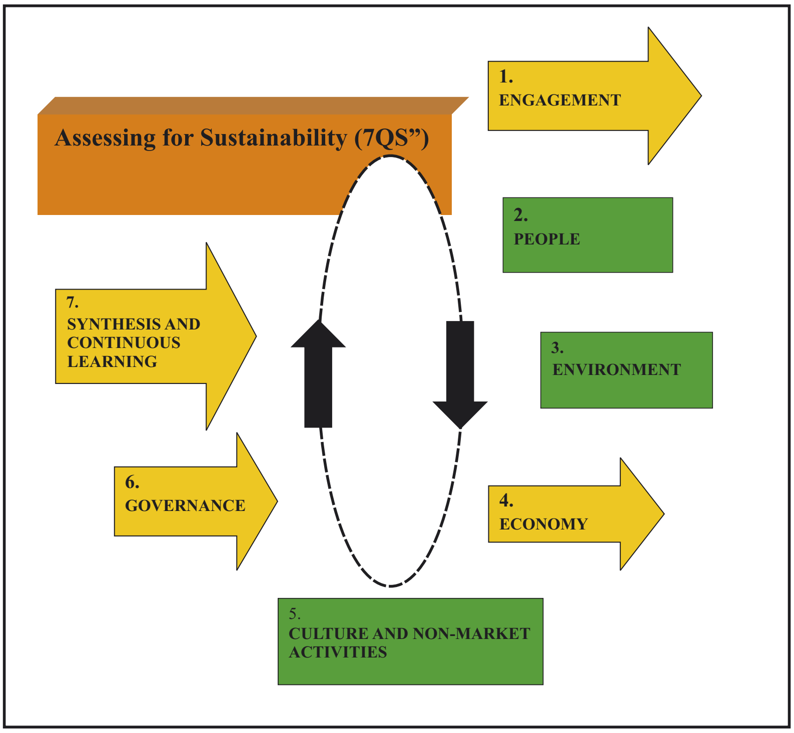


Figure 10. Seven assessment criteria ("seven questions", "7QS") for determining contribution of the mining process to sustainable development (MMSD 2002b). Green enclosures represent individual questions to analyze various aspects of the system, whereas yellow arrows indicate questions that transcend all aspects of the assessment system.

if the process is not followed in detail, this approach nevertheless provides guidelines, which can be adopted in closure planning and defining closure-related performance objectives and criteria.

2.3 BEST PRACTICE, CORPORATE RESPONSIBILITY AND ENVIRONMENTAL MANAGEMENT SYSTEMS

The overall legislative framework and monitoring by regulatory authorities provide the principal mechanisms for defining objectives of the industries´ environmental performance and in ensuring compliance during implementation and management. In addition, it has proven both effective, and in some cases necessary, to provide incentives to encourage industry to set voluntary environmental targets and codes of corporate behaviour that reflect best practice and responsible business management. A further important development has been the introduction of formally recognized environmental management systems (EMS), designed to continuously enhance performance in environmental management (Euromines 2005).

Examples of successful incentives promoted by international agencies include principles of clean production, environmental management agreements, and various partnerships between the mining industry and governments. Such arrangements are inevitably rather general in nature with regard to the mining industry and closure issues. Furthermore, large companies increasingly operate according to corporate responsibility policies, which cover not only environmental practices but also relationships to the wider community. Social responsibility and international best practice guidelines that have been formulated in recent years are discussed in more detail in a separate report prepared for the TEKES project "Environmental Techniques for the Extractive Industries" (Noras 2005b). The table in Appendix 3 provides examples of project initiatives and recommendations for applying sustainable development principles and guidelines to the mining sector, including closure procedures.

Clean production principles provide an incentive for companies to adopt environmental management systems, of which the ISO 14000 and ISO 9000 series standards promote enhanced environmental performance; this is achieved through improved management procedures and recognition of client responsibilities, by adhering to published procedural guidelines and submitting to regular review and reporting. Even if the environmental management systems do not deal with the specific details of mine closure, they nevertheless provide the mining operator with systematic guidelines and support in obeying regulations that should lead to continually improving environmental performance. Moreover, compliance with environmental performance standards, such as ISO 14001, may provide additional reassurance to regulatory and permitting authorities and other stakeholders, since ISO certification carries an explicit acknowledgment of responsibility for environmental risk management and compensation in the event of an environmental breach. If the operator is informed concerning ISO 14000 standards and undertakes reporting and auditing accordingly, this will assist greatly in meeting legal reporting and monitoring obligations.

In addition to compliance with ISO 14001 standards, the European Union environmental management system (EMAS – Eco-Management and Audit Scheme) requires a more transparent, public reporting process and thus approaches the issue more from a perspective of corporate responsibility and accountability. The industry itself is encouraging changes to both EU and Finnish legislation such that more companies will become registered with EMAS and so that certification will carry greater weight in both environmental permitting and performance monitoring.

2.4 SCHEDULING CLOSURE PLANNING WITHIN THE MINING PROCESS

As stated earlier (see Section 1.2.1), the mining life-cycle commences with a regional exploration program, which may continue intermittently over a period of years or even decades, particularly as new exploration technologies are introduced. Although it is seldom possible to anticipate the likely date of mine closure at an early stage of the life-cycle, it is, nevertheless, desirable to commence planning the closure process as soon as practicable (refer to Section 3.4 on EC 2004).

In the case of new mining ventures, it is advisable to initiate closure planning before the actual commencement of mining, preferably during the mining concession application process, or at the latest, during the course of technical feasibility studies. The application for a mining concession should be accompanied by a plan for the exploitation of the concession itself and a surrounding auxiliary area (Mining Act, Section 23), which may also include a tentative closure strategy. In certain cases (see the Decree on Environmental Impact Assessment Procedure 268/1999, Section 6), it is also required under the Mining Act (Mining Act, Section 23) to submit an environmental impact assessment report, as defined in the Act on Environmental Impact Assessment Procedure (468/1999), with the concession application. The report should contain an adequate description of proposed activities, including possible closure, decommissioning and dismantling plans, in accordance with Section 12 of the Decree on Environmental Impact Assessment Procedure (268/1999). Further details of these procedures are given in Section 3.1. The plan submitted for the proposed mining activity should also include a detailed account of the placement of various operations at the site (see Section 3.1.1). It is therefore possible to simultaneously outline in the provisional closure plan decommissioning and site remediation strategies, together with an estimation of closure cost. Such preliminary estimates may be refined during the feasibility process, by which stage the precise nature and requirements of the mining operation are well defined, allowing more precise planning of closure and remediation procedures. At this stage, it is also possible to calculate more accurately the resources that need to be allocated to the closure program, which can then be incorporated into the feasibility assessment itself.

Mine closure planning should be initiated as early as possible during the mining life-cycle

Before mining can commence, a general operational plan is prepared in conjunction with relevant environmental and other permit applications. The general plan should include technical and economic assessments as well as address safety issues. The plan needs to be submitted to the Safety Technology Authority of Finland for approval, in accordance with the Ministry of Trade and Industry Decree (Ministry of Trade and Industry Decision 921/1975). It is also recommended that this general operational plan takes environmental considerations into account and provides a provisional closure plan, ideally including decommissioning and site rehabilitation strategies and recommended post-closure land use options (cf. KTM 2003a). Permits granted under the Environmental Protection Act (86/2000) usually stipulate precise measures to be taken with respect to closure, including site rehabilitation, prevention of contamination, and ongoing site surveillance. Alternatively, the permit may require drafting of a specific closure plan before a specified date, in line with Sections 43 and 46 of the Environmental Protection Act. On commencement of mining operations, the provisional closure plan may require modification, depending on additional regulations relating to the approval and permitting process. Further revision may be necessary during the course of mining, especially if the nature of mining changes or the extent of operations expands significantly. Closure strategies may also need to be modified in response to periodic mine inspections. By taking closure procedures into consideration during mining, in particular decommissioning and rehabilitation strategies, it may be possible to make considerable savings in closure-related expenditure, as well as averting or minimizing a variety of potential environmental problems.

Towards the end of the production phase, the closure plan is finalized and submitted to the relevant environmental authorities. According to current permitting practice in Finland, it has been standard procedure for the mine operator to submit a closure plan for approval between six and twelve months prior to commencing closure procedures (refer to Appendix 5). This final plan must include clearly defined objectives and detailed description of specific closure-related procedures, as well as an ongoing monitoring program and recommendations for post-closure land use. These issues are dealt with further in Chapter 6.

Once the operator has completed the closure procedures in accordance with the general operational plan, officers of the Safety Technology Authority of Finland carry out a final site inspection for mine workings and dam stability. To assess whether the required objectives have been met and to ascertain whether or not the site is likely to remain stable and inert over the longer term, further follow-up surveillance is undertaken and reported to the appropriate regional environmental office, in accordance with environmental permits. Even after mining has ceased and the closure process has been implemented and approved, the operator remains responsible for further remedial measures, should they be necessary to prevent contamination, and for ongoing monitoring to ensure that no further risk exists (Environmental Protection Act 86/2000, Section 90). The various stages of planning and implementation of the closure process, within the context of the mining life-cycle, are shown in Figure 11.

It is very important to accurately and comprehensively document all activities undertaken during closure, for example in a report cataloguing specific sites and procedures. Such a catalogue should include details of personnel responsible for each activity, the time of implementation, and the nature of the procedure. It is also important to ensure that measures carried out during the closure process do not prevent or endanger subsequent attempts to resume mining operations.

If planning for closure is integrated into the overall mine planning process from its inception, there is a greater opportunity for setting objectives that minimize the total environmental impact of mining. In this way, it is possible to anticipate and obviate many potential environmental problems, which could otherwise incur considerable expense and require long-term re-

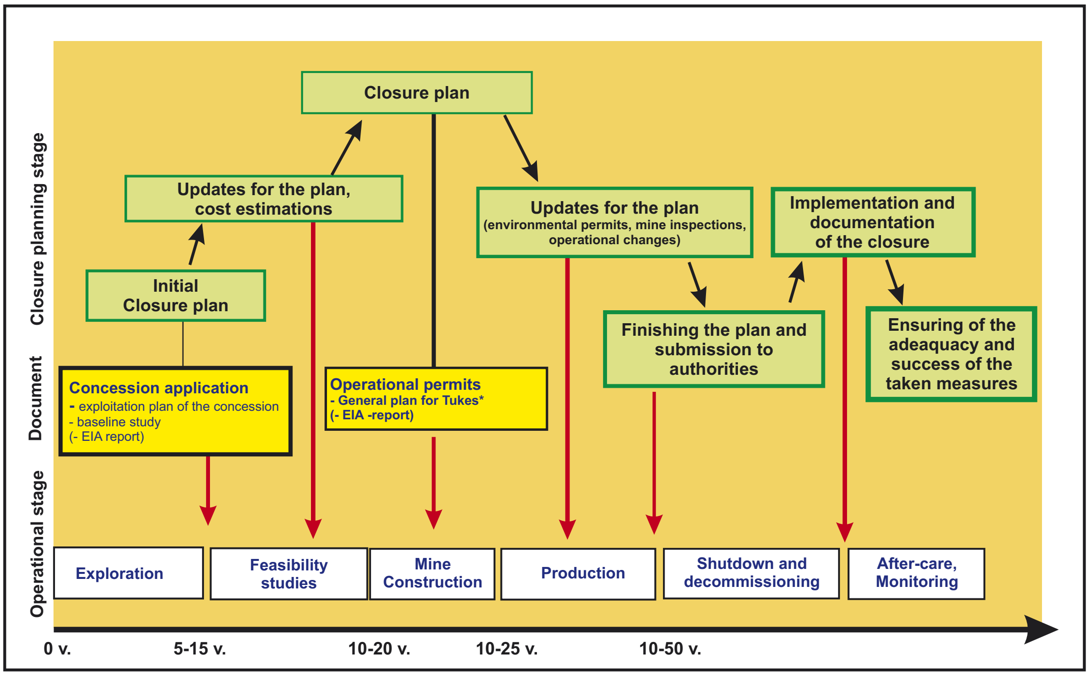


Figure 11. Integration of closure planning and implementation at various stages within the overall mine life-cycle context.

mediation, in addition to their adverse impact on health and surrounding ecosystems. The closure plan should also include, at an early stage if possible, a strategy for post-closure environmental monitoring.

The closure plan, as submitted prior to commencement of mining, could already cover the following points:

- overburden removed during open cut operations is sorted and placed so as to optimize its subsequent use in earthworks at the mine site, or in landscaping and covering tailings during site rehabilitation,
- construction of waste rock areas and placement of tailings impoundments so as to minimize risk of contaminated discharge passing into the surrounding environment,
- designing of drainage network for the mine workings and waste rock and tailings areas such that any water treatment required on mine closure can be done relatively easily,
- placement of declines and shafts in a way that avoids potential overflow of mine waters, or ensures that such outflow into the surrounding environment can be readily contained,
- ensuring that sufficient buffer zones are available by acquiring adequate land during the mine planning process, and allowing for adequate volumes of overburden for remediation purposes.

Additional measures that can be taken during mining to ensure that closure procedures can be effectively implemented include:

- separation of waste rock on the basis of material and environmental properties, allowing different types of materials to be used in various applications, for example as underground backfill, or so that materials with a high propensity for acid generation (particularly in sulphide mines) are located in an area, where risk of groundwater interaction and contamination is minimal,
- use or marketing of waste rock and tailings in other applications, for example road construction,
- progressive landscaping and commencement of covering of tailings (Figure 12),
- sealing of drill holes and shafts connecting underground operations with the surface, in order to prevent discharge of mine waters.

Due to earlier legislative practice in Finland, it has nevertheless been customary, with respect to current mines which commenced operations in recent decade, as well as those which have been recently shut down, that closure plans have only been formulated when closure is imminent. Under these circumstances, the standard procedure has been to assess the potential environmental impacts based on surveys carried out to characterize the present state of the mine site, as outlined further in Section 4.1. Closure procedures and responses have then been prescribed on the basis of whether or not observed negative impacts could have been either prevented or minimized. Under the terms of the Act on Implementation of the Legislation on Environmental Protection (113/2000), all mines currently in operation should have sought an environmental permit by the end of 2004. These permits, and those granted to new mining operations, require that specific closure procedures are implemented during site rehabilitation (refer to Appendix 5), or that closure strategies are defined, including decommissioning and landscaping, and plans for ongoing site maintenance and surveillance.

Closure procedures at older mine sites have been carried out in accordance with earlier legislative requirements, under which highest priority was given to ensuring that the area presented no risk to general safety; in effect this means that areas prone to collapse or subsidence were fenced off, mine entrances and shafts were sealed and excess water flow was contained. Subsequently however, many mine operators have undertaken further measures, such as covering tailings impoundments. Such retrospective activities at abandoned mine sites may also require permits from the appropriate authorities, in accordance with environmental and water legislation.

Figure 12. It is possible to commence landscaping and covering of tailings concurrently with mining activities, which facilitates integration of the mine area with the surrounding environment. Covering in this way also serves to inhibit oxidation of sulphide-rich tailings (Landscaped tailings embankment, Hitura nickel mine, Nivala, Finland).

3. STATUTORY REQUIREMENTS AND STIPULATIONS FOR MINE CLOSURE

This chapter discusses the stipulations placed by mining, environmental and other legislation on mine closure, beginning with general mining legislation and going on to provisions specifically related to mine closure. Closure is separately discussed from the viewpoint of mine planning, a mine in operation and a mine being discontinued. One major point is the organization of waste management and the determination of whether mining by-products – extracted soil, tailings and waste rock – are defined as waste or as by-products. This definition has a bearing on the use of by-products and the structural requirements for their storing areas. The chapter further discusses the liability for rehabilitation of contaminated soil, the legislation on compensation for damage, and pending legislative proposals. There is a separate section on the recent BAT Reference Document (EC 2004). After some points on land use, the chapter concludes with examples of the stipulations regarding mine closure and rehabilitation in the granted environmental permits. The review of legislation is not intended to be exhaustive.

A separate report on legislation has been prepared by the working group, which reviewed legislation in the project "Environmental Techniques for the Extractive Industries" (Leino *et al.* 2005).

3.1 STIPULATIONS IN MINING, ENVIRONMENTAL AND OTHER LEGISLATION

Mining in Finland is governed by several acts and decrees. In addition to the Mining Act (503/1965), there are substantial provisions and guidelines in the Environmental Protection Act (86/2000), in the Act on Environmental Impact Procedure (468/1994), in regulations on waste and landfills, and in regulations on the use and protection of waterways. Other regulations that apply pertain to the handling and storage of chemicals and explosives and to occupational safety, land use and construction.

Mining Act

There are few provisions in the Mining Act (503/1965) relevant to environmental aspects of mine closure, but the importance of this Act as the principal instrument governing mining is apparent in that the concepts and descriptions of the various stages of a mine's operation, set forth in the Mining Act, form a basis for all other legislation governing mining.

Environmental Protection Act and Decree, water legislation

The Environmental Protection Act (86/2000) lays down clear guidelines for industrial operations. The objective of the Act is to prevent the pollution of the environment and to repair and reduce damage caused by pollution; to safeguard a healthy, pleasant ecologically diverse and sustainable environment; to prevent the generation and the harmful effects of waste; to improve and integrate assessment of the impact of activities that pollute the environment; to improve citizens' opportunities to influence decisions concerning the environment; to promote sustainable use of natural resources; and to combat climate change and otherwise support sustainable development (Environmental Protection Act, Section 1). The Act applies to any activity, which causes or may cause environmental pollution as provided for in the Act. The Act also applies to activities that generate waste, and to the recovery and disposal of waste. Mining comes under the scope of the Act as per section 1 of the Environmental Protection Decree (169/2000, Section 1.1 paragraph 7) and as per Section 28.1 of the Environmental Protection Act. The following principles apply to activities that pose a risk of pollution: the principle of preventing and minimizing harmful impact; the principle of caution and care; the principle of best available technique; the principle of environmentally best use; and the 'polluter pays' principle (Environmental Protection Act, Section 4). The Act also contains provisions pertaining to discontinuation of operations.

The Water Act (264/1961) applies to matters such as the extraction and conveying of groundwater, civil engineering and regulation of a watercourse. The Environmental Protection Act contains provisions on the discharge of harmful and dangerous substances into water. Appendix 1 of the Environmental Protection Decree lists the substances for whose discharge into water or into a public sewer a permit is required, and Appendix 2 lists the major contaminants for whose discharge maximum limits are defined in the permit in cases where operations lead to the release of such amounts of contaminants into the environment as to cause harmful effects. In the future, water legislation will place increasingly strict requirements on industrial operations. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, also known as the Water Framework Directive, is aimed at achieving a sound ecological and chemical state in surface waters and a sufficient volume and sound chemical state in groundwater by 2015. The Water Framework Directive has been implemented in national legislation through the Act on Water Resources Management (also known as the Water Management Act, 1299/2004) and related amendments to the Water Act (1301/2004) and the Environmental Protection Act (1300/2004). There are several pending legislative proposals related to water protection (see Section 3.1.4).

Act and Decree on Environmental Impact Assessment Procedure

It is recommended that an environmental baseline study be conducted in the area when the operations are being planned, if only in the interests of the legal protection of the operator (cf. Salminen *et al.* 1999 and Section 4.1.1). If the project will have significant environmental impact, the Act and Decree on Environmental Impact Assessment ('EIA') Procedure (468/1994 and 713/2006, respectively) will apply. In the EIA procedure, options for implementing the various stages of the operations are explored with regard to their environmental impact. Generally, alternative locations cannot be proposed for a mine, but there may be several alternative locations for tailings and waste rock areas. EIA legislation is applied in Finland to the extraction, processing and handling of metal ores and other minerals when the total volume of material extracted is more than 550,000 tonnes per annum or when the site is an open pit whose area is more than 25 hectares (Decree on Environmental Impact Assessment procedure, section 6; Figure 13). Also, the Regional Environment Centre can in individual cases apply a discretionary EIA procedure (Act on Environmental Impact Assessment Procedure, Section 6). Even if a project is not by law subject to a full-scale EIA procedure, the operator must nevertheless be sufficiently

Figure 13. Open pits whose area is more than 25 hectares come under EIA legislation in Finland.

aware of the environmental impact of the project to such an extent as can be required of the site in question ('awareness responsibility', ibid., Section 25).

Nature Conservation Act

The Nature Conservation Act (1096/1996) and other legislation pertaining to natural values contain provisions on mining. These norms apply through the 'portal' of the Mining Act (the 'integration principle'). For example, operations in or near a 'Natura 2000' area must be subjected to a 'Natura assessment' (Nature Conservation Act, Section 65). This provision applies to mining specifically by virtue of the references in the Mining Act. However, if the Natura assessment is included in the EIA procedure, a separate assessment is not required (ibid., Section 65).

Waste legislation

In addition to the Environmental Protection Act and legislation based on it and the water legislation, waste legislation also pertains to mining. Waste provisions can be found in the Waste Act (1072/1993) and Decree (1390/1993) and in the Government Decision on landfill sites (861/1997). Under the Waste Act, waste means any substance or object, which the holder discards or intends, or is required, to discard (Waste Act, Section 3). Under its predecessor, the Waste Management Act (673/1978), waste was defined as substances or objects, which are discarded because of low value or worthless, and also any substances or objects collected at or delivered to a location reserved for waste for the purpose of transportation, storage, neutralization or other treatment.

The Government Decision on landfill sites (861/1997) places substantial planning requirements on the foundation structure and surface structure of landfill areas.

In addition to the above legislation, legislation on the handling and storage of chemicals and explosives, and on land use and construction apply to mining. There is further relevant legislation, which is listed in Appendix 4 to this handbook. The following sections contain a summary of statutory stipulations pertaining to mine closure.

3.1.1 Closure-related legislation relevant before starting operations

As per the Mining Act, a mining concession application must include a **usage plan for the mining concession and its auxiliary area**, with an explanation of the placement of by-products such as extracted soil, waste rock, tailings, and waste in the mining concession or its auxiliary area so that the safety of the vicinity of the mine and any harmful impacts have been taken into account (Mining Act, Section 23). Well-planned, implemented and monitored storage areas are in the operator's interest both during operations and during closure. Closure planning should be begun well ahead of time, indeed already when the mine is being planned.

A mining concession application pertaining to a project as referred to in the Act on Environmental Impact Assessment Procedure must include an **EIA report** (ibid., Section 23a). The Ministry of Trade and Industry may decide at its discretion that this report must be appended to the general plan to be presented to the Safety Technology Authority (TUKES) as per the Ministry of Trade and Industry Decision on mining safety instructions (921/1975) if it is obvious that the mining concession application will not result in mining preparation measures that will substantially alter the environment (Mining Act, Section 23a). A Natura assessment as per the Nature Conservation Act must be appended to the mining concession application if necessary (see Section 3.1 of this book).

For the purpose of the **general plan to be presented to TUKES**, the following must be established: the nature and thickness of soil layers in the excavation areas, groundwater conditions over the bedrock and excavation properties such as: the mechanical strength of the rock; the composition, orientation and fracturing of the bedrock; and, if necessary and possible, the primary rock tension state (Ministry of Trade and Industry Decision 921/1975). The general plan must contain the approximate limits for soil extraction, groundwater and surface water regulation arrangements, excavation implementation, shafts and access routes, general provisions for water extraction and ventilation, the location of industrial and waste areas with regard to the excavation areas, and the mine construction timetable (ibid., Section 4). The plan must also include an explanation justifying the above. Mining must not be begun before the general plan has been approved (ibid., Section 2).

The extracted soil, waste rock and tailings generated in mining and stored in the mining concession or its auxiliary area and which either can be used in the mining operations or can be further processed, are considered by-products of mining as per the Mining Act (Section 40). The Supreme Administrative Court, in the reasoning of its judgement dated June 10, 2004 (1387), addressed the issue of by-products (discussed in more detail later in this chapter). Under the Waste Act (1072/1993), by-products are defined as waste if the holder discards, or intends or is required to discard them (Section 3). In such cases, the environmental permit decision can include provisions on by-products based on waste legislation and can also designate storage areas as landfill sites (see chapter 10, definitions). Waste rock and tailings which will permanently be deposited on the mine site and which are defined as waste are either inert waste, non-hazardous waste or hazardous waste (see chapter 10, definitions). However, if the by-products are not defined as waste, provisions regarding them can be issued based on other legislation.

Beginning mining requires a valid **environmental permit** (Environmental Protection Decree, Section 1). The operator may also be required to obtain a **water permit** as per the Water Act for the extraction and conducting of groundwater, for civil engineering and for regulation of watercourses (see Water Act, Sections 1.18, 9.7, 2.1, 7.2). These permits are processed together and issued in the same decision (ibid., Section 16.2). Also, construction in a mining area requires a **permit as referred to in the Land Use and Building Act (132/1999)**, and a permit is also required for the **handling and storage of chemicals and explosives.** The permits required for mining are listed in Appendix 6.

The Act on the Safe Handling of Dangerous Chemicals and Explosives (390/2005), hereinafter the 'Chemical Safety Act', entered into force on July 1, 2005. The necessary amendments to the Chemical Act (744/1989) and the Penal Code (39/1889) were enacted at the same time. The Chemical Safety Act contains provisions pertaining to the industrial storage and handling of all chemicals, which are dangerous, flammable, explosive or harmful to health or the environment. Most of these provisions had already existed in current legislation, mainly in decrees. The Constitution, however, requires an Act providing for such obligations. The Decree on the Industrial Handling and Storage of Dangerous Chemicals (59/1999) was amended at the same time. The Chemical Safety Act contains provisions on designing the vicinity of the production facility, the placement of the production facility and the discontinuation of operations. A Government Decree can be issued to give more specific provisions on how operations must be organized at the production facility and how the facility must be designed, built and located. Under the Act, the placement of production facilities, where dangerous chemicals and explosives are produced, handled or stored, must take into account the current and future use of the location and its vicinity as given in a legally valid town plan as per the Land Use and Building Act, and also any town plan provisions that apply to the area (Chemical Safety Act, Section 20). The Act does not apply to the production, use or storage of explosives in a mine insofar as this is provided for in the Mining Act.

The environmental permit application must include a closure plan if relevant. A permit decision issued under the Environmental Protection Act contains the necessary provisions on measures to be undertaken after operations are discontinued (Environmental Protection Act, Section 43.1), or else the permit decision requires the operator to draw up a rehabilitation plan and gives a deadline for its submission (Figure 14). In the case of long-term operations, this deadline may coincide with the renewal of the permit. It may be assumed that the closure plan will be reviewed and updated in connection with permit renewal, and thus when operations are actually discontinued, the plan will only need to be slightly updated. This would incorporate closure planning as a continuing process within the permit process (cf. Section 2.4). An EIA report, as referred to in the Act on Environmental Impact Assessment Procedure, and a Natura report, as referred to in the Nature Conservation Act (Section 35), must be appended to the environmental permit application as necessary.

The organization of appropriate waste management is an important aspect of both operations and closure. Before beginning operations, the operator must pledge a guarantee to ensure waste management. The permit authority determines the costs of managing waste generated in the operations with a view to the discontinuing of operations (Environmental Protection Act, Section 42). The operator must give in the environmental permit application a justified proposal for the guarantee, how large it should be and how it should change over time or in accordance with some other factor. The guarantee should be linked to the increase in the volume of waste material over the course of operations, so as to ensure that the size of the guarantee will not constitute an obstacle to beginning operations. A background report has been published on the guarantee requirement in Section 42.3 of the Environmental Protection Act and its practical application (Kauppila & Kosola 2005). The Ministry of the Environment has also issued an instruction on the application of the guarantee provision under Section 117 of the Environmental Protection Act (March 9, 2005, diary No. YM2/401/2003) to the Regional Environment Centres and Environmental Permit Authorities.

By-products in case law and in environmental permits

In case law, by-products have generally been defined as waste. The Court of Justice of the European Communities has issued a preliminary ruling in two cases pertaining to the Finnish extractives industry. In the case of Palin Granit Oy (C-9/00, April 18, 2002), the Court ruled that:

"The holder of leftover stone resulting from stone quarrying, which is stored for an indefinite length of time

Figure 14. An environmental permit decision can contain provisions on measures to be undertaken after discontinuing operations, such as covering and landscaping a tailings area or treatment of discharge from storage areas. The tailings area at Keretti mine in Outokumpu has been covered and revegatated (background). There is an aerobic wetland for treatment of the discharge from the tailings area (foreground).

> *to await possible use, discards or intends to discard that leftover stone, which is accordingly to be classified as waste within the meaning of Council Directive 75/442/EEC of 15 July 1975 on waste".*
>
> *"The place of storage of leftover stone, its composition and the fact, even if proven, that the stone does not pose any real risk to human health or the environment are not relevant criteria for determining whether the stone is to be regarded as waste."*

In the case of AvestaPolarit Chrome Oy (Kemi mine; C-114/01, September 11, 2003), the Court ruled that:

> *"In a situation such as that at issue in the main proceedings, the holder of leftover rock and residual sand from ore-dressing operations from the operation of a mine discards or intends to discard those substances, which must consequently be classified as waste within the meaning of Council Directive 75/442/EEC of 15 July 1975 on waste, as amended by Council Directive 91/156/EEC of 18 March 1991, unless he uses them lawfully for the necessary filling in of the galleries of that mine and provides sufficient guarantees as to the identification and actual use of the substances to be used for that purpose."*

The Supreme Administrative Court, in its own decisions, ruled that waste rock (decision of November 25, 2002 (3055), Palin Granit), and waste rock and tailings (decision of April 29, 2004 (918), AvestaPolarit) are waste and further noted in the latter case that the company had not submitted even a preliminary plan or estimate as to how and where in the underground mine the waste rock and tailings, currently stored at the site, would be used.

The Supreme Administrative Court subsequently ruled in its decision of June 10, 2004 (1387) regarding by-products (emphasis by the present authors):

> *"In view of the principles of law in the preliminary rulings C-9/00 and C-114/01, the large blocks 1.5 to 5 m^3 in size <u>in the extracted soil and rock generated in the quarrying of soapstone which are stored in the storage area of the company's soapstone quarry for no more than a year and are then directly usable in production cannot be defined as waste, because they generally are and can be used without any further processing in the company's production process.</u> Soapstone quarrying also generates small blocks 0.2 to 1.5 m^3 in size and lesser waste such as rock material of secondary quality, powdered soapstone and extracted soil. These soil and rock materials too <u>cannot be defined as waste in</u>*

view of the principles of law in the preliminary rulings, just as the large blocks, if they can be used without any further processing in the company's production process and if the company presents a sufficiently detailed plan for such use. On the other hand, they can also not be defined as waste if they are used in extraction operations at the mine and if the company presents sufficient evidence specifying the extracted rock and soil involved and their actual use. Documentation shows that some small blocks can be used for manufacturing objects, and a substantial portion of the small blocks stored in the area can be sold. Other waste can possibly be used for road building at the mine site."

A maximum storage period of one year was proposed by the company itself, so no general guideline for storage periods can be derived from this case.

The above shows that by-products can avoid being defined as waste if the operator uses them for filling in mine tunnels, uses them in the production process without any further processing, or uses them in the excavation itself, and also presents sufficient evidence specifying the extracted rock and soil involved and their actual use.

Since 2002, the Northern Finland Environmental Permit Authority has observed in its environmental permit decisions that crushed waste rock, which conforms to the product properties of crushed rock aggregate and similar crushed rock (i.e. waste rock which is similar in its properties to normal building stone) and, which is delivered for use in building or other operations directly or after a reasonable period of storage, shall not be defined as waste (e.g. Northern Finland Environmental Permit Authority decision of December 20, 2002 no. 77/01/1 diary No. 123/00/1). Accordingly, their use is not subject to an environmental permit.

Following the decision of the Supreme Administrative Court, the Western Finland Environmental Permit Authority observed the following about by-products in the reasoning of its decision of July 9, 2004 No. 29/2004/2 diary No. LSY-2003-Y-255:

"Waste rock and extracted soil are usable for building roads at the site and for use as aggregate. The rock is also used in the support structures of the underground mine. The extracted rock from the mine shall not be considered waste in the meaning given in the Waste Act provided that it is used in a planned manner. Mixing waste with such rock will cause the rock to be defined as waste."

The Eastern Finland Environmental Permit Authority observed in its decision of June 6, 2005 No. 53/05/2 diary No. ISY-2004-Y-210:

"Extracted soil and rock, which are used without any further processing for earthwork construction in the mining district or for road construction or improvement within 36 months of the discontinuing of mining operations, shall not be considered waste but shall instead be considered by-products. By-products that remain unused after the above period must be delivered to a previously designated deposit area."

The reasoning contains the following observation:

"Waste rock and moraine, which are comparable in their properties to normal building stone and, which are directly or after a short period of storage delivered without any further processing to be used as building material, are in this decision defined not to be waste. Some of the bedrock and basal moraine in the area contain sulphide minerals and heavy metals and cannot thus be used as building material. It is therefore directed that only materials whose properties are known and which pose no risk of environmental pollution may be used for building."

The handling of by-products is treated on a case-by-case basis in permit procedures, and the issue of waste management is resolved separately for each mine. Operators must present sufficiently detailed plans for how and when the materials are to be used. What is essential for materials not to be considered waste, is that they must be specifically identified and actually used. Regardless of whether by-products are classified as by-products or as waste, it is important to submit a plan for their use to the Environmental Permit Authority when applying for the environmental permit. This makes the use of the materials clearer and avoids having to apply for separate permits for their use during operations. Institutional or commercial recovery or disposal of waste requires an environmental permit (Environmental Protection Act, Section 28).

Applying regulations on landfill sites

When waste rock and tailings are considered waste, a storage area for their final disposal can be considered a landfill site regardless of whether the Government Decision on landfill sites (861/1997) applies to it. This Decision does not apply to sites where only non-hazardous inert waste generated in the extraction, processing, storage, and quarrying of minerals is stored. However, the provisions of the Waste Act and the guarantee specified in the Environmental Protection Act will apply. What is essential for the delimitation is whether the stored material is inert waste (in which case the Government Decision on landfill sites does not apply) or non-hazardous waste or hazardous waste, for instance, because of its sulphide content and/or metal leaching. The properties of the material determine the foundation and surface structures to be planned and executed, and also the monitoring at the rehabilitation stage. Planning and execution should be done carefully so as to avoid having to repair the structures later. Foundation structure requirements must be observed at all landfill sites in use as of November 1, 2007, or they must be closed.

The permit authority can, at its discretion, alleviate the requirements for foundation or surface structures at a landfill site if the operator of the site can reliably demonstrate on the basis of an overall health and environmental impact assessment that the landfill site and the storing of waste cannot even over a long period of time constitute a danger or risk to health or the environment, as referred to in the Waste Act and the Environmental Protection Act, or violate the soil pollution prohibition (Environmental Protection Act, Section 7) or the groundwater pollution prohibition (ibid., Section 8). Even so, the technology and the methods used to prevent health and environmental risks at the landfill site must conform to the provision of the Waste Act, Section 6 paragraph 5 (Government Decision on landfill sites 861/1887, Appendix 1 paragraph 5).

Council Decision 2003/33/EC establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC sets criteria and procedures that had to be applied at landfills in the Member States as of July 16, 2005 at the latest. Without prejudice to existing Community legislation, the criteria and procedures shall not apply to waste resulting from prospecting, extraction, treatment and storage of mineral resources nor from the working of quarries, when they are deposited onsite. In the absence of specific Community legislation, Member States shall apply national criteria and procedures. This Decision has been implemented in Finland by amending the Government Decision on landfill sites by Government Decree 202/2006. Instructions on how to apply the Decision have also been issued.

In the future, waste management in the extractive industries will be governed by the Directive on the management of waste from the extractive industries (Directive 2006/21/EC of the European Parliament and of the Council of March 15, 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC) and the extractive waste characterization method (see Section 3.1.4). A working group has been set up to make proposals for implementing the directive into Finnish legislation.

The BAT Reference Document on the management of waste-rock and tailings in mining (EC 2004) is also important for mining operations and for environmental permit procedures for mines. The content of the BAT Reference Document is discussed in Section 3.4.

3.1.2 Closure-related legislation relevant during operations

Currently operating mines had to apply for an environmental permit, as referred to in the Environmental Protection Act, as provided for in the Act on the Implementation of the Legislation on Environmental Protection (113/2000). Earlier permits did not necessarily require detailed or even general plans concerning closure and rehabilitation, so operators may only have come up against this matter in the course of the permit application process.

A permit decision issued under the Environmental Protection Act contains the necessary regulations concerning measures after discontinuing operations, such as rehabilitation of the area, preventing discharges and monitoring the state of the environment; alternatively, the permit can specify that the operator must draw up a rehabilitation plan and submit it by a particular deadline (Environmental Protection Act, Sections 43 and 46).

The closure plan can be revised during operations. Some storage areas can be closed while operations are still in progress, in which case the waste management guarantee pledged can be reduced. The final closure plan must be submitted to the Environmental Permit Authority, usually no later than six months before closure according to the provisions of the permit decision. The Safety Technology Authority also requires a closure plan.

Legislation relevant during operations includes the Environmental Protection Act and legislation based on it, water legislation and waste legislation. For mines that have been in operation for a long time, during the validity of the Waste Management Act (673/1978), i.e. from 1979, or even earlier, the relevant legislation may include legislation which was valid before the Waste Management Act (and which has since been repealed), the Waste Management Act, the Waste Act as of 1994, and the Environmental Protection Act as of March 1, 2000. At that date, the provisions on contamination were moved from the Waste Act to the Environmental Protection Act, leaving only the littering ban in the Waste Act. The legislation on contamination is discussed in detail in Section 3.2. Landfill sites in use are governed by the Government Decision on landfill sites (861/1997) as applicable (cf. Section 3.1.1). Landfill sites in use must fulfil the requirements of the Decision, for example regarding foundation structure, no later than November 1, 2007. If the foundation structure of a landfill site does not conform to the Decision, the permit authority can require that the landfill site be closed. Thus, it is very important to take foundation structure requirements into account when planning operations. If, in the course of operations, hundreds of thousands or perhaps even millions of tonnes of waste rock and/or tailings have been stored, there is very little potential for correcting foundation structures after that.

In addition to national legislation, the BAT Reference Document on the management of waste rock and tailings in mining (EC 2004, cf. Section 3.4) also applies to operating mines. In the future, waste management in the extractive industries will be governed by the Directive on the management of waste from the extractive industries (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) and the extractive waste characterization method (see Section 3.1.4).

The Mining Act does not contain any provisions that specifically require an operator to prepare for closure and eventual rehabilitation while operations are in progress.

3.1.3 Closure-related legislation relevant after discontinuing operations

The Mining Act stipulates that if a holder of mining rights relinquishes those rights, the holder must notify the Ministry of Trade and Industry in writing. The mining rights are considered to have expired on the date on which the Ministry receives the notification (Mining Act, Section 48).

When a holder of mining rights relinquishes those rights or they are declared forfeit, the mining concession and auxiliary area revert to the landowner without compensation. However, the holder of mining rights is entitled to keep the mine products and any buildings and equipment at ground level in place for two years. Unless they are removed by the end of this time, they will be forfeit to the landowner without compensation (ibid., Section 51).

Any equipment, ladders and stairs built in the mine itself to ensure its safety and security, as well as concrete (hoisting towers) in the mining concession and other fixed structures that can only be feasibly used for the mining itself must be left in place unless the Ministry of Trade and Industry authorizes their removal. All such equipment and structures will be given over without compensation to any party that subsequently obtains the right to use the mine (ibid., Section 51).

After mining operations are discontinued, the holder of mining rights must keep the mine in such a condition that map data on mining and exploration can be obtained. The mine must be kept in this condition until the necessary map data has been delivered to the Safety Technology Authority (ibid., Section 51).

Moreover, having relinquished the mining concession or having had the mining rights declared forfeit, the holder of mining rights must immediately restore the area to a condition consistent with general safety (ibid., Section 51). An open pit must be fenced and provided with warning signs (Figure 15). The procedure depends on the location of the open pit, the quality and durability of its rim, the water level once the open pit has filled up, and the suitability of the water for human and animal consumption. If a zone with a danger of collapse remains above an underground mine, the provisions of the Mining Act regarding open pits must be followed as applicable. Waste rock piles must be prevented from collapsing, or they must be fenced in if

Figure 15. After operations are discontinued, an open pit is fenced and furnished with signs prohibiting entry. (Open pit at the Orijärvi copper mine in Kisko, closed in 1956.)

necessary. Wet portions of waste areas must be dried or marked with warning signs and fenced in if necessary. The operator must also ensure that the waste does not endanger environment (Ministry of Trade and Industry Decision 921/1975, Sections 129 and 130).

The holder of mining rights must also ensure that future use and extraction in the mine is not compromised and that the excavated minerals are not used uneconomically (Mining Act, Section 47). When a mining concession is given up, the mine (the ore deposit), the waste rock piles and the tailings areas can become the subject of a new claim.

Dam safety is commonly regarded as an important issue in mining. However, the Dam Safety Act (413/1984) does not directly apply to mining, i.e. to dams covered by the provisions of the Mining Act. The national Safety Technology Authority (TUKES) monitors the dams referred to in Section 3.2 of the Dam Safety Act, to which the provisions of the Mining Act apply. These include dams built in the mining concession or its auxiliary area, and tailings area and water basin dams built outside them but related to mining operations. TUKES is the supervising authority on mine safety and recommends that the provisions of the Dam Safety Act and Decree (574/1984) and of the Dam safety instructions be applied. Dam safety is discussed in more detail in section 5.7 of this book. The Dam Safety Act is also being amended.

Figure 16. An environmental permit can require the operator to monitor the impact of operations even after operations are discontinued. The monitoring programme may include monitoring of the quality of water discharged from disposal areas. The photo shows Redox measurement of water from a mine site.

TUKES carries out the mining operations final inspection. Once the mining rights expire and the final inspection has been conducted, monitoring by TUKES also ceases (Mining Act, Sections 57 and 59).

If a production facility or any part of it is completely closed down, the operator must under the Chemical Safety Act ensure that the structures and areas of the disused production facility or parts thereof are cleaned as necessary and that dangerous chemicals and explosives are taken care of so that they do not cause damage to people, property or the environment. The operator must notify the competent supervising authority if a production facility is closed down or if its operations are suspended for more than one year (Chemical Safety Act, Section 133).

Under the Environmental Protection Act, the operator is responsible even after the permit-based operations are discontinued for undertaking measures required in the permit provisions to prevent environmental pollution, to investigate the impact of the operations and to monitor the site (Figure 16) for the period of time specified in the permit decision (Environmental Protection Act, Section 90). The permit provisions may pertain for example to monitoring of wastewater. If the operator no longer exists or cannot be contacted, and if it is still necessary to monitor the environment to investigate the environmental impact of the discontinued operations, the holder of the operating area is responsible (ibid., Section 90). If the environmental permit does not contain sufficiently detailed provisions on measures required when discontinuing operations, the permit authority must issue such provisions. The matter shall be processed like an environmental permit application, as applicable.

An environmental permit decision concerning a landfill site must also contain the provisions specified in Section 20 of the Environmental Protection Decree, particularly on measures related to closing and rehabilitating the landfill site and on the period of time for which the operator of the landfill site is responsible for its rehabilitation. The provisions must take into account the potential danger or harmful effects of the landfill site on health and the environment for a period of at least 30 years after its closure (Environmental Protection Decree, Section 20). The Mining Act and the environmental legislation thus apportion responsibility differently. Even if the operator is no longer responsible under the Mining Act, he can still be responsible under environmental legislation.

3.1.4 Future legislation

Mining Act reform

By a decision taken on April 6, 2005, the Ministry of Trade and Industry appointed a working group for further preparation of reform of the Mining Act, to prepare a proposal for amending the Mining Act and legislation based on it with regard to the final reports of the working groups investigating needs for change in the Mining Act and mining safety regulations (KTM 2003a and KTM 2003b) and the statements received on those reports. The working group was instructed to pay particular attention to the integration of mining legislation and other legislation and the principles of precision and delimitation in legislation. The working group was required to submit an interim report on January 31, 2006, and its term was to end on December 29, 2006. The working group was to submit its report in the form of a Government Bill (Ministry of Trade and Industry Decision, April 6, 2005). The Ministry of Trade and Industry has extended the period for the working group until April 30, 2008.

Dam Safety Act reform

The Ministry of Agriculture and Forestry appointed a working group (October 1, 2005 to December 31, 2006) to prepare a reform of the Dam Safety Act. The working group was instructed to pay particular attention to the relationship between dam safety legislation and other legislation and the flood risk management legislation being prepared in the EU. The domain includes the relationship of dam safety to overall flood risk management and means in existing legislation to implement flood risk management. The working group was also required to take into account international practices, technological advances in dam monitoring and use and in the management of safety data. The working group was also required to investigate the potential of insurance companies to compensate for damages caused by dam accidents. The working group was to prepare bills for amending the Dam Safety Act and Decree by the end of 2006.The working group has submitted its report to the Ministry in January 2007.

Waste management

The EC has prepared a separate Directive on the management of waste from the extractive industries (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). This special Directive applies to the extractive industries, and the Waste Framework Directive (75/442/EEC) and the Landfill Directive (1999/31/EC) no longer apply to waste covered by the new Directive. The new Directive defines the minimum requirements for waste management in the extractive industries, partly graduated according to how hazardous the waste is. The Directive provides for waste facilities, their classification, procedures for closure and after-closure of the waste facilities, waste management plans, guarantees, and so on. A working group has been set up to make proposals for implementing the directive into Finnish legislation.

The procedure for characterization of extractive wastes based on the new Directive is also being prepared by the European Committee for Standardization (Technical Committee CEN/TC 292, working group WG8). The purpose of this project is to create a standard for defining the properties of extractive waste, covering research methods, sampling, testing and analyses.

The Commission has issued a strategy on the prevention and recycling of waste (COM(2005) 666 final) in December 2005. The Waste Framework Directive (75/442/EEC), which has a very ambiguous definition of waste, is to be amended at the same time, or rather a new Waste Directive will be given. The new Directive is to include 'end-of-waste' criteria (EOW). A comitology procedure could be used to find out, for each category of waste, exactly when waste ceases to be waste.

Environmental damage

Directive 2004/35/EC of the European Parliament and of the Council on environmental liability with regard to the prevention and remedying of environmental damage, also known as the Environmental Liability Directive, applies to damage caused to water, soil and biodiversity and direct threat of same (compensation, prevention). Member States were required to implement the Directive through legislation by April 30, 2007.

The liability is severe for commercial parties engaged in operations defined in Annex III of the Directive. However, any commercial operator is liable for biodiversity damage if caused through negligence or carelessness. The Directive shall not apply to damage arising from emissions, discharges, events, or situations occurring before April 30, 2007, or to damage arising after that date if the operations causing the damage ceased before that date. The Directive shall also not apply to damage arising from emissions, discharges, events, or situations occurring more than 30 years earlier.

Member States may allow an operator to be released from the costs incurred through corrective action as per the Directive if the operator can demonstrate not having caused the environmental damage through negligence or carelessness and that the damage was caused:

1) by emissions, discharges or an event which does not breach the terms of the permit and is specifically allowed under that permit, or
2) by emissions, discharges or use of a product during operations for which the operator can demonstrate that the scientific and technological information available at the time of the emission, discharge or event indicated that the operations were not likely to cause environmental damage.

The Ministry of the Environment appointed a committee to investigate the legislative amendments required by the Directive and to draft the necessary bills. The committee's term ended on May 31, 2006. The implementation of the Directive into Finnish legislation is still ongoing.

Water legislation

The Ministry of the Environment appointed a committee (August 1, 2004 to September 30, 2006) to prepare bills for Decrees to be based on the Water Management Act. These Decrees were to define:

- investigations and plans concerning water management areas, and cooperation,
- basis for ecological typology and classification of surface waters,
- basis for defining radically altered and artificial surface waters,
- basis for classifying groundwater, and
- basis for monitoring surface waters and groundwater.

An earlier working group appointed by the Ministry of the Environment prepared a bill for a Government Decree on environmental quality standards for nationally defined substances harmful to water environments (VESPA 2005), based on the Finnish Environment Institute's proposal for national priority substances (SYKE 2002). The working group explored which operations could result in the discharge into water of such amounts of the harmful substances on the proposed list that they could cause a risk to the water environment. It was found that sufficiently accurate and standardized determination methods do not exist for all the substances on the list. Environmental quality standards can only be defined for substances whose levels can be reliably measured, and accordingly threshold values that can be modelled were proposed for certain industrial and consumer chemicals. The Government Decree was scheduled to be issued at the end of 2005. An amendment of the Environmental Protection Decree to specify the regulation of discharges of dangerous substances was also prepared (Government Degree 889/2006). The Government Decree on substances harmful and dangerous for the water environment (1022/2006) entered into force on December 1, 2006 and supersedes the Government Decision on the discharge into the aquatic environment of certain substances dangerous for health and the environment (363/1994).

In June 2005, the Ministry of Justice appointed a working group to continue the preparation for a complete overhaul of water legislation. According to the Ministry, reform of the Water Act requires a broad review of other environmental legislation. The committee appointed by the Ministry of Justice in March 2000 proposed in its report dated June 16, 2004 (KM 2004:2) that the water legislation should be completely overhauled. The report contained a proposal for reforming the Water Act, written in the form of a Government Bill. The committee proposed that the first three chapters of the new Water Act should include definitions, general rights of water use and common demands for all projects, the project-specific chapters providing for the rights and responsibilities particular to each project. The legal survey and assessment proceedings and the final inspection were to be abandoned. The task of the later working group was to prepare the amendments to other legislation required by the Water Act reform, to draw up a proposal for the Water Decree and to address matters which had low priority in the committee, by May 31, 2006. Report has been given.

3.2 CONTAMINATED SOIL TREATMENT RESPONSIBILITY

Mining, like any other industrial operation, can lead to soil contamination. The following is an outline of the responsibilities related to this and the significance of the time of contamination for those responsibilities. Liabilities arising from the interpretation of the concept of waste are covered in Section 3.1.

3.2.1 Soil pollution prohibition and soil protection

The Environmental Protection Act states that waste or other substances shall not be left or discharged on the ground or in the soil so as to result in such deterioration of soil quality as may endanger or harm health or the environment, substantially impair the amenity of the site or cause comparable violation of the public or private good (soil pollution prohibition, Environmental Protection Act, Section 7). A Regional Environment Centre can order treatment of contaminated soil (ibid., Section 79).

The Act also prohibits groundwater pollution (ibid., Section 8, Government Decision 364/1994) and provides for the duty to treat, notify and investigate soil and groundwater and to assess the need for treatment, and for restoration of soil and ordering of restoration (ibid., Sections 75 to 79).

The European Commission has issued a soil protection strategy and a proposal for a soil protection framework directive. There is also national Government Decree for assessing the contamination and need for rehabilitation of soil (Government Decree on assessment of soil contamination and need for remediation 214/2007; known as the PIMA Decree). This Decree contains provisions on assessing the contamination of soil, the threshold and guideline values to be used, and assessing the need for rehabilitation of the soil. The assessment of soil contamination is based on risk assessment, taking into account the levels of harmful substances found in the soil in relation to the threshold and guideline values and to background levels, the overall amounts and properties of the harmful substances, soil properties in the area, the potential for the migration and spreading of the harmful substances in the area and beyond, and the present and proposed future use of the area (Government Decree on assessment of soil contamination and need for remediation 214/2007).

3.2.2 Treatment responsibility

The basic principle applied in rehabilitation of contaminated soil areas in Finland, is the ‘polluter pays’ principle. Any party whose activities have caused the pollution of soil or groundwater is required to restore said soil or groundwater to a condition that will not cause harm to health or the environment or represent a hazard to the environment (Environmental Protection Act, Section 75). The use of the area is taken into account in the soil contamination assessment: for example, an industrial storage area is not expected to be as clean as a housing district. The extent of the need for restoration is also assessed in relation to the future use of the land, for example in the conversion of an industrial property for housing (Government proposal 84/1999).

If a substance, which may cause pollution, has entered the soil or groundwater, the polluter shall notify the supervisory authority immediately. If the soil or groundwater is manifestly polluted, the regional environment centre may order the party responsible for treatment under Section 75 to establish the extent of the polluted area and the need for treatment (Environmental Protection Act, Section 77); this assumes that the authority has just cause to suspect contamination but does not have accurate information on it (Government proposal 84/1999).

An environmental permit is required for the treatment of polluted extractable land resources (Environmental Protection Act, Section 78). In minor and clearly defined projects, the environmental authority can also accept that rehabilitation is carried out using only a notification procedure. Action may be initiated to restore soil in a polluted area or to remove polluted soil material for treatment elsewhere by making the relevant notification to the Regional Environment Centre if:

- the extent of the polluted soil and the degree of pollution have been adequately established,
- treatment observes an approved treatment method in general use, and
- the activity does not result in any other pollution of the environment (Environmental Protection Act, Section 78).

The Regional Environment Centre scrutinizes the notification and makes a decision concerning it. This decision may include the necessary orders on how the activity must be organized and supervised (ibid., Section 78). If there is an exceptional situation as referred to in Section 62 of the Environmental Protection Act, such as an accident or a production disturbance, the notification procedure defined in the Environmental Protection Decree for treatment of contaminated soil shall be observed (Environmental Protection Decree, Sections 24-25).

The environmental permit application pertaining to the handling of contaminated soil must include a general restoration plan with a description of the site, the harmful substances observed, a risk assessment based on these, the restoration method and the projected result. The plan must also provide for quality control and measures to alleviate the adverse effects of the restoration itself.

The Regional Environment Centre shall order treatment of polluted soil or groundwater if the party responsible for treatment does not take action (ibid., Section 79). If the treatment requires treatment of surface deposits in the polluted area, the order is issued in compliance with the provisions on environmental permits, as applicable.

In case law, contaminated soil has been considered waste, which requires waste management measures (restoration of soil). The relevant legislation in restoration projects is generally environmental protection, waste management and waste legislation. In Finland, soil contamination is assessed on the basis of the Government Decree on assessment of soil contamination and need for remediation (214/2007). The investigation and restoration of contaminated soil is discussed in more detail in Section 5.8.

3.2.3 Significance of date of contamination for treatment responsibility

The provisions of chapter 12 of the Environmental Protection Act concerning treatment of contaminated soil and groundwater apply if the contamination occurred after the Waste Act entered into force on January 1, 1994 (Act on the Implementation of the Legislation on Environmental Protection 113/2000, Section 22). The primary responsibility for treatment rests with the party causing the pollution (Environmental Protection Act, Section 75.1). Secondary responsibility rests with the holder of the area if the party that has caused the pollution of soil cannot be established or reached, or cannot be prevailed upon to fulfil its treatment duty, and if the pollution has occurred with the consent of the holder of the area or said holder has known, or should have known, the state of the area when it was acquired. The holder of the area is also responsible, on the same preconditions, for treating groundwater if the pollution has arisen from pollution of the soil in the area. The holder of the area can be released from the treatment responsibility if it is clearly unreasonable (ibid., Section 75.2). Assessment of whether it is unreasonable must take into account the extent of the contamination and the economic burden represented by the treatment measures (Government proposal 84/1999). Responsibility does not pass on to the local authority until it has been established that the above parties cannot be required to undertake the treatment or their responsibility cannot be enforced. In such cases, the local authority must establish the need for and carry out soil treatment (Environmental Protection Act, Section 75.3).

Concerning restoration of soil contaminated before the Waste Act entered into force, the earlier Waste Management Act (April 1, 1979 to December 31, 1993) applies. However, the processing and procedure of restoration matters is always pursued in accordance with the Environmental Protection Act (Act on the Implementation of the Legislation on Environmental Protection, Section 22.1). In cases where soil contamination occurred while the Waste Management Act was in force, the provisions of that Act on the treatment of a littered area (Waste Management Act, Sections 32-33) or on organizing waste management (ibid., Section 21) apply. Primary responsibility for treatment of a littered area rests with the party causing the littering. Secondary responsibility rests with the property holder/holder of the area. The local authority may also have responsibility, but only if the area to be treated is not located in a densely populated area. The responsibility of submitting a waste management plan can only be enforced on the property holder. In a case where both the responsibility for treatment of a littered area and the responsibility of submitting a waste management plan would apply, the latter (ibid., Section 21) would apply in accordance with a decision taken by the Supreme Administrative Court ('Korkein hallinto-oikeus' (in Finnish); KHO November 22, 1994 (5740)). The responsibility of submitting a waste management plan means in practice that the operator submits the plan to the environmental permit authority, which then processes the plan according to the permit application procedure. A summary of legislation pertaining to contamination is given in Appendix 7.

Responsibility for treatment of groundwater contaminated before the year 2000 is determined on the basis of the Water Act (264/1961). In cases of groundwater contaminated after the Environmental Protection Act entered into force, responsibility for treatment is apportioned as per the Environmental Protection Act according to the above procedure.

The Land Use and Building Act, the Mining Act, the Chemical Act, the Radiation Act (592/1991), and the Health Protection Act (763/1994) contain general provisions which in some cases are applicable to the restoration of contaminated soil. Restoration of contaminated soil is discussed in more detail in Section 5.8 of this document.

There are provisions on sediment dredging and depositing in the Water Act and the Environmental Protection Act. The Ministry of the Environment has also published a separate instruction booklet on sediment dredging and depositing (Ympäristöministeriö 2004), covering the essential legislation applying to dredging.

3.3 LEGISLATION ON DAMAGE COMPENSATION

3.3.1 Applicable legislation

A mine in operation may be subject to the damage compensation provisions of the Mining Act, the Act on Compensation for Environmental Damage (737/1994), the Tort Liability Act (also known as the Damages Act, 412/1974) and the Directive on environmental liability with regard to the prevention and remedying of environmental damage (2004/35/EC, April 30, 2004; cf. Section 3.1.4).

There are two provisions on damage compensation in the Mining Act. Under the Mining Act, the holder of a mining concession must pay compensation for the right to use the mining concession and its auxiliary area. If an area being developed as a mining concession or its auxiliary area causes a detriment to the use of the remaining portion of the property or otherwise causes obstruction or damage to the property, compensation must be paid. Similarly, if the legal recognition of a mining concession, or the mining operation itself, causes a loss or restriction of other rights, compensation must be paid (Mining Act, Section 36). The Mining Act also provides for unforeseen damage. If the mining operation causes damage or obstruction not taken into account when defining the mining concession, compensation for this may be separately applied for by filing suit with the district court of the location where the mining concession is located (ibid., Section 46). The suit must be filed within three years of the damage or obstruction being discovered.

The Act on Compensation for Environmental Damage and the Tort Liability Act apply in addition to the Mining Act. The environmental permit procedure may involve specifying compensation to be paid in advance for the damage estimated in the permit application to be caused by water pollution. When a permit authority grants an environmental permit, it shall at the same time, unless otherwise is laid down in Section 68, order ex officio that damage from water pollution caused by the activity be compensated (Environmental Protection Act, Section 67). In such cases Section 9 of the Act on Compensation for Environmental Damage does not apply. When deciding on a compensation, due consideration shall be given to the provisions of Section 55 of the Environmental Protection Act on the fixed-term nature of the permit and the possibility of reviewing the regulations of a permit granted until further notice (ibid., Section 67). Compensation for other damage must be sought by filing suit with a district court as per the Act on Compensation for Environmental Damage and the Tort Liability Act.

3.3.2 Environmental damage

The Act on Compensation for Environmental Damage stipulates that compensation shall be paid for a loss defined in this Act as environmental damage, caused by activities carried out in a certain area and resulting from: 1) pollution of the water, air or soil; 2) noise, vibration, radiation, light, heat or smell; or 3) other similar nuisance (Act on Compensation for Environmental Damage, Section 1). Liability for compensation arises regardless of whether the activities are legal or not. This is a ‘strict liability’. Cause and effect does not need to be fully established as in the case of applying the Tort Liability Act.

Compensation shall be paid for environmental damage by virtue of the Act on Compensation for Environmental Damage only if toleration of the nuisance is deemed unreasonable (obligation to tolerate the nuisance), consideration being given, among other things, to local circumstances, the situation resulting in the occurrence of the nuisance, and the regularity of the nuisance elsewhere in similar circumstances. The obligation to tolerate the nuisance shall not, however, apply to loss inflicted deliberately or criminally, or to bodily injury, or to material loss of greater than minor significance (ibid., Section 4). Compensation shall be set for bodily injury and material loss in accordance with the Tort Liability Act. Compensation shall be paid for financial loss not connected with bodily injury or material loss if the loss is not minor (ibid., Section 5). Compensation shall, however, always be paid for loss inflicted criminally. Reasonable compensation shall be paid for environmental damage other than that specified above; in the determination of this compensation, due consideration shall be given to the duration of the nuisance and the loss, and to the chances of the person suffering the loss avoiding or preventing this loss (ibid., Section 5).

Even when the loss has not been caused deliberately or negligently, liability for compensation shall lie with a person

1) whose activity has caused the environmental damage,
2) who is comparable to the person carrying out the activity, as referred to in sub-paragraph 1, and
3) to whom the activity which caused the environmental damage has been assigned, if the assignee knew or should have known, at the time of the assignment, about the loss or the nuisance referred to in Section 1 or the threat of the same (ibid., Section 7).

In the assessment of the comparability referred to in sub-paragraph 2, due consideration shall be given to the competence of the person concerned, his financial relationship with the person carrying out the activity and the profit he seeks from the activity (ibid., Section 7). The Act also provides for costs of prevention and reinstatement and for joint and several liability.

If, in a procedure under the Mining Act, compensation is to be set for environmental damage as referred to in the Act on Compensation for Environmental Damage, the provisions of the latter on liability for compensation and on the grounds for compensation shall apply, except for Sections 8 to 10 inclusive. The Act shall apply if activities under the Mining Act lead to bodily injury deemed to be environmental damage (ibid., Section 12). Compensation must be demanded within ten years of the damage occurring. The Tort Liability Act is applied as a supplementary act.

The content of the Environmental Liability Directive is discussed in Section 3.1.4 of this book.

3.4 BAT AND MINE CLOSURE

The Environmental Protection Act states that the best available techniques (BAT) shall be used (Environmental Protection Act, Section 4). BAT refers to methods of production and treatment that are as efficient and advanced as possible and technologically and economically feasible, and to methods of designing, constructing, maintenance and operation with which the contaminative effect of activities can be prevented or most efficiently reduced (ibid., Section 3).

The Environmental Protection Decree requires operators to present an estimate of the application of BAT in their proposed operations when submitting the environmental permit application (Environmental Protection Decree, Section 9.2). The BAT estimate must take into account the efficiency of raw material use and energy consumption, the level and applicability of technology, emissions and discharges into the environment, and the BAT Reference Documents published by the Commission and other international bodies. In addition to the BAT Reference Documents, reliable national and international reports and instructions can be referred to.

The operator must assess his own operations and proposed measures against the technologies and criteria given in the BAT Reference Document on a case-by-case basis, taking into account local circumstances, plant-specific properties and economic circumstances. If some other reference other than the BAT Reference Document is used, the permit application must contain a justification for this choice and an estimate of environmental load and technological level in comparison with the reference technology given in the reference document.

The relevant BAT Reference Document for mining is *BAT for Management of Waste-Rock and Tailings in Mining* (EC 2004). This is related to the Directive on the management of waste from the extractive industries (Directive 2006/21/EC of the European Parliament and of the Council) and applies to measures related to the handling of tailings and waste rock at all stages of operation in metal ore and mineral mines. The content of the BAT Reference Document is discussed in more detail in the separate report of the 'Environmental Techniques for the Extractive Industries' project (Mroueh *et al.* 2005b). The closure of other functions such as open pits, mine tunnels and ore processing plants is beyond the scope of the report. In addition to the above document, general BAT Reference Documents such as the document on the General Principles of Monitoring (EIPPC 2003) and the document on Economics and Cross-Media Effects (EIPPC 2004).

In the BAT Reference Document (EC 2004), the definition of best available technique is based on the management of the entire life-cycle of a mine. It requires closure and rehabilitation to be taken into account at all stages of mine operations. Closure criteria and closure objectives must be defined and a closure plan drawn up when the mine is being planned. The closure plan must then be revised and updated at suitable intervals while the mine is in operation and updated for a final time when closure is being prepared for.

The general closure objectives are:

- physical and chemical stability of structures left in place at the site,
- the natural rehabilitation of a biologically diverse, stable environment,
- the ultimate land use is optimised and is compatible with the surrounding area and the requirements of the local community, and
- taking the needs of the local community into account and minimizing the socio-economic impact of closure.

In the management of waste rock and tailings, the primary target is to minimize the volume of material for final disposal. For the remaining materials, a disposal management plan must be drawn up in order to minimize accident risks and to ensure that the risk level of the site will decrease over time. Choice of technologies must be based on risk assessment, which takes into account the environment, safety and technical properties. Basic characterization to explore the properties of materials is an essential part of planning and must be conducted before operations are begun. Material characterization must be revised and updated while operations are in progress.

The material characterization includes the study of the following properties of waste rock and tailings:

- chemical composition and mineralogy,
- acid generating potential (AP),
- leachable harmful substances,
- long-term behaviour, and
- physical and hydrological properties.

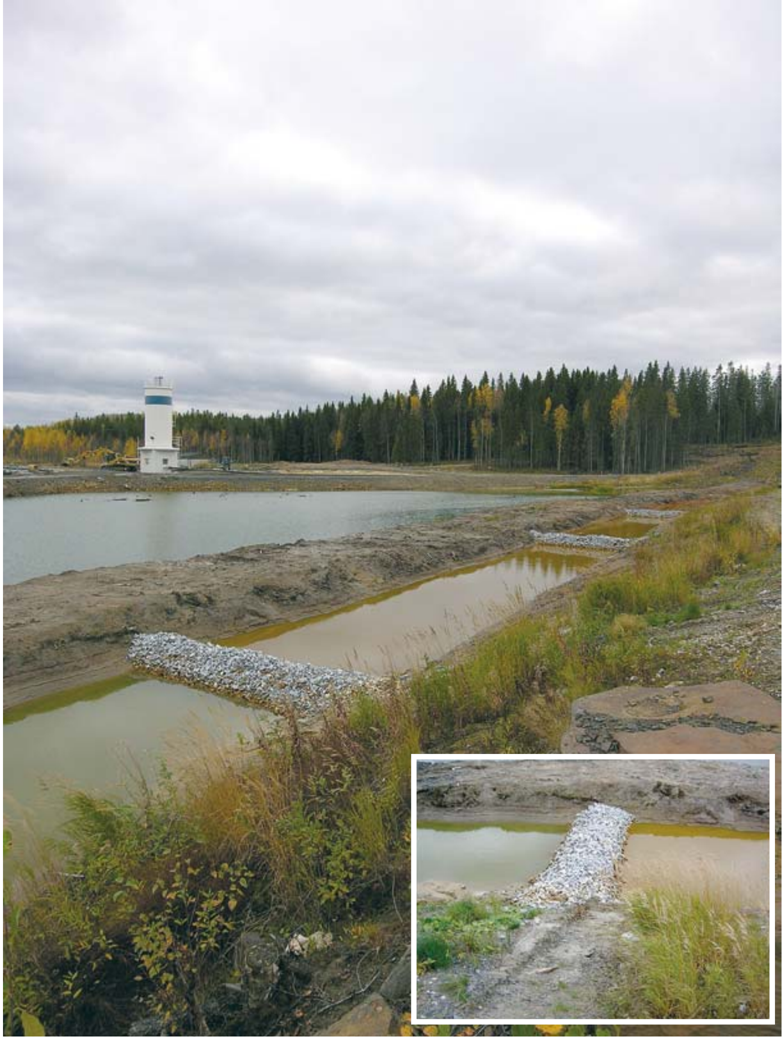


Figure 17. BAT for treating acid mine drainage includes neutralizing with lime. The Lahnaslampi talc mine in Sotkamo has a series of limestone batteries to filter the water discharged from the waste rock disposal areas.

The acid producing potential (AP) of the waste rocks and tailings deposited at the mine site is the single most important factor affecting the nature of closure measures. The BAT for preventing acid production or alleviating its impact include:

- water covers and dry covers,
- sub-aquatic disposal,
- oxygen consuming covers,
- removal of sulphide minerals from tailings or waste rock,
- separating acid generating materials from other materials,
- wetland construction, and
- raising the water table.

In order to limit acid production, it is essential to prevent oxygen from getting into contact with the material. Decisions must be made on a case-by-case basis, taking into account the water balance, the availability of cover materials and the water table (cf. Section 6.2.2). In addition to preventive methods, water treatment methods are often also needed, at least in the early stages of rehabilitation. BAT in water treatment involves neutralizing with lime; quicklime or sodium hydroxide (for water with manganese content); wetlands; anoxic limestone drains/open limestone channels; and diversion wells (Figure 17, cf. Section 6.2.1).

If the tailings or waste rock are not reactive, i.e. if they do not contain significant amounts of oxidizing sulphide minerals, the main factors in closure planning are ensuring long-term physical stability, planning landscaping and revegetation, and preventing erosion and dusting (see Sections 6.1.3 and 6.1.5). Dam safety and stability issues are important both during and after operations. The document presents scaling parameters and certainty coefficients used in stability calculations for dams and waste rock piles. There is also a recommendation on how often inspections and audits should be performed during rehabilitation.

3.5 ASPECTS OF LAND USE

The extractive industries use some 0.05% of the land area of Finland (mining concessions 0.04% and operating mines 0.02%, verbal communication, K. Söderholm, Ministry of Trade and Industry 2005); sulphide-containing tailings areas cover some 1,000 hectares (0.003% of the land area). Mining uses relatively little land compared to agriculture, which uses 10% of the land area of Finland (Raw Materials Group 2002).

The Land Use and Building Act (132/1999) governs how land is used and built. The objective of this Act is to ensure that the use of land and water areas and building activities on them create preconditions for a favourable living environment (Land Use and Building Act, Section 1).

Land use is governed through regional plans, master plans and town plans. Mine sites are indicated on all plans with the code 'EK' (Ministry of Environment Decree, March 31, 2000). The regional plan sets out the principles of land use and community structure, and designates areas as necessary for regional development (Land Use and Building Act, Section 25). Regional plans are drawn up by the Regional Councils. The code 'EK' on a regional plan designates areas which are necessary for exploitation of extracted minerals and which as such come under the Mining Act. These areas either already have mines or have been investigated for the purposes of mining. A regional plan can indicate how areas are to be used after mine closure and provide for the need for planning and studies when changes in land use are proposed (Ympäristöministeriö 2003a).

The purpose of the local master plan is to provide general guidance regarding the community structure and land use of a municipality or a part thereof, and to integrate functions. A local master plan may also be drawn up to guide land use and building in a specified area. The local master plan presents the principles of targeted development and indicates the areas required as a foundation for detailed planning, other planning and building, and other land use (Land Use and Building Act, Section 35). The master plan is drawn up by the local authority and approved by the municipal council. Planning ordinances guiding the permit processing by the authorities can be adjoined to areas reserved for mining in the master plan (Ympäristöministeriö 2003b). These may address for example the later use of the area. The local detailed plan, or town plan, is drawn up for the purpose of detailed organization of land use, building and development (Land Use and Building Act, Section 50). Granting a permit under the Environmental Protection Act requires that the activities conform to the detailed local plan. Activities may not be located in conflict with a detailed local plan (Environmental Protection Act, Section 42).

A local authority must have a building ordinance, approved by the municipal council (Land Use and Building Act, Sections 14-15). The building ordinance can address land use and building in an area of impact of mining operations. For instance, the building ordinance of the towns of Vammala and Outokumpu specifies the following:

> *"Construction subject to permit in an area of impact of the mining operations requires permission from the holder of mining rights or, if the mining rights have expired, the last holder of mining rights entered in the mining register. The area of impact of the mining operations, including areas above the extraction zones, protection zones and tailings areas, are shown on the map appended to the building ordinance."*

For practical reasons and for reasons of safety, it would be advantageous to have a specific provision in law on the area of impact of a mine. The Mining Act working group, for example (KTM 2003a), stated in its proposal that the area of impact of a mine which may entail land use limitations should be determined in connection with the final inspection. This area of impact would then be entered on the mine map and also in the cadastral register. The local authority would then be notified of the delimitation of the area of impact and of the decision of the final inspection. In preparing construction and other projects, the local authority would need to request a statement from the mining authority. Restrictions on land use in the area of impact would involve construction, leisure or commercial use. The delimitation of the area of impact would help convey information of the special nature of mining operations to the local authority and other land use planners.

If the area is to be zoned for housing after mining operations are discontinued, inspecting the area for the presence of harmful substances before planning or building is considered part of due diligence according to current knowledge for example in old mining areas. If this is neglected, the planner is liable for compensation under Section 3.2 of the Tort Liability Act. Responsibilities for investigation and restoration are defined in the Waste Act (Tuomainen 2001). If the soil in an area is found to be contaminated and if it causes an obstruction to the land use indicated in the town plan, the plan is in violation of the Land Use and Building Act and can be discarded. The plan does not need to be changed if the contaminated soil can be restored to a state consistent with the intended use of the area. If the contamination is slight, a suitable use for the area can sometimes be found without having to undertake any restoration. In such cases, limitations on the use of the area should be entered in the plan.

Land use after the mine closure should already be considered when planning a new mine. Under the Mining Act, the mining concession application must include usage plans for the mining concession and its auxiliary area (Mining Act, Section 23), but a general plan on operations must also be submitted to the Safety Technology Authority before operations are begun. General plans and usage plans are very detailed regional land use plans, containing information on the placement of products, by-products and waste in the mining concession or its auxiliary area so that not only the needs of the mining operations but the safety of the vicinity and eventual adverse effects are taken into account. The plan should also include a preliminary or completed closure plan (cf. Section 2.4). What happens after mining operations are discontinued can also be required to be stated in the EIA process (cf. Section 3.1.1) in addition to describing the mining operations.

Setting up a mine involves various permit procedures, including the mining concession process, the EIA process, the planning process, and applications for various permits. Each of these has specific hearing procedures. It is advisable to combine processes in order to avoid duplication of work. Appendix 8 shows an example of how to combine planning and the EIA process in a mining project.

A disused and properly rehabilitated mine site has often relatively limited significance on local land use, although there may be variance. Mines often locate in areas where there is little competition for land use, though there are certainly exceptions. Even if areas cannot be strictly restored to their original state, proper rehabilitation helps to adapt the mine sites in with its surroundings.

3.6 PARTIES TO CLOSURE AND OFFICIAL PROCEDURE

Mine closure permit applications are processed in the same way as environmental permit applications under the Environmental Protection Act as applicable in cases where the environmental permit decision pertaining to the mine operations does not contain sufficient provisions regarding closure measures. Under the Environmental Protection Act and Decree, environmental permit decisions are taken by Environmental Permit Authorities. This is due to the nature of the operations also because often a permit under the Water Act is required in addition to the environmental permit. In such cases, the applications must be processed jointly by the Environmental Permit Authority.

When processing an environmental permit application, the permit authority shall request an opinion on the permit application from the environment authorities in the municipalities and regions where the activity referred to in the application may have environmental impact. The permit authority must also request an opinion from other authorities charged with protecting the public interest and any other opinions needed in considering the permit application. The permit authorities shall request an opinion from the local authority where the activity referred to in the application is located and, if needed, from other local authorities whose territory is affected (Environmental Protection Act, Section 36). Before passing a decision on a permit, the permit authority shall provide those rights or interests might be concerned (stakeholder) with an opportunity to lodge a complaint regarding the matter. Persons other than stakeholders shall be provided with an opportunity to state their opinion (ibid., Section 37).

Having taken the environmental permit decision, the permit authority must deliver the decision to applicants and to those who have separately so requested, and to supervisory authorities and authorities protecting the public good in the case (ibid., Section 54). In addition, those who have made a complaint in the case or who have separately requested to be notified and those who have been separately informed of the permit application, shall be notified of the decision. A notice on the decision must be published immediately in the municipality where the activity is located, and in other municipalities where the impact of the activity may show. Also, a notice on the decision must be published in at least one newspaper in general circulation in the area affected by the activity (ibid., Section 54).

Also, under the Mining Act the Ministry of Trade and Industry must make a public announcement in the municipality where the mine is located if the operator relinquishes mining rights (Mining Act, Section 55). The announcement must be accompanied by a direction how to appeal the decision of the Ministry of Trade and Industry. The date of publication of the announcement is entered in the mine register.

Under the Mining Act, mine closure involves a final inspection conducted by the national Safety Technology Authority (TUKES) (cf. Section 3.1.3). TUKES supervises mine safety as per the Mining Act and also conducts inspections while the mine is in operation (Mining Act, Section 59). The Ministry of Trade and Industry supervises compliance with the Mining Act, and legislation and instructions based on it, and also conducts inspections for this purpose.

3.7 EXAMPLES OF REQUIREMENTS FOR MINE CLOSURE IN ENVIRONMENTAL PERMITS

The following is a discussion of requirements for mine closure and rehabilitation entered in environmental permits in Finland. Appendix 5 contains a number of detailed examples on requirements in environmental permits regarding mine closure in certain individual cases.

The requirements in environmental permits are determined on a case-by-case basis and can differ from one site to the next. The following are requirements that the permit authorities have entered in the past:

- rehabilitation and monitoring,
- landscaping of waste rock piles and tailings ponds,
- surface structures to be used in covering tailings ponds,
- substances and equipment to be removed from the area,
- guarantee to ensure waste management,
- waste classification,
- submission of a closure plan, and
- submission of a plan for monitoring the post-closure performance.

In environmental permits related to the beginning of mining operations, operators are required to pledge a sufficient guarantee or similar arrangement to ensure provision of appropriate waste management (Environmental Protection Act, Section 42). The purpose of the guarantee is to ensure that resources are available for rehabilitation of the waste rock and tailings areas after closure. When determining the size of the guarantee, the authorities estimate the minimum costs of rehabilitation of the areas. There is more information on principles of the guarantee practice in Chapter 8, and practical examples of guarantees in Appendix 5.

The environmental authorities can further require the drawing up of a detailed closure plan and/or rehabilitation plan as soon as the mine is in operation or enter requirements for closure measures in the environmental permit. The closure plan must be submitted to the environmental authorities as an application, which must be approved by the authorities before the mine is closed. The plans and their content are usually described in the environmental permit. The Mining Act requires that the mining area, i.e. the open pits and the storage areas for waste rock and tailings, must be rendered into a state consistent with public safety once mining operations have been discontinued (Mining Act, Section 51). In other respects, mine closure measures are determined on a case-by-case basis. A closure plan often details landscaping and rehabilitation measures, the conducting and treatment of seepage and other waters, the closure of tailings areas and/or waste rock areas, the removal of other functions, and monitoring after closure (cf. chapter 6).

Requirements in environmental permits regarding closure have included removing from the site all machinery, equipment, chemicals, fuels, and waste, which pose a contamination risk except for waste with a final disposal repository at the site; this will have been provided for by permit earlier. Requirements have also included landscaping waste rock areas by covering them with clean soil and growth layers and shaping their surfaces so that no depressions remain that could gather water. Environmental permits generally stipulate that attention must be paid to preventing acid mine drainage in the landscaping of waste rock areas and tailings ponds if the waste rock or tailings are potentially acid generating. In order to prevent acid production, the tailings ponds should be covered at closure with a surface structure with low water permeability, topped with a growth layer (cf. Appendix 5).

The environmental authorities have also required in the past that the mining operator (the holder of the environmental permit) be responsible for rehabilitation and monitoring of the final repositories for waste rock and tailings at the site for as long as these can be assumed to have potential for harmful impact on the environment, usually for at least 30 years (cf. Appendix 5).

4. ENVIRONMENTAL IMPACT ASSESSMENT AND RISK ASSESSMENT IN MINE CLOSURE

Environmental impact assessment (EIA) and risk assessment constitute an essential part of the mine closure process and the lifecycle of mining operations. Assessments are made at several points over the lifecycle of a mine, for example when planning the operations and when preparing a mine closure. The purpose of the assessments is to minimize the risks to the environment and to human beings through a variety of risk management measures. The following Sections discuss EIA factors and how to handle risk assessment and risk management.

The EIA procedure related to the opening of a mine is provided for in the Act on Environmental Impact Assessment Procedure (cf. Section 3.1). The following is a discussion of EIA at a general level, though with special reference to mine closure.

4.1 ENVIRONMENTAL IMPACT MAPPING AND ASSESSMENT

EIA and the monitoring of environmental impacts are relevant throughout the life-cycle of a mine. EIA may first be necessary even at the prospecting stage, for example in the case of a 'Natura assessment', which must be carried out regarding any proposed operations in Natura 2000 areas (cf. Section 3.1). Today, it is usually the practice to conduct an environmental baseline study when a mine is being planned and established in order to collect basic data and environmental information on the soil and bedrock conditions and the surface water and groundwater in the area (see Section 4.1.1). The environmental impacts of the proposed mine are also assessed, and procedures to alleviate those impacts are planned (cf. Section 3.1 EIA procedure). While the mine is in operation, the state of the environment is continuously monitored by comparing it with the environmental baseline study, which has been conducted before the mine opening. If necessary, measures are undertaken to reduce the adverse effects of operations. Then, at the latest when the mine is to be closed, a present state study is produced to outline the environmental impacts caused by the mining and to assess the environmental impacts that could be caused by the mine site even after mining has been discontinued. At the same time, required after-care measures are planned, and an after-care monitoring program is drawn up. The planning of a mine closure makes use of the environmental information generated at the various stages of the mine project, including the studies conducted before the mine was opened.

Mining can have an environmental impact on the natural environment, on human beings, and on society. Table 5 illustrates the most important environmental impacts of a mining operation at the various stages of the project.

The following sections discuss the content of the environmental baseline study and factors to be taken into account in the EIA.

Table 5. Areas affected by the most significant impacts of a mining operation (shaded cells) on the natural environment, on human beings and on society at the various stages of the project (Salminen et al. 1999, adapted).

Receptor	**Natural environment**						**People and society**			
Operational stage	Soil and bedrock	Land-scape	Ground-water	Surface water	Air and noise	Flora and fauna	Busi-ness and employ-ment	Rec-reational use	Health, comfort, living condi-tions	Culture, land-scape
Establishment stage										
Excavation and concentration										
Water arrange-ments										
Disposal										
Transport										
Energy supply										
Storage (fuels, chemicals)										
Closure										
After closure										

4.1.1 Environmental baseline study

Before a mine is constructed, an environmental baseline study is conducted to establish the baseline state of both the natural and the social environment. If a sufficiently comprehensive environmental baseline study has not been conducted by the time operations are started, this information must be collected as far as possible at the time of closure planning. In such a case, however, important matters may have to be evaluated on the basis of guesswork or research data which has been obtained elsewhere and which is difficult to generalize. In some cases, various studies such as sediment studies can in fact help establish what the baseline situation was, even if they are conducted during or after the actual mining operations (cf. Section 5.2).

The purpose of the information gained through the environmental baseline study is:

- to provide baseline information for conducting an EIA on the mining operation,
- to provide baseline information and benchmarks for the monitoring of levels of elements and compounds in the environment at closure, and
- to provide a benchmark and potentially also a target level for the planning of environmental impact management actions to be taken at closure.

The factors included in the environmental baseline study are shown in Table 6.

Table 6. Content of the environmental baseline study (Mining Association of Canada 1998; Salminen et al. 1999; DME 2002).

Item	Points to be included
a) Meteorological conditions	• Principal meteorological baseline data include average annual and monthly rainfall, the number of rainy days, the maximum monthly intensity of rain (e.g. 60 min, 24 h, 24 h / 50 yrs, 24 h / 100 yrs), temperature by month (minimum, maximum, average), average wind speed and direction by month, average evaporation by month, and depth of ground frost (average and maximum).
b) Landscape	• The general description indicates whether the area is of special importance in terms of its landscape, topography or geomorphology. Particular attention is paid to whether the area is part of an area of outstanding natural beauty as referred to in the Nature Conservation Act (Section 32) or is along an important tourist route.
c) Natural habitat types	• A description of the natural habitat types in the area and its immediate vicinity and their locations (including protected natural habitat types; see Section 29 of the Nature Conservation Act, Section 10 of the Forest Act and the Government Decisions on Natura 2000 areas, 20 August 1998, 25 March 1999, 8 May 2002 and 22 January 2004).
d) Flora	• Presence of threatened, protected or rare plant species, general description of flora (e.g. dominant plant species) and a vegetation map. • Establishing whether the area is of rare natural value.
e) Fauna	• Presence of threatened, protected or rare animal species (Sections 17-23 of the Nature Conservation Decree), and general description of fauna.
f) Geochemical baseline state of the site	• Assessment of the geochemical properties of the site (e.g. moss and humus specimens, surface water and groundwater samples, and sediment and soil samples). The variables to be determined should be chosen as comprehensively as possible so as to illustrate the natural conditions of the area where the exploitable deposit is located, the elements contained in the raw material in the area, and the chemicals that could be used in the mining operations. Potential contamination by other operations should also be taken into account.
g) Air quality and noise	• Assessment of air quality in the area and in the impact area of the future mine. Survey of emission sources. Noise measurements as required.
h) Topography	• Description of the topography of the area on a map with contours chosen at sufficiently close intervals to demonstrate the shapes of the bedrock and/or quaternary deposits.
i) Quaternary deposits	• Soil survey data that can be used to divide the area into sub-areas not only by soil type but also by factors such as erosion sensitivity, water permeability and risk of groundwater contamination. Establishing the thickness of soil layers is also part of the soil survey. This usually includes an area description in addition to the site description.
j) Bedrock	• The environmental baseline study shows the composition of the bedrock (both at the site and in the area), and also contains data relevant for groundwater flow, such as cleavage and fracture zones. The study also includes a description of the ore deposit (including average composition and potential levels of harmful substances).
k) Surface water and groundwater	• A study of surface water and groundwater conditions based on maps and on soil and bedrock data. This includes the following: - extent of catchment area, - annual average of surface runoff, flood peaks and maximum flood levels e.g. 20-year flood, 50-year flood, 100-year flood (entire catchment area, catchment area upstream of site), - location of site in relation to important groundwater basins and their buffer zones (areas in groundwater classification classes I-III, see Britschgi & Gustafsson 1996), - surface water areas and their location (rivers, ponds, lakes), hydrology and flow, including low discharge, normal discharge, potential impact area of water discharge from the site, - groundwater table and flow directions, - extent of mine site impact area (groundwater), - springs and their peak discharge, - groundwater and surface water quality at the site and downstream of the site in the area of potential impact, - use of surface water and groundwater in the mine impact area (purpose, volumes), - well yields and water levels in various seasons.
l) Extreme natural phenomena	• An assessment of the probability of various natural disasters (floods, landslides, earthquakes) and their impact on the area.
m) Land use and protection	• Land use in the site area and its immediate vicinity (housing, agriculture), including earlier land use. Existing nature protection areas or locations protected for historical reasons (e.g. Sections 2 and 4 of the Antiquities Act).
n) Culture	• In addition to any housing at and near the site, a survey of sites of pre-historic, historical or cultural importance, including roads and buildings.
o) Socio-economic factors	• A survey of the basic socio-economic factors at the site, including: - historical background of the site, - population and population structure - regional health care and education services, culture, - employment, - infrastructure (roads, energy supply, water and waste management).

4.1.2 Factors to be considered in the EIA

The purpose of the EIA is to estimate what the effect of the mine operations will be on the natural environment, on people and on society. The most significant impacts of mining are generally caused by changes in land use and topography, dust, noise, and long-term changes in disposal areas and excavations, such as weathering. The impacts can be divided into physico-chemical impacts, ecological and socio-economic impacts, and land use and infrastructure impacts (Table 7).

Table 7. Examples of the impacts of mine operations (United Nations / UNEP 1994; UNEP/WHO 1998; Environment Australia 2002; adapted).

Nature of impact	Impact
Physical or chemical	• change in natural state of the soil • erosion, subsidence or changes in stability • changes in watercourses • impact on the quality, quantity and usability of surface water and groundwater • contamination of soil, surface water and groundwater with organic or inorganic harmful substances • impact on riparian processes
Ecological	• direct impact on flora, e.g. clearing of woodland • changing and destruction of habitat • disappearance of fauna • impacts on ecological processes • changes in biodiversity • spread of plant diseases and harmful weeds • impacts of poisonous and hazardous substances • creation of new habitats
Social or economic	• migration to the area • impacts on health, safety, wellbeing and quality of life (e.g. traffic, smells, dust, noise, forced migration) • potential changes in the structure of society (culture, income distribution, employment, price levels) • increased employment • increased tax revenue
Land use related	• changes in land use and impacts on land use elsewhere in the area • increased use of natural resources (e.g. water)
Infrastructure-related	• increased demand for services and infrastructure (e.g. roads, electricity, water, housing, hospitals, schools)

Table 8 contains a more detailed description of the factors related to the physical and chemical impacts of mines and of what these factors affect and how. Also, the tables in Appendix 1 list potential chemical and physical impacts of mine operations and concentration, analyzed by what is being excavated. In addition to describing the impact mechanisms, the EIA takes into account how the impacts change when environmental conditions change, e.g. nutrient balances, oxidation/reduction conditions or rainfall.

Impact on the natural environment

As far as the natural environment is concerned, the EIA must take into account the effect of the functions of the mine site and its potential emissions on the natural environment, such as the topography of the area and its landscape, biodiversity, the ecological and physico-chemical properties and amount of surface water and groundwater, and flow directions. At a mine site there are many sources of substances potentially harmful to the natural environment:

- mine dewatering water,
- eroded soil (migration and re-sedimentation of fines),
- emissions from concentration,
- wastewater,
- chemical, oil or fuel emissions (soil and water contamination),
- leaching of harmful substances from tailings and waste rock areas and from contaminated soil areas, and/or
- emissions into the air from processes (e.g. mercury and cyanide gasification) and mines (methane, exhaust gases).

Impacts on the natural environment are evaluated according to their magnitude (e.g. extreme, negligible), time (e.g. immediately, after closure) and duration (e.g. temporary, long-term).

Table 8. Physical and chemical environmental impacts of mining (United Nations / UNEP 1994; UNEP/WHO 1998; Environment Australia 2002, adapted).

Location	Factor	Object/impact
Underground workings	• cave-ins, sinking, subsidence	• subsidence, surface water flows, change in habitats, land use
	• access and ventilation shafts	• surface water flows, change in habitats, land use
	• formation of acid mine drainage and/or metal mobilization	• mine dewatering water, surface waters downstream of the mine, groundwater contamination
	• process reagents in backfilling and/or metal transport, other harmful substances (oils)	• mine dewatering water, surface waters downstream of the mine, groundwater contamination
Open pit/Quarry	• formation of acid mine drainage, metal leaching and transport	• mine dewatering water, surface waters downstream of the mine, groundwater contamination
	• cave-ins, erosion	• landscape, land use, habitat
	• excavation area	• landscape, land use
Tailings area	• erosion, stability	• landscape, land use, habitats, sedimentation in surface watercourses and basins, dust
	• formation of acid mine drainage, metal leaching, metal transport	• seepage, gravitational water, covering materials, surface water and groundwater contamination, stability, soil acidification, toxicity, gas formation
	• process chemicals	• seepage, surface water and groundwater contamination
	• dust	• soil and surface water contamination, impacts on flora and fauna
	• compactness of surface material	• surface runoff, changes in rainwater infiltration
	• landform and disposal area	• land use, landscape
Waste rock and soil disposal areas	• erosion, stability	• landscape, land use, habitat, sedimentation in surface watercourses and basins, dust
	• formation of acid mine drainage, metal leaching, metal transport	• surface water and groundwater contamination, stability, soil acidification, toxicity, gas formation
	• dust	• soil and surface water contamination, impacts on flora and fauna
	• density of surface material	• surface runoff, changes in rainwater infiltration
	• landform and disposal area	• land use, landscape
Buildings and structures	• sedimentation, stability	• drainage and culverts, buildings, landscape, land use
	• chemicals, harmful substances	• surface water and groundwater contamination, soil acidification, toxicity, gas formation
	• infrastructure	• changes in use potential and maintenance
	• dense surfaces (roads, fields)	• changes in surface runoff and rainwater infiltration
	• buildings and structure areas	• land use, landscape

Impacts on human beings and society

The assessment of impacts on human beings and society involves a study of factors related to the health of the population and the healthiness of the living environment. Social conditions are also considered (cf. previous Sections 2.2.3 & 2.3). The ‘living environment’ can here be understood to refer to a housing area, the immediate vicinity or any area used for recreation. In the procedure defined in the Act on Environmental Impact Assessment, the assessment of social and health impacts involves analyzing the capacity and will of a community to adapt to the proposed project and identifying problems and interests in its implement (Salminen *et al.* 1999).

Social and health impacts may involve the population (number, social groups, temporary population, family structures), the local economy (employment, finances, business opportunities), public and private services (transport, shops), land use (forms and value of land use), lifestyle and lifestyle values, living conditions, culture, the community, attitudes, conflicts and relationship to nature (Juslén 1995). The assessment of health risks is usually based on a risk assessment that proceeds in stages and covers points such as exposure of the population to a variety of harmful substances. The content of this risk assessment is discussed in more detail in Section 4.2. Social impacts can be assessed, for example, on the basis of the factors listed in Table 9.

Table 9. Identifying social impacts (Sosiaali- ja terveysministeriö 1998).

Factors influencing social conditions	Changes in social conditions caused by project
Character of the area	Significant changes in the physical or social character of the area
Population	Changes in the volume or structure of the population, relocation
Movement	Changes in the potential for moving around; public, private and non-motorized transport
Services	Supply and availability of services
Economy	Changes in employment and business opportunities
Nature	Fewer recreation opportunities, considerable loss of natural environment sites
Emissions	Increased adverse effects from emissions; noise, emissions into the air and discharges into the water
Anticipatory fears	Anticipatory fears arise with regard to health, living conditions, etc.
Conflicts	The project causes conflicts among the population in the area of impact

The assessment of how significant social impacts are can be based on the size of the affected area, the size of the affected population, the accumulation and multiplication of the impacts, how probable the impacts are and how long they are likely to last. Health impacts can be similarly assessed on the basis of their nature, the size of the affected population, the special groups exposed, the intensity and duration of the impact, and impact variations. All these comparisons should be made against the benchmark, i.e. the situation before the project is implemented.

There are several problems in the social impact assessment, such as which social impacts need to be investigated and monitored and which ones do not. At the personal level, the problems can be seen from a very narrow viewpoint. For example, unemployment has not been considered a huge problem for the individual because the 'safety net' of society is considered comprehensive enough. At the communal level, however (e.g. a municipality), unemployment is a problem of a completely different magnitude.

4.1.3 EIA delimitation and weighting of impacts

The area considered in the EIA must be delimited so as to take into account all the major impacts. Factors in delimitation include:

- operating area of the mine (mine site, processing facilities, storage, office, water treatment and disposal areas),
- extent of catchment area,
- surface water and groundwater flows and courses in the area, extent of impact on watercourses,
- dust migration,
- chemical properties of the soil (reactivity, retention capacity, sensitivity to acidification, etc.), and/or
- land use in the vicinity.

Also, the level of detail and the weighting of the various impacts must always be gauged in relation to the environmental values of the surrounding area and the location of the site. Impacts may be of very different importance depending on whether the site is 1) in an area of significant value in terms of natural environment or landscape, 2) near housing, or 3) along a waterway, on a shoreline or in a groundwater basin. Near housing areas, more attention must be paid to the health, comfort and living conditions of people living near the site than if the site is in a remote area. Impacts on the natural environment and the landscape must be assessed in relation to the unique or exceptional nature of the area. The accuracy of assessing the contamination risk for surface waters and groundwater is particularly important along waterways, on shorelines and in groundwater basins (Salminen *et al.* 1999). Table 10 illustrates how the location of the site affects the factors to be considered.

Table 10. Weighting the EIA depending on where the site is located (shaded cells) (Salminen et al. 1999, adapted).

Weighting	Location		
	Exceptional natural environment	**Housing in area**	**Ground-water basin**
Natural environment			
Soil and bedrock			
Landscape			
Groundwater			
Surface water			
Air			
Flora and fauna			
Population and society			
Business and employment			
Recreational use of natural environment			
Health, comfort, living conditions			
Culture, landscape			

4.2. RISK MANAGEMENT AND RISK ASSESSMENT

A ‘risk’ is defined as the possibility of damage. The measurement of a risk involves the probability of a hazardous event occurring and the severity of its consequences. Risks can be grouped, for example, into environmental and safety risks, and financial and social risks. However, currently instead of risk categorization the aim is to achieve a comprehensive risk assessment process that covers all the risks involved in any given business venture. The following, though, is primarily a discussion of environmental and safety risks.

Mine closure is actually a risk management process which goes on throughout the lifecycle of the mine. At all stages, the choices of technology must be made on the basis of a risk assessment which takes the environment, safety and technical properties into account (EC 2004). The risks and risk levels are different in different types of mines. The level and extent of risk assessment required is determined separately for each site. However, a risk survey to identify danger points and to make a preliminary analysis of risk management needs should be performed at all sites. The survey and the risk scenario analysis are used to draw up action plans for hazards and accidents. Also, a management plan must be drawn up for the residuals generated in the operations. The purpose of this plan is to minimize accident risks and emissions and to ensure that the risk level of the site decreases over time.

The assessment of risks related to closure and a risk management plan must be made when the mine is being planned, in connection with the first version of the general risk survey and closure plan. Thereafter, the risk management plan should be updated as necessary. The risk assessment makes it possible to identify the need for closure measures and prioritization of risks, enabling the focusing of closure measures on the management of the significant risks. Also, the comparison of risk management options can be used in selecting the best possible closure options overall. If a risk survey and risk assessment have not been conducted previously, then at the very latest this should be done when the final closure plan is drawn up.

The following sections discuss risk assessment and risk management and their methods at a general level. Finally, an example is given of how risk assessment is applied to mine closure.

4.2.1 Risk assessment implementation

It is recommended that risk assessment will be implemented in stages, as shown in Figure 18, moving, as necessary, from the general to the particular. The process is generally iterative except for the simplest cases. It may happen that during the assessment a need for further studies is noted, and the findings of these new studies may serve to reorient the assessment process or cause a review of its earlier stages. The schematic in Figure 18 is specific to environmental risks, but the principle is applicable to any other type of risk.

In all cases, risk assessment begins with defining the problem, which may include a basic identification of risk factors. Available information on the site is collected for defining the problem, and the preliminary delimitation of the assessment is set (area, time period, which risks are included, etc.). It is useful to draw up a conceptual model in the form of a schematic, a picture or table to support defining the problem. The conceptual model shows the connections from the source of the risk through the pathway to the receptor. Figure 19 contains a simple example of a conceptual model illustrating the exposure of human beings and other life forms to harmful substances from the tailings area.

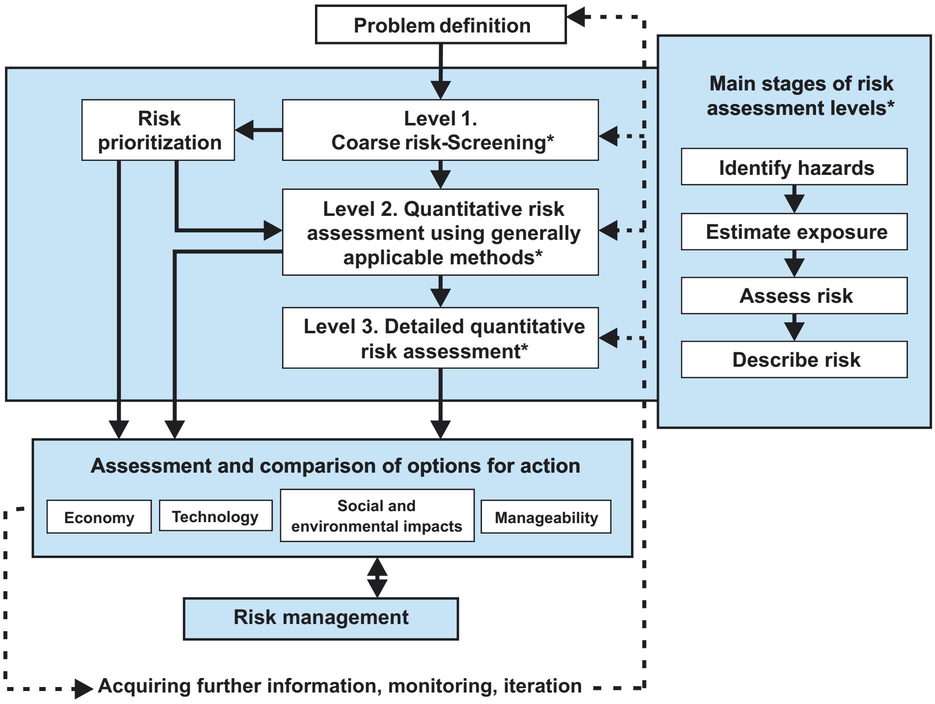


Figure 18. Example of the stages for implementing risk assessment and management process for environmental risks (DETR 2000). The principle is, in the main, applicable to other risks too.

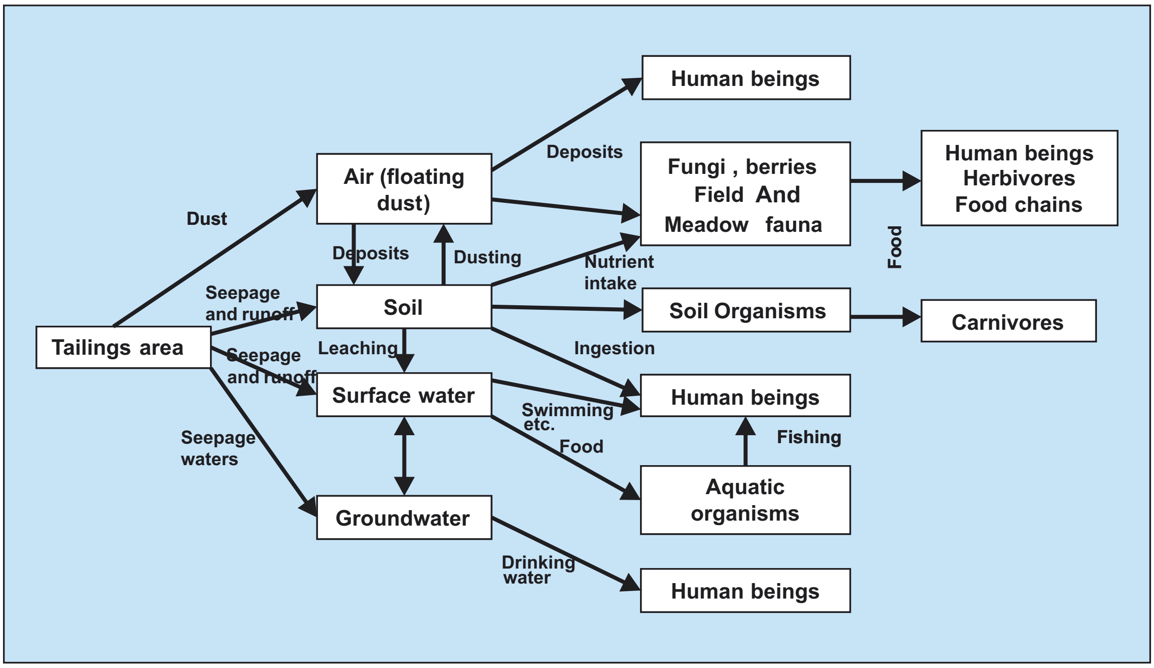


Figure 19. Example of a conceptual model illustrating potential exposure of human beings and the environment to harmful substances from a tailings area (Mroueh et al. 2005a).

Table 11. Matrix for coarse risk classification (Koskensyrjä 2003, modified).

Probability	Severity of consequences				
	Extremely mild	**Mild**	**Moderate**	**Severe**	**Disastrous**
Extremely probable	Moderate risk	Moderate risk	Significant risk	Significant risk	Intolerable risk
Highly probable	Low risk	Moderate risk	Moderate risk	Significant risk	Significant risk
Fairly probable	Low risk	Low risk	Moderate risk	Moderate risk	Significant risk
Improbable	Insignificant risk	Low risk	Low risk	Moderate risk	Moderate risk
Extremely improbable	Insignificant risk	Insignificant risk	Low risk	Low risk	Moderate risk

The levels of the risk assessment process include risk identification, exposure estimation, risk assessment and risk description (Figure 18). At the coarse level, simple and primarily qualitative methods are used, and here the risks are first prioritized. A risk classification is performed, for example, in accordance with Table 11, and a preliminary decision is taken on the need for action (Table 12). This classification can be made, for example, in the form of brainstorming by a team of experts. If substance level data is available, threshold levels for soil, water or air quality can be used as a classification aid.

If it is not possible to estimate the severity of a risk or the need and level of risk management action required through the coarse of risk classification, the risk assessment must be specified using more detailed methods (such as analysis and modelling of consequences). A more detailed assessment is usually required if a risk is considered moderate (Class 3, Table 12) or higher, or if it is difficult to estimate how serious the consequences of a hazardous situation are likely to be because of multiple factors involved.

4.2.2 Risk assessment methods

There are several methods available for risk surveying and coarse risk classification (Table 13). More important than the choice of method is making the assessment systematic and having it performed by persons who have sufficient expertise and a critical, unprejudiced attitude. The most recommendable and general way to assess and classify risks is to assemble an analysis team consisting of people familiar with the site. In the case of mine closure, the team can include experts on technology, environmental matters, dam safety and water management. To make the risk identification process systematic, checklists or flow charts or similar aids can be used. Further information on risk assessment methods can be found at the website of the VTT Technical Research Centre of Finland (VTT 2003), and in the separate working report of the project ‘Environmental Techniques for the Extractive Industries’ (Mroueh *et al.* 2005a).

The assessment conducted using methods listed in Table 13 needs to be specified in more detail as necessary, for example by using modelling, measurement and analysis methods selected on the basis of the site and the situation, or by using site-specific field studies. Figure 20 shows stages in an environmental risk assessment implementation process. Table 14 gives examples of methods used for assessing emissions, exposure and response.

Table 12. Assessing the need for action on the basis of risk classification (Koskensyrjä 2003, modified).

Risk type	Need for action
1. Insignificant	• No action is needed.
2. Low	• Action is not necessarily needed. • Better solutions at no additional cost should be considered. • The situation needs to be monitored to keep the risk under control.
3. Moderate	• Action must be taken to minimize the risk, but this is not urgent. • The cost-efficiency of the action taken must be considered. • If the risk involves damaging consequences, the probability of the risk materializing must be investigated in more detail.
4. Significant	• Action must be taken urgently to minimize the risk. • The activity to which the risk applies must not be started before the risk has been reduced. • If started, the activity can be continued, but everyone involved must be acquainted with the risk and must be prepared to stop the activity as quickly as possible, if required.
5. Intolerable	• Action must be taken urgently to neutralize the risk. • The activity to which the risk applies must not be started, or must be stopped immediately, until the risk has been removed.

Table 13. Examples of methods for risk survey and coarse risk classification (VTT 2003, modified).

Method	Description
Checklists and risk maps	List of possible risk sources or hazards. Can be used as a basis for risk assessment whatever method is used.
Analysis of potential problems	Hazards are identified and classified using a brainstorming-type teamwork effort. Problems are recorded on an idea form circulated in the working group. A checklist or keywords can be used as an aid. This serves as a basis for a rough estimate of the magnitude of the risks and the needs for improving risk management.
Hazard scenario analysis	Hazards and accident factors are sought systematically on the basis of an activity or process model of the site. The site is divided up into functions; at a mine site, this may mean tailings and waste rock facilities, underground tunnels, open pits, wastewater treatment processes, refinery, storage, infrastructure, yards, other land areas, and so on. A separate process diagram is drawn up for each function (cf. the conceptual model) to help chart the potential hazards and accidents. The assessment can then be continued with risk classification and evaluation of risk management actions.
Hazard and operability study (HAZOP)	A method developed particularly for the chemical industry, where the site is divided into functional units and each unit is analyzed separately. A functional unit is a segment of the process where a single chemical or physical event takes place. The purpose of the investigation is to find situations where the functional parameters can deviate from their normal values. The method used is to combine a process parameter with a keyword (none, more, less, partly, opposite, other). This helps find all imaginable changes to the system. Then, the reasons for those systems are found and their consequences evaluated. If the process parameter is, for example, the intake flow of water to the water treatment plant, the following deviations can be identified: no flow; increased flow / increased level of hazardous substance / increased temperature; decreased flow / decreased level of hazardous substance / decreased temperature; change in the composition of water / partially diverted flow; contrary flow; other deviations.
Failure mode and effects analysis (FMEA)	The system to be investigated is divided into sub-systems and these further into their component parts. Then, potential faults in each part are identified and their effects on the sub-system and ultimately on the system as a whole are estimated. The method is detailed and suitable for well-defined technical systems, but it has also been much used in mining abroad.

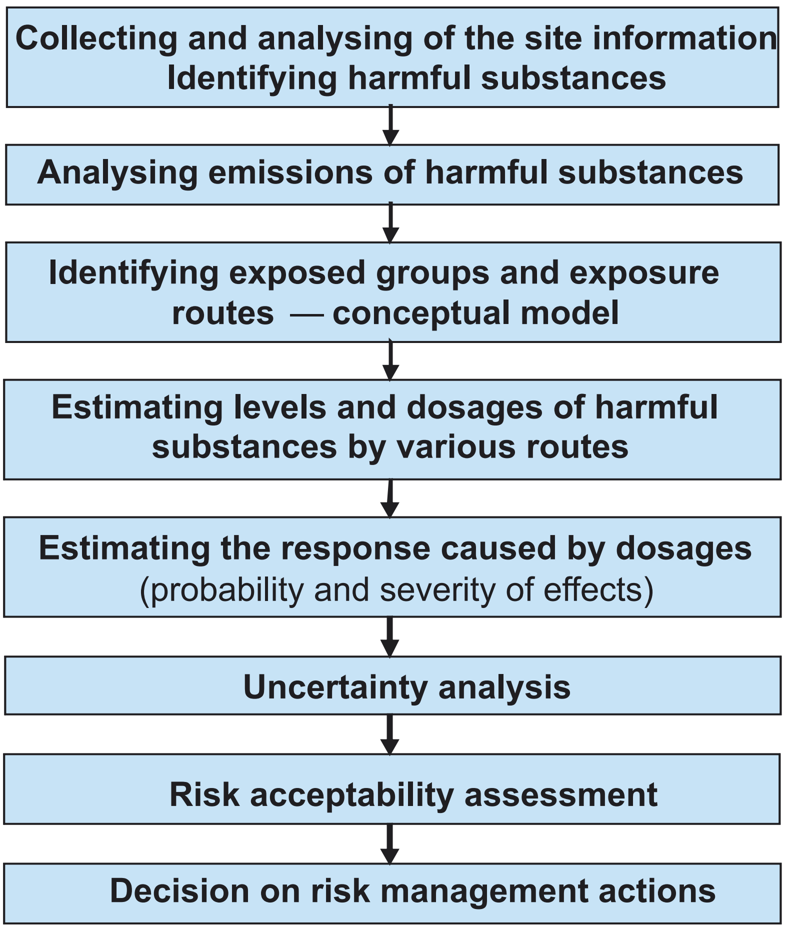


Figure 20. Principal stages of the risk assessment and risk management process for emissions of harmful substances (Mroueh et al. 2005a).

Table 14. Methods suitable for assessing site-specific and situation-specific emissions/loads, exposure and response (Mroueh et al. 2005a).

EMISSION ASSESSMENT	EXPOSURE ASSESSMENT	RESPONSE ASSESSMENT
Measurement and observation methods	**Measurement methods**	**Health studies**
• emission and load measurements	• personal measuring devices	Hazard screening studies
• measurements of properties affecting emissions (e.g. chemical steam pressure, solubility)	• measuring devices for air, water, soil or sediment quality	• molecular structure analysis
• laboratory analyses	• remote sensing methods	• short-term exposure tests
	• biological measurements (chemical residue, bioaccumulation, biodegradation, physiology, indicator species)	
Simulation tests	**Testings**	**Animal testing**
• leaching tests	• laboratory testing	• acute toxicity
• simulation of hazardous situations	• field testing	• chronic toxicity
• simulation of accidents	• scale models	
Statistical methods	**Dosage calculations**	**Human exposure tests**
• sampling methods based on statistical distribution	Dosage calculation models taking into account exposure time, degradation time, accumulation etc.	Epidemiological studies
• probability distributions, regression analysis		Exposure-response models
Modelling methods	**Migration models**	**Pharmacokinetic models**
• fault trees, event trees	• models for transport and transformation of impurities in the air	Ecosystem studies
• process models	• surface water models	
• emission models	• groundwater models	
• models for assessing the functioning of protective structures	• food chain models	
• failure analysis	• multimedia models	
	Exposure pathway models	
	Exposure group assessment	
	• population counts, sensitive population groups, mobility models	

4.2.3 Assessment and comparison of risk management options

The purpose of the assessment of risk management options is to select the best one. The impacts of the technical options available for closure on the risk and the remaining or residual risk are assessed separately for each method, using applicable modelling and consequence analysis alternatives. The residual risk is usually not the only criterion for determining the course of action; other factors that need to be considered include economic factors, the functioning and controllability of technologies, social impacts and the overall environmental impact. Some criteria may have threshold values that cannot be exceeded. Criteria that may limit the range of options available include the funding available, the permissible level of emissions, as well as the maintenance and monitoring requirements.

If there are several options which will all attain the desired target, there are various scoring and weighting procedures available for systematizing the decision-making process. In Multi-Criteria Analysis (MCA), the most important factors for decision-making are chosen as criteria. They are given point scores using a table or a matrix, for example from 1 to 5. Alternatively, the value of each criterion – such as the cost of the option – can be entered in the table. In the simplest case, this table itself is the decision tool. The analysis is usually performed by giving the features of each option a point score on a scale from 0 to 100, the best being 100 and the worst being 0. Then the features are weighted so that the sum of all weighting values is 1, and the point score for each feature is multiplied with the weighting score for that feature. Finally, the point scores are added up, giving the overall score for that option (Table 15).

Table 15. Example of a Multi-Criteria Analysis (DTLR 2001, adapted).

	Residual risks	Social impacts	Costs	Technical functioning and reliability	Maintenance and monitoring requirements	Total
Option 1	69	0	70	40	56	55.85
Option 2	0	100	40	100	100	56.00
Option 3	89	20	0	20	41	45.35
Option 4	51	0	75	20	0	34.10
Option 5	100	100	100	0	86	70.20
Weighting of features	**0.35 (35 %)**	**0.05 (5 %)**	**0.15 (15 %)**	**0.25 (25 %)**	**0.2 (20 %)**	**1.0 (100 %)**

4.2.4 Risk communications

Although a risk can be assessed mathematically as the product of two quantities – the probability of an event and the severity of its consequences – a risk is also always a value issue (Lonka *et al.* 2002). Human values and conception of risks play a significant role in what is perceived as an acceptable risk. A risk is the more frightening the more uncontrollable, disastrous or involuntary it is. The perception of risk is also influenced by how well the risk is known, how reliable the source of data on the risk is and what kind of image the media projects of the risk. Therefore, risk communications, i.e. the conveying of information and results in the risk management process to the parties involved, is an essential part of the risk management process. The level and extent of the communications, and the parties at whom it is aimed, should be determined on a case-by-case basis, preferably when the risk assessment is started. Risk communications are best handled iteratively by assessing the need for action and the action already taken throughout the risk management process while taking experiences into account when planning further action.

4.2.5 Environmental risk assessment in mine closure

The tables in Section 4.1 list factors that may cause risks to human beings or the environment. Risk assessment is carried out in stages as shown in Figure 18 in Section 4.2.1 so that quantitative risk assessment is only undertaken if a decision on risk management cannot be taken on the basis of the coarse risk classification. In some cases, it is enough to demonstrate that the spreading of harmful substances does not have a material effect on the quality of surface water, groundwater or soil. This can be done by comparing the results of dispersion and transport models to site-specific measurements or general environmental quality guideline values. A risk assessment on health risks or ecological risks due to harmful substances is necessary if it has to be demonstrated that elevated levels of such substances at the site do not constitute a risk.

Table 8 in Section 4.1.2 can serve as a preliminary checklist for risk identification. The assessment of the risks involved in mine closure begins when the mine is being planned, because particular attention has to be paid at that point to the control of emissions into the environment. It is particularly important to identify the sources of emissions and the transport pathways, and to use this data to minimize the release of harmful substances into the environment. The following factors should be assessed when the mine is being planned (cf. Table 16):

- formation of acid mine drainage and leaching and other disintegration of harmful metal/non-metal ions or compounds from tailings and waste rock, and the potential migration of water containing harmful substances as a result, and the impact of this on the quality of surface water and groundwater,
- dust (storage dumps, tailings and waste rock facilities) and dust spreading,
- risks related to the use and storage of chemicals, and how to control them, and
- stability issues (dams, open pits) with a view to extreme natural events (floods, storms, etc.).

Impacts on the state of the environment and potential environmental risks are monitored throughout the life-cycle of the mine, and reassessments are made as required. When the final closure plan is drawn up, risk assessments must be either complemented or updated in accordance with the state of the environment at the time preceding the closure; if necessary, the risk assessment process must be launched again, beginning with risk identification. In such a case, this process should include environmental risks caused by changes in the environment and the need to manage them, insofar as this is necessary (cf. Table 8 in Section 4.1.2). Appendix 14 contains an example of a risk identification and classification procedure for mine sites.

The closure plan must include an estimate of the residual risks of the actions proposed in the closure plan, and the development of the risk level over time. The impact of risk management actions on risks must be investigated as part of the planning and selection of actions. If this has already been done, there is also a fairly reliable estimate of residual risks. Whether this is sufficient, can be checked by comparing it with the descriptions of those risk factors, which definitely and possibly require action according to the risk assessment process carried out during closure planning.

Table 16. Environmental risk assessment methods in mining.

Object	Risk assessment
Acid mine drainage formation and metal leaching from tailings and waste rock	• Estimating acid production potential of materials and leachability of harmful substances, static and kinetic tests (see Section 5.4) • Modelling of levels of harmful substances released into the environment with runoff and seepage from the tailings and waste rock areas (see Section 5.6) • Investigating the soil properties and hydrogeological properties of the area, and modelling the dispersion and transport of harmful substances
Dust	• Estimating the volume and spreading of dust using emission and deposit measurements and spreading modelling • Monitoring metal levels in environmental samples (soil, moss, fungi, berries, etc.)
Stability issues	• See Section 5.7
Harmful substances in the soil	• Soil studies, comparison with background levels and guideline levels (see Section 5.8) • Estimation of health risks and ecological risks and/or modelling of transport of harmful substances, if levels exceeding guideline levels will be left in the area or if the area is to be converted to a particularly sensitive use
Contaminated surface water and groundwater	• Water quality studies, modelling of dispersion and transport of harmful substances if necessary

5. FIELD STUDIES, ANALYSES AND MODELLING IN PLANNING AND MONITORING OF MINE CLOSURE

When planning for mine closure, it is necessary to be able to draw upon a wide range of information pertaining particularly to environmental indicators and conditions at the site, and the types of materials to be stockpiled during mining or for potential use during rehabilitation processes. It is advisable to commence collecting or generating relevant data, especially for baseline referencing, as early as possible during the mining cycle, preferably before the mine enters production. Information will be progressively updated during mining, along with monitoring of specific processes and parameters in accordance with environmental management reporting requirements.

The following sections provide examples of research methods related to closure planning, or to environmental impact and risk assessment, as well as summarize the overall objectives and applications of these methods. It should be kept in mind that the nature of the investigations and supporting technologies used depends in turn on the detail and scope of information required. It is therefore always desirable to plan the research program carefully according to site-specific circumstances, and to evaluate whether a particular data collection or monitoring program is justifiable in terms of the results and insights gained. Conversely, to obtain a comprehensive understanding of the total mine environment and appropriate risk management strategies, a broad range of investigations are generally required. Moreover, some of the analytical tools used in monitoring and evaluation, such as hydrogeological and geochemical modelling, rely heavily on data obtained through a wide range of investigative techniques.

5.1 RELEVANCE OF STUDYING QUATERNARY DEPOSITS IN RELATION TO MINE CLOSURE

Mapping and characterization of Quaternary deposits at and surrounding the mining concession is essential for several reasons, including assessment of whether suitable materials can be sourced on site for remediation programs (see Section 5.9), and as background information for groundwater flow and transport modelling, should this be required (refer to Section 5.6). Surficial geological studies form an integral part of routine baseline investigations designed to characterize overall site conditions, prior to the commencement of mining (refer to Section 4.1). Such studies, involving systematic mapping of Quaternary deposit profiles down to bedrock over the whole site, are also necessary for determining the most suitable locations for storage of tailings and waste rock.

The Geological Survey of Finland has undertaken surficial geological mapping at scales of either 1:20 000 or 1:50 000. In general, published maps provide a general overview of the nature and distribution of surficial deposits, including proportions of gravel, sands, and clays surrounding the mining concession (Figure 21). During regional mapping, sampling depths are usually no more than one meter, although surveys are supplemented by information from drilling wherever available, thus providing further constraints on depth to bedrock and the thickness and composition of individual stratigraphic units (Haavisto 1983). Characterization of Quaternary deposits is nowadays an accepted and essential part of baseline studies in the mine environment. If detailed information is not already available, provisional interpretations can be made from regional scale maps and aerial photography, or from data obtained during exploration-related drilling programs and any excavation activities undertaken in connection with deposit delineation and feasibility studies. Other earlier observations are in principle valid, as long as they are accurately georeferenced, or can be supplemented by updated information where necessary.

For the purposes of planning for mine closure, it is advisable to compile all observations relating to surficial deposits into a comprehensive database, which can be used in assessing suitability and sufficiency of materials for covering programs, or for numerical hydrological simulations. Ideally, all data entries should include spatial referencing information concerning latitude, longitude and elevation, thicknesses and depths to upper and lower surfaces of principal stratigraphic units, sediment classification in terms of grain size and composition, and depth and degree of fracturing of the underlying bedrock. In addition, the database can include groundwater information and attributes. The elevations of groundwater observation

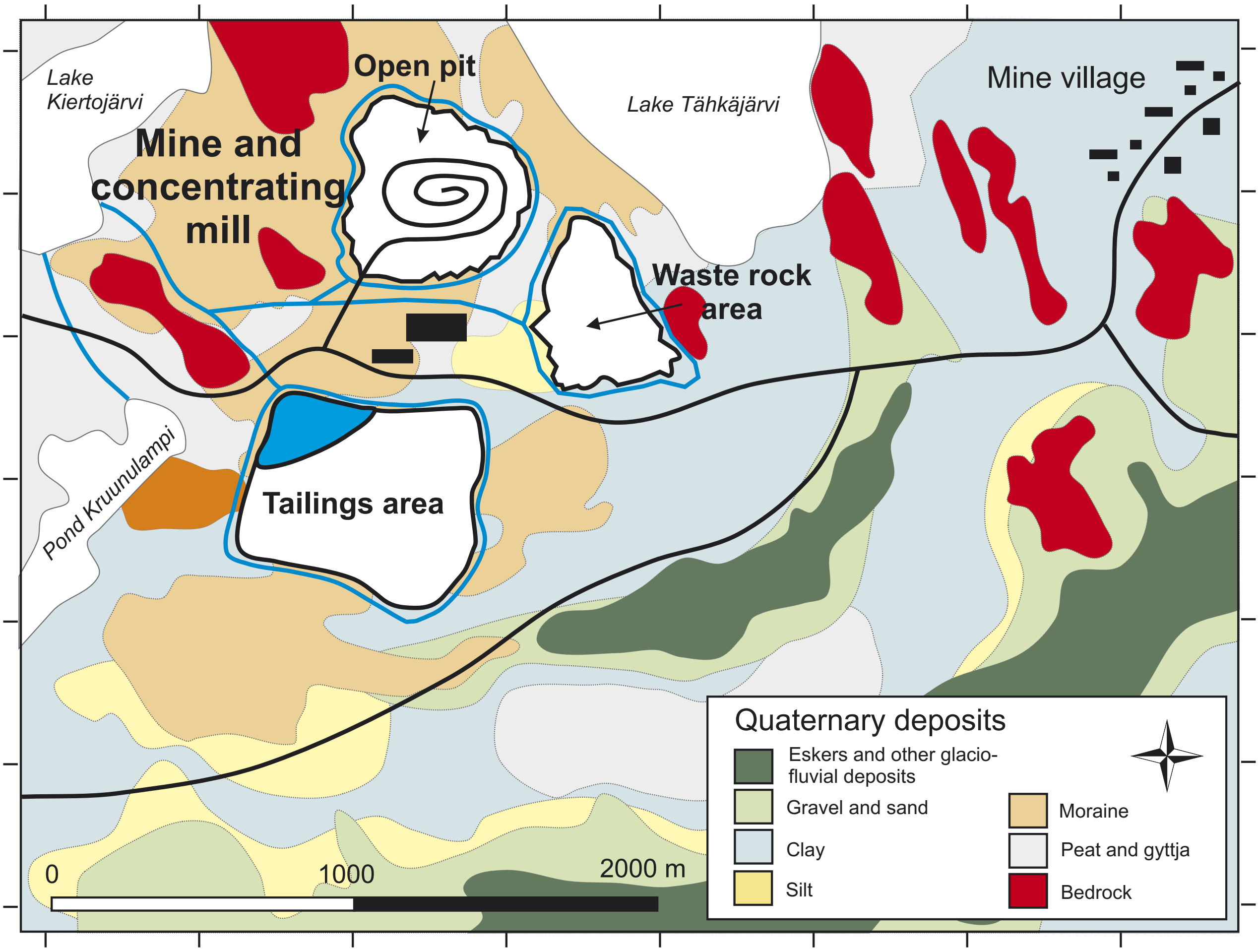


Figure 21. Maps of Quaternary deposits of the mining concession are prepared as a routine aspect of baseline investigations and enable assessment of the availability of materials for use in closure-related remediation. Environmental impact and risk assessment also requires understanding of the properties and distribution of surficial materials.

and monitoring wells should be surveyed with levelling techniques or tachymetry, or to centimetre accuracy using differential GPS, to ensure that fluctuations in the water table can be measured precisely, for example for the potential subsequent use in groundwater modelling. Standard GPS precision should, nevertheless, generally be sufficient for horizontal coordinates of monitoring wells.

In the absence of systematic information on surficial materials, specific surveys may be undertaken to establish 3-dimensional subsurface geometry. Excavation of test pits is an effective and relatively cheap technique for determining the character and structure of Quaternary deposits, albeit to a maximum depth of around 5 meters. This approach also reveals more comprehensive information on sediment structure than does drilling. Nevertheless, the latter method, either through direct sampling, or by measuring physical resistance to drilling progress, can be used at greater depths than excavations. Profiles through surficial deposits revealed during mining also provide valuable information, as do results of site surveys beneath tailings impoundments. Sections exposed during overburden stripping prior to mining should be investigated thoroughly, to obtain a comprehensive understanding of sedimentary structures and stratigraphical relationships over as wide an area as possible.

Variations in the bedrock surface can be delineated most effectively if the area is covered by a dense drill hole network. If drilling has been sparser, interpolation can be facilitated by geophysical profiling, in particular gravity and seismic surveys. Geophysical techniques can also be used to delineate distinctive stratigraphic units where depths are otherwise only constrained by drill hole intersections. Ground penetrating radar (GPR) is a relatively cost-effective and particularly useful technique for characterizing internal features within Quaternary deposits. The method is especially suited to coarse-grained materials (Hänninen 1991). As the proportion of finer grained material increases, the strength of the signal is progressively dampened, such that in clay-dominated strata the technique is no longer of practical value. In addition to ground penetrating radar investigations, electrical resistivity surveys can be used to identify subsurface features, such as silty or clay-rich units confining perched groundwater within coarser grained and sorted material in eskers and end-moraines (see for example Valjus *et al.* 2004).

5.2 INVESTIGATION OF SURFACE- AND GROUNDWATERS

Characterization of surface- and groundwaters in relation to mine closure is necessary for determination and evaluation of environmental baseline parameters (baseline study), and for the environmental impact assessment (EIA) and environmental permit applications procedures (refer to Section 4.1). Investigation is also necessary to determine the source and extent of possible contamination and as the basis for hydrological or reactive chemical transport modelling (refer to Section 5.6), or in deciding the most appropriate closure strategies. Monitoring the potential effect of mining operations on water quality and abundance is also an essential statutory requirement under environmental legislation; the results of monitoring can also be used to determine the need for further follow-up investigations or remedial actions.

The potential effect of the mine site on surface waters can be examined directly through analysis of water quality, or by using biological indicators (including plankton, benthic fauna, fish populations) and also by studying sediments. Effects on groundwater are usually determined by monitoring changes in composition and flow or yield. The purpose of this section is principally to describe procedures for water quality assessment, whereas investigations of aquatic sediments are dealt with in detail in Section 5.3 and hydrological modelling in Section 5.6.

The potential effect of mining activities on water catchments downstream from the mine is usually evaluated before mining commences, prior to application for an environmental permit (Environmental Protection Act 86/2000, Section 11). During mine closure, it is essential to define and investigate the impact on water quality or flow, which can be attributed to mining activities, both downstream from the mine site as well as at the site itself, as a routine aspect of present-state site study. This is especially important if this data is not otherwise obtained during mining within the mandatory monitoring programs or other investigations, or if significant groundwater resources are present in proximity to the mine. In addition to routine monitoring of surface water downstream from outflow and discharge sites, it is advisable also to study the surface water quality at the mine site to identify which, if any mining activities have the potential for adversely affecting water quality or yield. As a basis for groundwater quality assessment it is firstly necessary to accurately define subsurface geometry and hydraulic parameters (refer to Section 5.6 and Suomen Vesiyhdistys 2005).

Evaluation of the potential influence on the quality of both the surrounding watershed and groundwater aquifers is primarily based on comparisons with reference background data obtained during baseline studies or during the initial environmental assessment phase. In many countries, national datasets for monitoring the quality of surface- and groundwaters are available (e.g. Backman *et al.* 1999, Soveri *et al.* 2001), and in some cases coverage extends to comprehensive national geochemical databases and maps (e.g. Lahermo *et al.* 1990, Lahermo *et al.* 1996, Korkka-Niemi 2001, Lahermo *et al.* 2002, Salminen *et al.* 2004, Tenhola *et al.* 2004), all of which can be used for referencing and comparison against local studies of background concentrations. During evaluation of the potential effect on the water quality, background concentrations for surface waters are further defined by sampling one or more locations upstream of the point or points at which mine waters enter the watershed, and also from surface waters flowing into the mine area, if deemed necessary. In practice, mine waters may be released into the surrounding watershed from many separate discharge points, in which case it is advisable to study water quality upstream and downstream from each discharge site in order to identify the influences of different types of waters derived from diverse mining-related processes. Groundwater background compositions ought to be determined from samples collected upstream from the mine site with respect to the groundwater flow patterns.

In order to establish the potential effect of mining activities and to delineate the likely areal extent of such effects, water quality is studied below the discharge points where mine waters enter the surrounding watershed; the number of observations sites required is determined according to site-specific considerations. It is also recommended that the quality of mine waters should be studied prior to their release, as well as the composition of any surface waters collected at or flowing through the mine area. Variations in the quality of groundwaters and fluctuations in the water table can be assessed firstly by examining any (private) wells or natural springs in proximity to the mine, or from potential observation wells and boreholes. If there are insufficient observation sites available, or where evidence of contamination by mine waters is suspected, the observation well network should be supplemented, to obtain adequate data from the site, or to precisely delineate the area potentially subject to mine influence. The placement of observation wells and choice of materials for well casings will again vary on circumstances and conditions at individual mines (refer to Section 6.1 and Hatakka & Heikkinen 2005).

Water quality is determined from a combination of field measurements and laboratory analysis. Parameters routinely measured in the field include pH, electrical conductivity and temperature; other properties amenable to field-based analysis are dissolved oxygen concentration and saturation, alkalinity and redox potential, and also groundwater levels. The latter measurements allow potentiometric surfaces and hence groundwater flow patterns to be defined, which in turn provides the basis for evaluating whether dewatering of the mine workings has any appreciable effect on the ambient water table or groundwater supply. For an accurate assessment of the potential influence of mining operations, it is important to determine both cations and anions, since it is not only absolute metal ion abundance that is critical to water quality, but also the presence or absence of sulphate, chloride and nitrate species. Cation-anion analysis also enables evaluation of changes in water quality according to the distribution of major ions, and thus allows the detection of relatively small changes in water chemistry due to mining activities (Figure 22, see also Heikkinen *et al.* 2002, Heikkinen *et al.* 2005). In addition to inorganic pollutants, the potential environmental effect of organic contaminants, either through routine mining activities or as a result of accidental contamination, should be established.

The range of variables to be analyzed varies on an individual basis, but it is desirable to comprehensively characterize waters originating within the mine area in terms of total chemical composition, at least once, in order to test for the presence of potential contaminants. Cation abundances are usually measured by means of either a standard ICP-AES/MS or AAS techniques, whereas anions are determined using ion chromatography. Organic contaminants are generally determined with gas- or liquid chromatographic methods. Sampling and analytical procedures are described more fully in a separate report produced for the TEKES project 'Environmental Techniques for the Extractive Industries' (Hatakka & Heikkinen 2005). If analytical results are to be used to infer annual mine-induced discharge and loading of waters downstream from the mine, it is necessary to measure flow rates in conjunction with sampling, for example with specifically installed V-notch weir or some other form of current velocity meter. In this case it is advisable to take repeated measurements several times a year, in order to quantify potential seasonal variations.

It is also standard practice to include an assessment of seepage water distribution and quality in the present-state study of mining activities (Figure 23). The main purpose of this is to identify active and po-

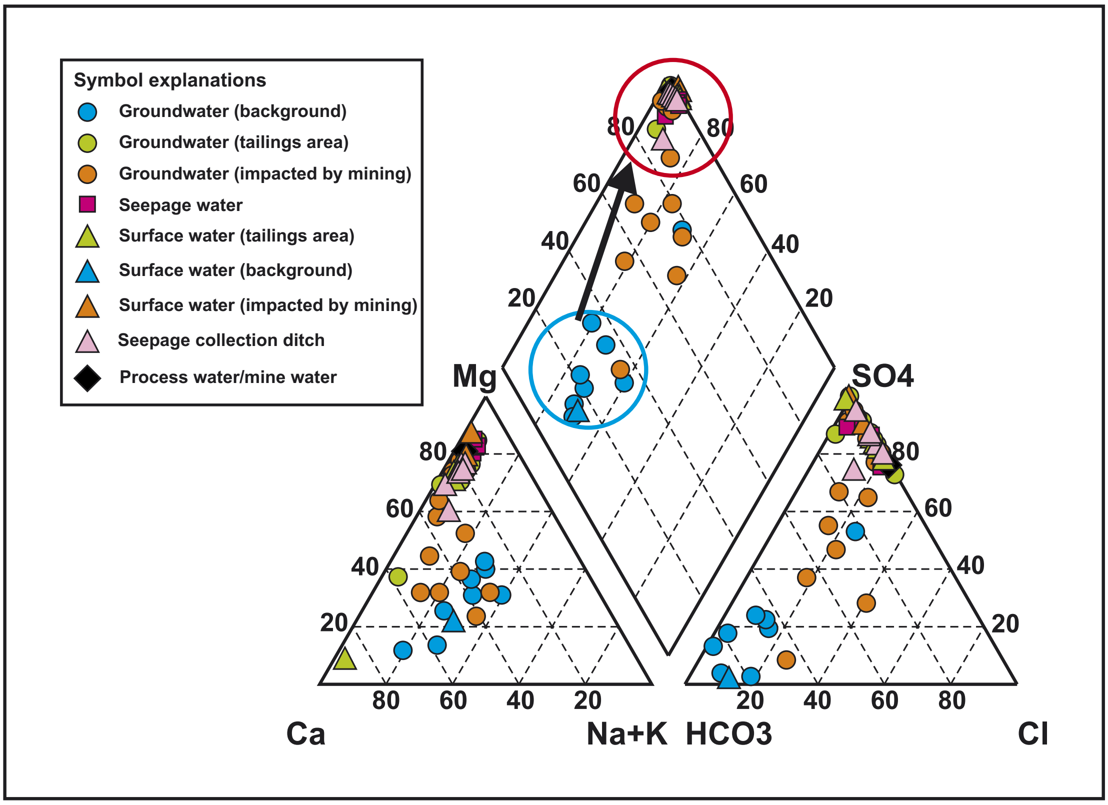


Figure 22. Interaction of mine water discharge from sulphide-bearing tailings or waste rock with the surrounding surface waters or groundwater can be detected by changes in water quality, for example by changes in proportions of major ionic components. In the example shown here, discharge waters from tailings area are enriched in Mg-SO_4 ions, contrasting with the Ca-HCO_3 dominated compositions of ambient waters in the surrounding watershed. Mixing of mine waters with both surface waters and groundwater is indicated by a shift towards higher Mg-SO_4 concentrations (Heikkinen et al. 2002, Heikkinen et al. 2005).

a) b)

Figure 23. Surveys of the distribution and composition of seepage water are aimed at documenting current and potential discharge sites from tailings and waste rock areas to assist in closure planning and ongoing site monitoring. Seepage water discharge under acidic conditions can precipitate iron-, aluminium and/or manganese hydroxides or oxyhydroxides on grain surfaces, which are discernible as reddish (a), yellowish or whitish (b) coatings and aggregates.

tential surface discharge points from tailings and waste rock areas and on the basis of water flow and quality measurements, to determine whether a specific water treatment program, or modifications to site remediation plans are warranted (see for example Räisänen *et al.* 2003, Heikkinen *et al.* 2004). Seepage water surveys involve measuring pH and electrical conductivities of all waters flowing into and out of drainage systems surrounding tailings impoundments, and documenting in particular evidence for accumulation of secondary precipitates within the bottom of the drainage channels. Survey results are then used as the basis for selecting appropriate sites for sampling of both seepage water and surface water. Precipitates within drainage system, such as iron-, manganese- and aluminium hydroxides and oxyhydroxides, may also be sampled and analyzed, in terms of their mineralogy as well as chemical compositions; such precipitates can in fact adsorb significant amounts of potentially hazardous metals and anions from surface waters.

5.3 APPLICATIONS OF SEDIMENTARY STUDIES

Mining and related processing and enrichment are commonly responsible for degradation of surficial waters in the surrounding environment. Analysis of sediments deposited in the sea or lakes, rivers and streams can provide a record of contamination and its effects on aquatic ecosystems, not only in terms of lateral extent, but also through time. Progressive accumulation of sediment within discrete basin depocenters also tends to smooth out the effects of local spatial and temporal fluctuations, thus providing a proxy for composition averaged over time, which is ideal for long-term monitoring after the mine closure. Moreover, analysis of the sedimentary record is one of the few ways of establishing background environmental conditions prior to the commencement of mining, which is of particular value if no pre-mining environmental studies are available for the area.

Investigations of sediments over a relatively broad area, analyzing surficial layers in particular for contaminant abundances, is an effective way of delineating the extent of mine influence, of identifying the most significant contaminant species and potentially for determining the relative importance of various transport mechanisms and pathways (Figure 24). Information pertaining to element and contaminant abundances in sediments falls into the category of geochemical characterization, within the overall context of mine closure planning, and can be used for example, in risk assessment. By virtue of their proximity to an ore body, surficial deposits and bedrock at the mine site typically display anomalous geochemical characteristics; it is therefore recommended that comprehensive surveys be undertaken to accurately define natural background abundances in the vicinity of the mine. When delineating the area potentially affected by mining activity it is also necessary to consider the proportion of organic matter and fine-grained minerals, for these tend to be more efficient at sequestering contaminants than coarser sediment fractions. The use of normalization procedures is therefore recommended to compensate for the effect of grain size and organic matter on apparent contaminant abundances (see for example Siiro & Kohonen 2003). The extent of the area subject to mine influence can also be delineated by systematically measuring abundances of an element which is not enriched at the mine, and using this as a baseline indicator (Rae & Parker 1996).

In exceptional circumstances, the contaminant levels in sediments may be so high that the sediment itself constitutes an ecological or health risk, requiring implementation of a specific mitigation strategy. Evaluation of the potential risk from elevated contaminant levels in sediments is based either on formally defined general guideline concentrations, or the results of specific risk analysis. Target values for element abundances in sediments may also be assigned on the basis of background abundances determined for sediments deposited prior to the commencement of mining within a natural, preferably undisturbed ecosystem. For example, quality control parameters for dredged materials in Finland are based on mean element abundances in Finnish coastal sediments, and they can be adjusted using local background abundances at the mine site. (Ympäristöministeriö 2004).

According to the European Water Framework Directive (European Parliament and Council WFD 2000/60/EC) attainment of acceptable water quality is subject to the condition that physical and chemical environmental characteristics do not have any adverse effect on aquatic biological processes, as measured by specific quality and performance criteria. Neither should the concentrations of any individual contaminant exceed normative values as defined by any of the relevant member states (European Parliament and Council 2000). In practice this means that contaminant levels should be low enough that there is no perceptible functional disruption to ambient ecosystems. However, if contaminant abundances are so high as to require remedial measures, further sediment investigations will be required during the planning process, for example in delineating lateral extent and depth of material that needs to be relocated and processed. More detailed laboratory investigations may be used to assess the potential behaviour, such as solubility and mobility,

Figure 24. The extent to which mining activities influence water quality in streams and lakes subject to mine water discharge can be evaluated by analysis of contaminant abundances in recent sediments. Use of a Limnos sampler enables retrieval of undisturbed samples.

Figure 25. Portable drilling equipment transported by snowmobile is capable of retrieving sediment cores up to several meters in length, enabling assessment of the effect of mining activities on sediment and pore water composition, and characterization of environmental parameters prior to mining.

of particular contaminants in sediments in response to different remediation techniques; results of these studies are then used in defining the appropriate rehabilitation measures and associated risk assessment.

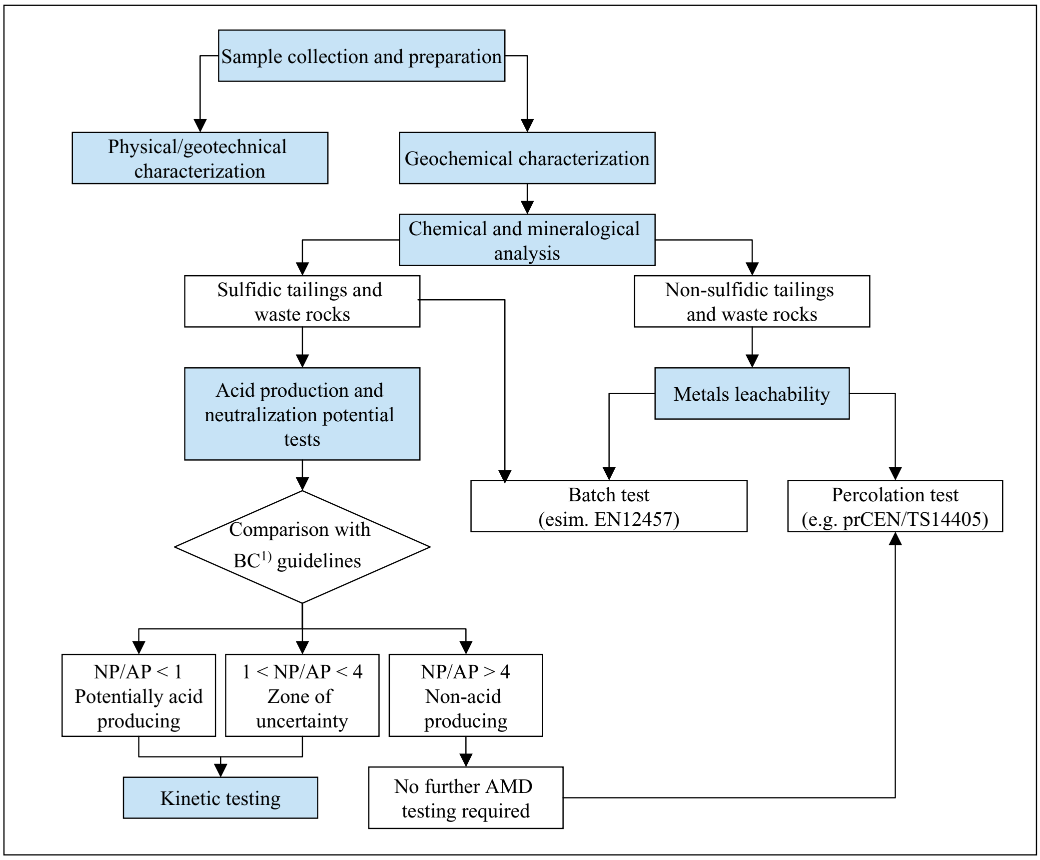
Systematic measurement of variations in sediment character with depth can be used to provide a proxy for water quality before, during and after mining (Figure 25). In the simplest case, variations in the abundances of contaminants with depth correlate directly with the history of emissions and discharge during the course of mining (for example Couillard *et al.* 2004). However, changes in depositional rate and conditions and in sediment properties, combined with the possibility of post-depositional mobility, may all affect measured concentrations and need to be taken into consideration. Nevertheless, it is usually possible, through normalization of various parameters, to follow the gradual decline of contaminant concentrations in surface sediments and to compare the abundances to the original concentrations. Such top sediment surveys may be based on relative sparse sampling and can readily be incorporated into the post-closure monitoring program.

The European Water Framework Directive (European Parliament and Commission WFD 2000/60/EC) places increasing emphasis upon the use of biological indicators in defining criteria for water quality. Analysis of sedimentary samples is also an effective way of performing comparative studies of water quality and evolution over time, providing information on many of the variables specified by the Water Framework Directive (see for example Kauppila 2006, Salonen *et al.* 2006). Biological analysis of sediments provides an additional possibility for constraining the range of variation in certain water parameters, such as pH, by calibrating results against specifically defined empirical models (see for example Smol 2002). If changes in biological indicators show a demonstrably positive correlation with mine-related environmental loading, or other environmental monitoring criteria, it is then possible to establish, at least statistically, which specific environmental factors have the strongest impact on local biological communities. The results of sedimentary studies may thus be used to help characterize the pre-mining status and target conditions for the local environment with respect to biological criteria, as well as in risk assessment and evaluation of the environmental impacts of mining, which are an integral part of mine closure planning. Furthermore, inference models based on biological remains in sediments may be used to reconstruct chemical baseline conditions and temporal changes in the chemical quality of local surface water bodies.

5.4 ANALYTICAL TECHNIQUES FOR ENVIRONMENTAL ASSESSMENT OF MINE TAILINGS AND WASTE ROCK

Assessment of tailings and waste rock from the perspective of their interaction with the surrounding environment requires determination of mineralogical and chemical attributes, together with an understanding of their likely behaviour in terms of acid production potential and leaching of potential contaminants. The BAT reference document on management of tailings and waste rock in mining activities (EC 2004) specifically recommends thorough characterization of the potential behaviour of tailings and waste rock over the short, medium and longer term, preferably prior to the mine entering the production phase, to allow assessment of options for storage and use during mining, and for designing closure strategies. A central focus of the environmental assessment of tailings and waste rocks, especially with respect to sulphide ores, is to ascertain their acid production potential. When tailings or waste rocks containing sulphide minerals interact with oxygen or oxygenated waters, they are subject to oxidation, which in turn generates acidification, resulting in reactions that release, amongst other species, sulphates and metallic ions. The potential for generation of acid mine drainage is ultimately dependent on the overall equilibrium between competing acid-producing and alkaline reactions. Any material containing sulphide minerals, such as pyrite (FeS_2) or pyrrhotite ($Fe_{1-x}S$), is acid producing. However, the formation of acidic mine waters, or as the phenomenon is more commonly known, acid rock drainage (ARD) or acid mine drainage (AMD), occurs only when there are insufficient alkaline materials, such as carbonates, available for neutralizing acidic solutions. Chemical reactions relevant to the oxidation of sulphide minerals are shown in Appendix 9.

The characterization of tailings and waste rock commences with geochemical and mineralogical analysis, which form the basis for planning further investigations. The flow diagram in Figure 26 outlines a general scheme for investigating material properties of tailings and waste rock relevant to environmental assessment. In the following sections, techniques for determination of chemical and mineralogical attributes, and solubility experiments, are described in more detail.



[1)] Price 1997, BC = British Columbia, Canada

Figure 26. Example of characterization procedure for tailings and waste rock (modified after EC 2004).

5.4.1 Mineralogical and geochemical characterization of tailings and waste rock

Comprehensive characterization of the mineralogy and chemical composition of tailings and waste rock is essentials in assessing and anticipating their long-term interaction with the surrounding environment. This is, amongst other reasons, because the acid production potential of tailings and waste rocks depends upon the balance between acid-producing and acid-neutralizing reactions, which is in turn largely a function of the relative proportions of different mineral species. Evaluation of long-term behaviour should be an integral aspect of designing mine closure strategies, already initiated at commencement of mining activities. During the mining process, it is further more advisable to routinely investigate the degree of weathering of the mineral grains in tailings and waste rocks, in order to decide, for example, whether covering is necessary or not (Figure 27). The mineralogical and chemical composition of tailings and waste rock is also required to determine the range of available options for subsequent use, in terms of their environmental or geotechnical suitability.

Tailings and waste rock composition is ultimately related to the nature of the deposit being mined, and thus varies accordingly. Significant mineralogical and chemical parameters with respect to mine closure processes include sensitivity to weathering, total concentrations and speciation or mode of occurrence of contaminants, as well as acid production and neutralization potential. Susceptibility to weathering is determined in large measure by grain shape and reactive surface area as well as crystallographic properties and, therefore, varies widely between different mineral species. The occurrence of metals and metalloids considered potentially hazardous to health or the environment is primarily a function of the mineralogical composition of various mining by-products. Nevertheless, tailings may also sometimes contain toxic residue from the concentration process. However, the way in which the toxic material is bound to the tailings minerals is ultimately the decisive factor in relation to environmental risk and bioavailability.

Determination of the range of mineral species present in tailings and waste rock is usually performed by microscopic examination of thin sections or using X-ray diffraction (XRD) studies. Mineralogical investigations include identification of mineral species and their respective abundances and an assessment of the relative

a) b)

Figure 27. The present-state environmental assessment includes investigation of chemical weathering of mineral grains in tailings deposits, in order to evaluate the need for covering procedures. Tailings samples are collected for analysis from excavated test pits (as shown here) or by drilling profiles through the tailings into the underlying substrate. Tailings deposits exposed here show the effects of oxidation of sulphides, especially within the uppermost 20 cm of the profile.

a) b)

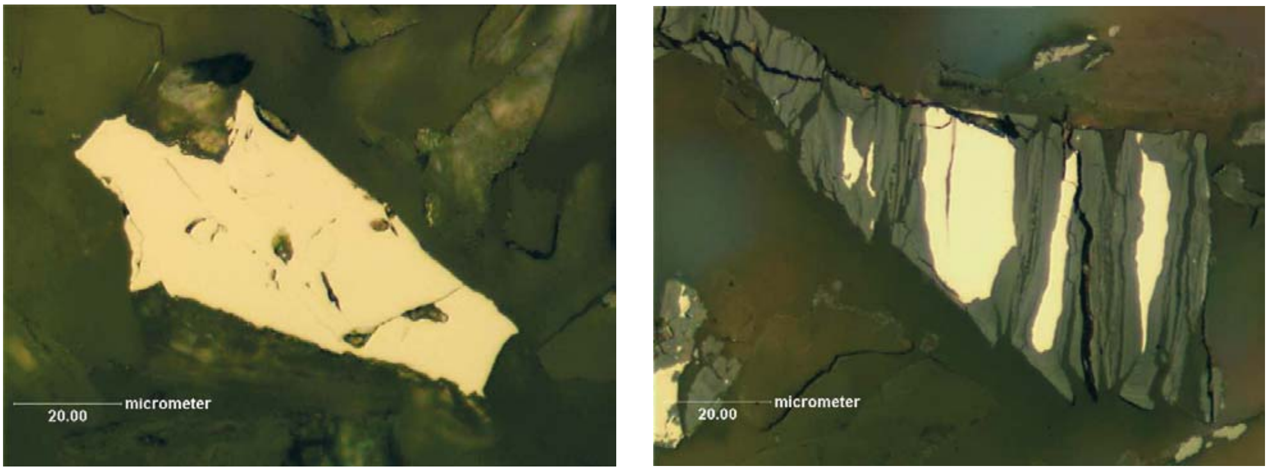


Figure 28. Sulphide minerals within tailings tend to oxidize when exposed to the atmosphere and water. Mineralogical investigations are used to determine the nature and proportion of sulphide minerals and degree of weathering. Photomicrographic images show a) unweathered and b) strongly weathered pyrrhotite grain in tailings material.

degree of weathering of mineral grains (Figure 28). Modal mineral abundances are usually estimated from thin section by microscopic point-counting techniques or from semi-quantitative analysis of peak height in XRD charts. Relative proportions of mineral species can also be determined with image analysis software, using either visible-light or electron microscopy. Microscopic investigations also enable more detailed evaluation of tailings material in terms of their suitability for other applications, through characterization of properties such as grain size distribution, grain morphology and the nature of grain boundary interfaces. Electron microscopy and microanalytical techniques can be used to determine the trace element composition of individual grains or to investigate the weathering of sulphide minerals. The presence and composition of iron, manganese and aluminium compounds precipitated as a result of oxidation of sulphide minerals can be established using XRD and infrared (IR) techniques.

Bulk chemical composition of tailings and waste rock is usually analysed by either X-ray fluorescence (XRF) or by total leach (perchloric hydrofluoric acid digestion) combined with ICP-AES/MS. Total sulphur content is typically determined separately, for example by means of a Leco analyzer. Normative mineral abundances can also be calculated from the bulk chemical compositions (see for example Paktunc 1998, Heikkinen 2005).

The leachability and dissolution of contaminants from tailings and waste rock can be studied with a range of selective extraction techniques or by conducting controlled leaching experiments (refer to Section 5.4.2). The purpose of selective extraction procedure is to ascertain the relative proportions of contaminants structurally bound within mineral lattices, compared to that loosely adsorbed on grain surfaces, and thereby estimate the potential for contaminant leaching under changing environmental conditions. Specific techniques in routine use for analysis of mine tailings and waste rock material include dilute saline dissolution ($BaCl_2$ and NH_4Cl extractions), ammonium acetate- and oxalate leaches and acid digestion (hot *aqua regia*, perchloric acid / hydrochloric acid / nitric acid) methods (see for example Hall *et al.* 1996, Dold 2001). Examples of the geochemical fractions simulated with these extractions are presented in Table 17. Metal concentrations are determined from solution using ICP-AES/MS techniques, while anionic concentrations are measured with ion chromatography. Comparison of results after total leaching and strong acid (perchloric acid / hydrochloric acid / nitric acid) digestion allows a so-called residual fraction to be defined, which represents material effectively bound to weakly soluble silicate minerals.

According to BAT reference document on management of mine tailings and waste rocks (EC 2004), it is recommended that materials that contain sulphide minerals are analyzed with respect to both acid production potential and neutralization capacity (refer also to Section 5.4.2). Acid production potential is generally deduced from total sulphur content, or from the amount of sulphur present in sulphide minerals. Neutralization potential can be determined either directly from laboratory measurements or calculated from mineralogical composition data (refer to Section 5.4.2). The latter approach may be variously based on the proportion of carbonate carbon in the material, the total abundance of carbonate minerals, or the proportion of minerals with neutralizing capacity. For the purposes of calculation, carbonate carbon abundances can be determined by wet chemical or combustion-based carbon analysis.

Table 17. Selective extractions in routine use for analysis of various geochemical fractions in mine tailings and waste rock.

Extraction method	Geochemical fraction
Diluted salt extraction	Physically adsorbed, easily leachable, bioavailable fraction
Ammonium acetate extraction	Chemically adsorbed, exchangeable fraction. Dissolves carbonates and partly also phases bound to non-crystalline oxyhydroxide precipitates.
Oxalate extraction	Phases bound to non-crystalline and crystalline secondary precipitates.
Perchloric acid / hydrochloric acid / nitric acid extraction	Phases bound to sulphide minerals.

5.4.2 Acid-base accounting and leaching procedures

Numerous methods are available for characterization of environmentally significant properties of tailings and waste rock, some of which are outlined in Table 18. Each of these methods can be used to provide a prior assessment of anticipated material properties and behaviour, which may be used for example, in mine design for determining the optimal disposal of tailings or waste rock, so as to minimize environmental impact and other risks. Although a number of diverse methods have been developed, there is considerable disparity amongst results. All the techniques listed in Table 18 are, however, either standard approved procedures, or have already been applied and tested in Finland (Kaartinen & Wahlström 2005). Information obtained from some selected methods is described further below to give an indication of the hierarchy of relationships between the various approaches and methods available for assessing material behaviour of tailings and waste rock. The hierarchy of characterization of tailings and waste rock as described in the EC BAT reference document (EC 2004) is also illustrated in Figure 26.

Table 18. Available methods for the assessment of environmental properties of tailings and waste rock.

Method	Principle	Objective	Notes
Determination of neutralization potential (NP)	Digestion of finely ground sample with strong acid, determination of acid consumption	Evaluation of the amount of neutralizing minerals in a sample	• easy to perform • quick tests / determinations • allows a large number of samples to be tested in a short time • waste rock samples have to be crushed prior to testing
Determination of acid production potential (AP)	Calculation on a basis of total sulphur or sulphide-sulphur in a sample	Evaluation of acid generating capacity of a sample	• total-S may overestimate acid production potential • European standard is under development
Humidity cell test (ASTM 5744-96)	Dry/moist air is blown through sample bed in cycles, weekly flushing of sample with water, flushing water is analyzed	Prediction of the effect of weathering on leachate quality, verifying the results from NP-/AP-determinations	• long duration (minimum of 20 weeks) • laborious • waste rock samples have to be crushed prior to testing • troublesome for materials with low air/water permeability
Percolation test (prCEN/TS 14405)	Water is pumped through sample bed in a cylindrical column, water percolating the column is analyzed	Simulation of leaching as a function of time with no changes in material properties caused by atmospheric oxidation taking place during testing	• duration from three weeks to a month • waste rock samples have to be crushed prior to testing • water saturated conditions
pH-dependence tests (prCEN/TS 14429, prCEN/TS 14997)	Mixture of solid sample and water is kept on a desired pH-level either with initial or continuous acid/base addition. After the test the mixture is filtrated and filtrate is analyzed.	Influence of pH on leaching with no changes in material properties caused by atmospheric oxidation taking place during testing, buffering capacity	• short tests (48 h) • waste rock samples have to be crushed prior to testing
Lysimeter tests	Large scale columns, usually real precipitation	Simulation of field surroundings	• long duration (even years) • No standard procedures

Determination of neutralization potential (NP) and acid production potential (AP) – acid base accounting

The main reason for determining the neutralization- and acid production potential of tailings and waste rock is to obtain information on the potential for generation of acid mine drainage. A rough indication of neutralization potential can be obtained in the laboratory by measuring the capacity of a crushed sample to neutralize a strong acidic solution. An estimation of neutralization potential can also be calculated indirectly by various means from detailed mineralogical and chemical data (refer to Section 5.4.1 and Kumpulainen & Heikkinen 2004, Heikkinen 2005). Acid production potential (AP) is usually calculated from total sulphur or the proportion of sulfidic sulphur. A European standard for assessing the net acid production potential in sulfidic waste is being developed under the European Committee for Standardization (CEN) TC 292.

The likelihood of generating acid mine drainage is generally estimated by comparison between the neutralization potential and acid production potential, expressed either as the difference between the two values, which is known as the net neutralization potential (NNP) or, alternatively, as the ratio between NP and AP, defined as the neutralization potential ratio (NPR). The potential for generation of acid mine drainage (AMD) can also be deduced from the overall sulphide abundance of the material; Price (1997) for example, concluded that materials containing less than 0.3 % sulphides pose no risk in relation to AMD.

Conversely, materials with negative NNP or with NPR less than unity are considered potentially capable of generating acidic mine waters (Table 19). Specific threshold values for neutralization potential ratio have also been defined (Price 1997), on the basis of which propensity for generating AMD can be assessed; these criteria are also cited in the BAT reference document on mine tailings and waste management (EC 2004).

The values referred to above are not intended to precisely quantify the prevailing NP and AP values at the mine site, nor do they provide any constraints on the amount of time required for production of acidic waters. Similarly, this approach does not address the rates of dissolution of sulphides or minerals with neutralizing buffering capacity. On the basis of these so-called static experiments, it is nevertheless possible to decide whether or not kinetic testing of tailings or waste rock material is required, using methods discussed further in the following section (EC 2004)

Table 19. Proposed threshold values for quantifying the AMD potential of mine tailings and waste rock (Price 1997).

Potential for AMD	NPR (=NP/AP)	Comments
Likely	<1	likely AMD generating unless sulphide minerals are non-reactive
Possible	1-2	possibly AMD generating if neutralizing minerals are insufficiently reactive or is depleted at a faster rate than sulphides
Low	2-4	not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive neutralizing minerals
None	>4	

Leaching tests

The purpose of leaching tests is to determine, under specific testing conditions, the proportion of material susceptible to leaching and to establish whether there is a tendency for leaching to change as a function of time. Standardized laboratory leaching tests in particular, which are usually carried out when assessing disposal options for different materials, should be designed to run over relatively short time periods (refer to Table 18). Laboratory leaching tests commonly deviate from natural conditions in terms of sample characteristics, where for example preparation has required crushing, and in respect of temperature and flow rates; as a consequence, estimates of solubility and contaminant abundance based on laboratory experiments may depart significantly from values obtained by direct measurement of *in situ* tailings or waste rock.

Leaching tests considered here fall under the categories of standard humidity cell (ASTM 5744-96) and percolation tests (prCEN/TS14405). Percolation- or column leaching tests have long been used in measuring leaching properties of mainly inorganic waste and by-products. The EC BAT reference document on tailings and waste management (EC 2004) refers to humidity cell tests as a standard kinetic technique for investigating leaching from tailings and waste rock having AMD potential. Humidity cell tests (ASTM-D5744-96) have been widely applied to investigations of rates of acid production of tailings and waste rock in Canada for example, and are recommended for predicting the likely geochemical behaviour of tailings and waste rock (Price 1997). It is also recommended that leaching tests be undertaken to assess solubility of harmful compounds from tailings and other waste materials lacking in sulphides or with low sulphide abundances (refer to Figure 26 and EC 2004).

For prCEN/TS14405 column leaching tests, the material being investigated remains water-saturated for the duration of the experiment, which means that the effect of atmospheric oxygen on sulphide oxidation cannot be assessed. Therefore, this type of column test does not adequately simulate the progressive dissolution and accumulation of soluble components under conditions where the tailings are not totally saturated and in at least intermittent contact with the atmosphere. Column leaching tests may nevertheless be regarded as appropriate for evaluation of leaching properties of material in waste rock facilities or tailings impoundments constructed in locations that are continually water saturated and where the waste material does not undergo changes with time.

In contrast, material tested in humidity cells is only saturated with water during a brief interval of flushing and rinsing. During the remainder of the experiment, atmospheric contact with the sample material is maintained, to facilitate an accelerated weathering process. The results of humidity cell tests can also be used to estimate the probability of formation of acid mine drainage and in some cases the rates of AMD production, to supplement interpretations based on NP and AP determinations. At the same time, it is possible to assess the effect of acidic conditions on solubility of potentially harmful substances, especially metals. Humidity cell test results can lead to a deeper understanding of the geochemical evolution of mine water and drainage in tailings and waste rock facilities when used in conjunction with geochemical simulations (Kumpulainen 2004). It should be noted however, that the humidity cell test summarized in Table 18 should be run for a minimum period of 20 weeks; for more reliable results, 40 weeks, and in some cases over 60 weeks duration is recommended.

Results from the leaching tests described above provide an indication of the amount of substances leached from a material as a function of cumulative liquid to solid ratios in the surroundings defined by the test procedure. Results obtained are often plotted as cumulative amounts of leached substances (for example mg/kg of sample) or concentrations of substances in the test eluate as a function of cumulative L/S ratio. Where disposal site characteristics, such as precipitation, and thickness and density of the tailings impoundment or waste rock pile are known, the results of the leaching test may be used to quantify rates of leaching over time. Through such scenario testing, it may be possible to constrain the effect of the specific surface area and adsorption capacity of the material on leaching.

Differences in the results of column and humidity cell tests are illustrated by comparison of the two

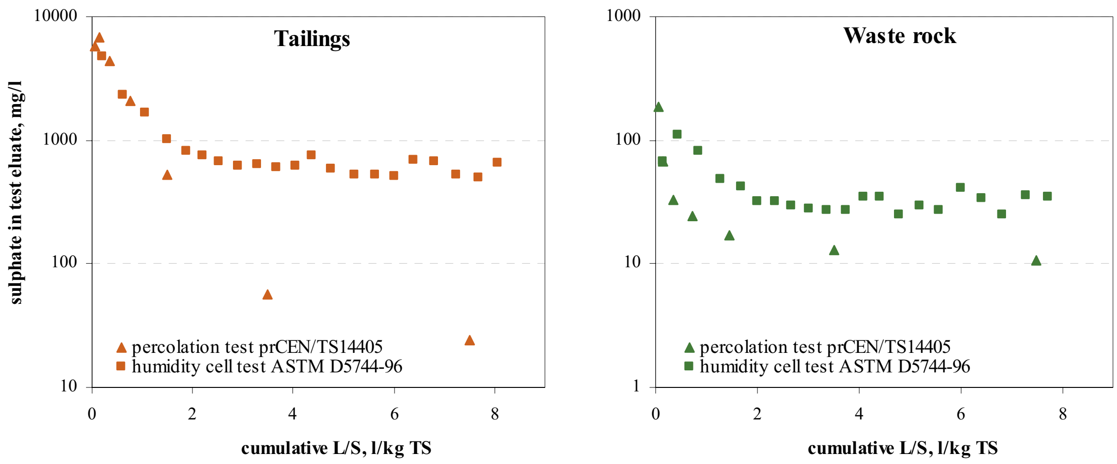


Figure 29. Sulphate concentrations in test eluates of tailings and waste rock in percolation tests and humidity cell tests. Duration of humidity cell tests was 20 weeks (Kaartinen & Wahlström 2005).

methods in Figure 29, which shows observed values for leaching of sulphate from tailings and waste rock samples as a function of cumulative L/S ratios. During the column test, sulphate concentrations in test eluates decrease relatively rapidly to low levels. Sulphate leached in the column test can be regarded as readily soluble sulphate, which is effectively flushed out during both experiments. In the humidity cell tests, it is probable that some of the leached sulphate has been derived from oxidation of sulphide minerals. Flushing of the system on a weekly basis tends to ensure that grain surfaces are continually accessible for oxidation and hence susceptible to leaching, which explains why leachate concentrations remain relatively stable throughout the duration of the experiment.

5.5 APPLICATION OF GEOPHYSICAL TECHNIQUES TO MINE CLOSURE PLANNING

In addition to applications in determining internal structure, stratigraphy and thickness of surficial deposits and other forms of overburden (see Section 5.1), geophysical techniques can be used in the mine closure planning process for present-state environmental assessment, as a basis for risk assessment and for surveying the structure and stability of the tailings impoundments and embankments (see for example Räisänen *et al.* 2000, Vanhala *et al.* 2004). Some geophysical methods are also suited to monitoring at the mine site following closure. A particular goal of environmental geophysical investigations during present-state assessment is to locate potential discharge sites of metalliferous and sulphate-rich seepage waters in relation to tailings management and delineation of the areal extent of potential mine influence, including distribution of airborne metal-bearing dust (e.g. Vanhala & Lahti 2000, Kuosmanen *et al.* 2003).

A preliminary assessment of the location and extent of discharge from tailings impoundments or waste rock areas can be made from airborne geophysical data or with remote sensing surveys. This is a rapid and cost-effective way of covering relatively large areas, which also assists in delineating critical areas for more detailed follow-up assessment and monitoring (e.g. Chevrel *et al.* 2003). For example, low-altitude electromagnetic and radiometric surveys have been used successfully in detecting and delineating acid mine drainage derived from coal mines and environmental effects around uranium mines (Beamish & Kurimo 2000, Vanhala & Lahti 2000). Remote sensing techniques, including AISA- and HyMap-hyperspectral surveys have proven useful in defining the extent of airborne metal-bearing dust, in identifying mining-induced stress on vegetation and in delineating the areal extent of surface waters affected by acid mine drainage (Figure 30, Chevrel *et al.* 2003, Kuosmanen *et al.* 2003). Remote sensing methods have also been applied to post-closure monitoring, particularly with respect to revegetation programs (Chevrel *et al.* 2003). To enhance interpretation, calibration of airborne and remotely sensed data is commonly supplemented with data obtained by ground geophysical surveys and geochemical studies. These techniques are also used to more precisely constrain the location of contaminated soil or groundwater. Commonly used ground geophysical techniques include electrical resistivity and dielectric and electromagnetic measurements (e.g. Räisänen *et al.* 2000, Gaál *et al.* 2001).

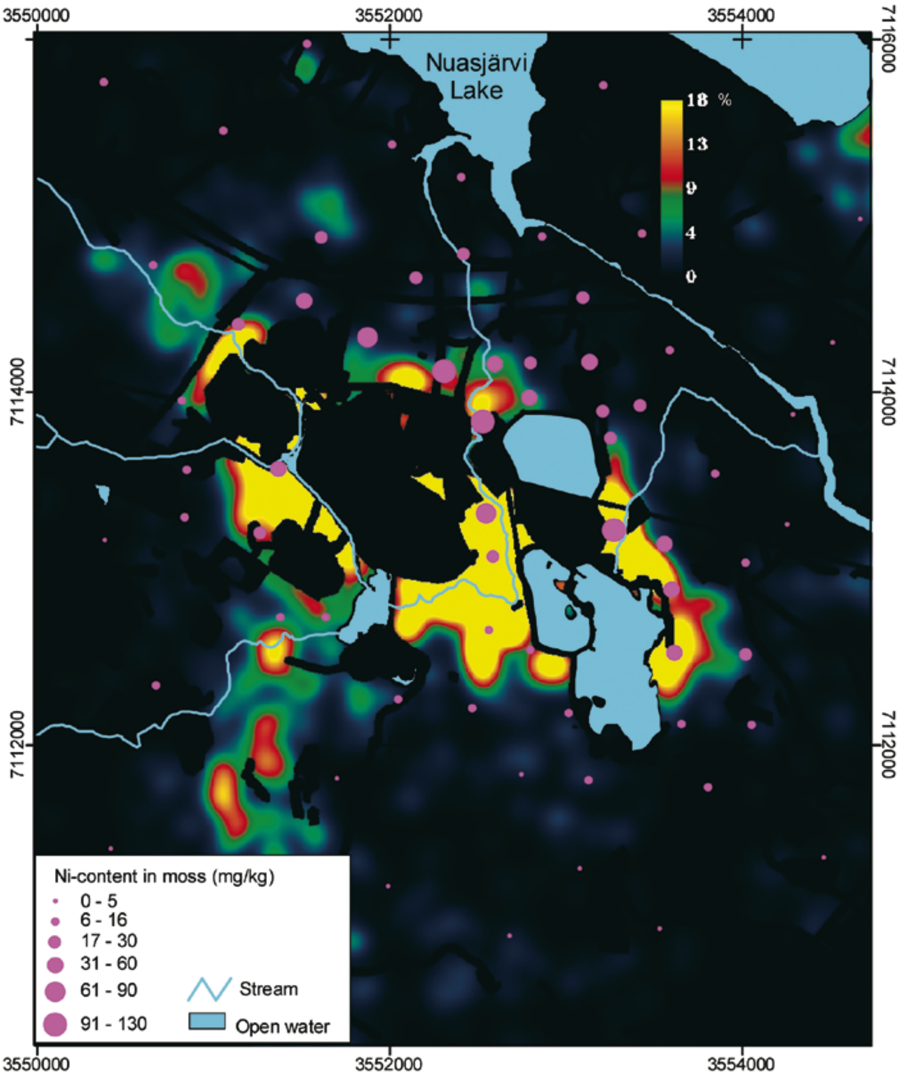


Figure 30. Example of application of hyperspectral mapping techniques to assess the influence of mining on vegetation at the Lahnaslampi talc mine, Sotkamo, Finland (Kuosmanen et al. 2004). Colour shading depicts degree (%) of contaminated forest pixels per 0.125 km^2. Yellow colour corresponds to areas where more intense concentrations of metalliferous dust and mine waters have affected vegetation. Filled circles indicate nickel contents determined from moss samples. Turquoise colour represents lakes and streams, while black areas correspond to infrastructure, or an absence of vegetation. The area contains naturally high baseline nickel abundances, which makes it difficult in some cases to effectively distinguish between background values and mine-induced contamination.

Electric and electromagnetic resistivity methods (EM and Electrical Resistance Tomography or ERT) measure changes in the electrical conductivity of surficial materials and bedrock, which are primarily a function of water content (which in turn ultimately reflects grain size distribution), specific resistivity of water and the mineralogical composition of soils, sediments and crystalline bedrock. These methods may be used to determine the internal structure and material properties of surficial materials, depth to the water table, fracture intensity in underlying bedrock and for detecting the presence of conductive features in the bedrock. Delineation of contaminated areas with these techniques is based on the premise that inorganic contaminants in particular, significantly enhance the effective electrical conductivity of pore waters and groundwater, conversely lowering the specific resistivity of ambient sediments and soils (Vanhala & Lahti 2000). These methods are therefore ideally suited to mapping the distribution and migration of contaminants that exert a strong influence on electrical conductivity. The magnitude of electrical conductivity or specific resistivity anomalies can also be used to infer the relative degree of contamination, for there is a correlation with dissolved ionic species abundance in pore water. Several studies of this nature have been undertaken in Finland, for example in locating seepage water flow paths through tailings and the spread of discharge from tailings into the surrounding environment, at the Hammaslahti (Cu-Zn) and Hitura (Ni) mines (Vanhala & Lahti 2000). In addition to resistivity measurements, dielectric survey equipment and conductivity forks can be used to detect and delineate the extent of contamination in surficial sediments outside the tailings impoundment or waste rock storage area (Räisänen *et al.* 2000, Carlson *et al.* 2002). These types of measurements are ideally suited to monitoring changes in abundance of contaminants, with the additional advantage that instruments can be deployed for automated year-round measurement (Penttinen 2000). After the extent of the contaminated area has been defined, more detailed investigations of surficial deposits and groundwaters may be needed to characterize the contamination in terms of composition, concentration and transport pathways, installing for example, groundwater observation wells and undertaking geochemical analyses.

As well as mapping the extent of contamination, the resistivity measurements may also be used to determine the internal structure of tailings materials (see Vanhala & Lahti 2000, Vanhala *et al.* 2004). These methods are especially applicable to investigation of tailings areas at sulphide mines and are moreover necessary in situations where there is, for some reason, insufficient knowledge concerning the history of filling and construction of tailings impoundments, or the material properties of surficial deposits and bedrock underlying the tailings area. Resistivity surveys can be used to determine thickness of the tailings, and also internal stratigraphical and compositional changes resulting from variable grain size and mineralogy. Resistivity measurements can also be used to define the thickness of the oxidized surface layer and the depth to the water table within the tailings impoundment (Figure 31). They can also be used to detect older embankments and dams that have been progressively buried beneath younger tailings deposits. Such structural engineering investigations can be complemented by gravity or reflection seismic surveys, which enable the bedrock interface and intensity of bedrock fracturing to be defined in proximity to and beneath the tailings impoundment, as well as the depth of the vadose layer within the sediments surrounding the tailings and the total thickness of the surficial sediments, regolith (if present) and tailings deposits. These kinds of investigations have been made at several mines in Finland, including characterization of the tailings at the Hammaslahti (Cu-Zn) mine at Pyhäselkä in conjunction with site remediation, and in present-state environmental assessment at the Paroistenjärvi mine at Ylöjärvi (Carlson *et al.* 2002, Vanhala *et al.* 2004).

Precision gravimetry can be carried out over the tailings area after cessation of the mining operations to monitor rates and extent of compaction and subsidence, using differential GPS to constrain location within centimetre accuracy and a gravimeter with a sensitivity of 0.01 mGal. In this way, it is possible to compensate for the effects of topography and variations in the gravity field and, assuming appropriate boundary conditions, calculate changes in the density and mass of the tailings material (Elo & Vanhala 2001).

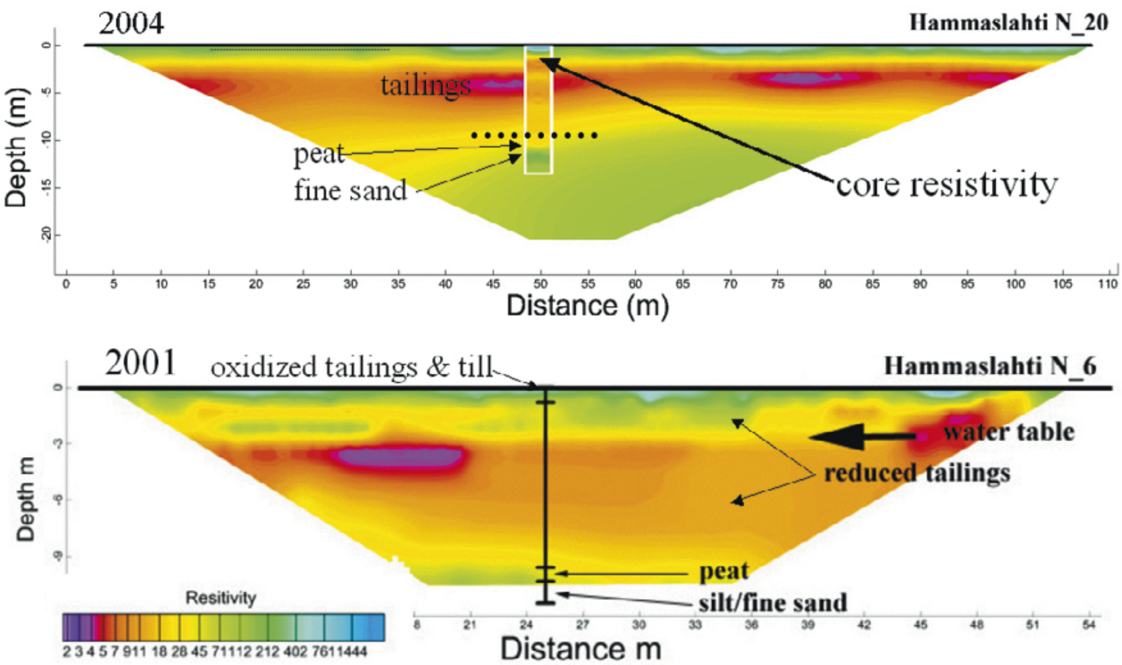


Figure 31. Resistivity profiles across the tailings impoundment at the Hammaslahti (Cu-Zn) mine, Pyhäselkä, Finland (Vanhala et al. 2005). Resistivity measurements can be used to determine the depth of the oxidized layer, and also the thicknesses of the water-saturated zone and tailings material.

5.6 HYDROGEOLOGICAL AND GEOCHEMICAL MODELLING

There is a wide scope for hydrogeological and geochemical investigations and modelling in relation to planning and implementation of mine closure procedures, for example in delineating the potential area subject to mine influence, evaluation of long-term behaviour of tailings and waste rock management facilities, risk assessment and, most of all, in designing closure-related and post-closure monitoring strategies. Modelling results can already be used in the mine design phase to anticipate potential environmental risks due to mining activities, on the basis of which risk mitigation strategies can then be developed. Similarly, result of modelling simulations may indicate with sufficient level of confidence that mining does not represent any significant risk, for example to the quality of groundwater exploited by surrounding communities. Modelling should be seen to have an essential role in decision support processes.

Hydrogeological modelling can comprise simulation of groundwater flow and delineation of potentiometric surfaces and quantitative estimation of rates of production and discharge of groundwater. Additional applications include analysis of the effects of different types of infrastructure on groundwater flow and recharge, production of alternative scenarios for use in risk assessment, and in designing of tailings and waste rock management facilities as well as engineering structures for groundwater protection.

Geochemical models are used in simulation of potential leaching of contaminants from tailings and waste rock facilities and the consequent chemistry of the discharge, particularly in relation to acid mine drainage risks. Geochemical modelling can also be used to characterize chemical reactions within the tailings and waste rock areas and the effect of different rehabilitation strategies on reaction progress. Additional applications for this type of modelling are in simulating the chemical evolution of mine waters during and after progressively filling of open pits, and in designing water treatment processes using, for example, remedial wetlands. Reactive transport models, which are based on the simultaneous coupling of chemical reactions with groundwater flow and transport processes, permit analysis of the aqueous migration and dispersal of groundwater contaminants, for example, from tailings and waste rock management facilities into the surrounding environment, along with estimation of changes in contaminant concentrations. Coupled reactive transport modelling is especially desirable in situations where an understanding of metal migration in groundwater under variable pH and redox gradients is required.

The modelling process can in some cases be simplified and the cost of acquisition of input data minimized, by adopting a conservative modelling techniques. This approach can, for example, be appropriate for ensuring that planned remediation strategies are adequate for risk mitigation, even where background data are few and poorly constrained.

The simplest forms of modelling involve input of given variables into mathematical equations derived by a so-called analytical modelling or, for example, calculations of complexation and speciation of chemical components in aqueous solutions, or the dissolution and precipitation of mineral species. More complex numerical simulation, involving, for instance, the use of 3-dimensional flow or reactive transport in porous media, requires well-constrained boundary conditions and intrinsic parameters, before reliable and robust results can be obtained. This includes, for example, material properties such as thickness and internal stratigraphy of surficial materials, hydraulic parameters, fracture patterning in underlying crystalline bedrock, groundwater composition, redox conditions, retention and dissolution properties of contaminants, and hydrological budget of the site. The type and amount of input data or background information required for modelling depends on the nature of the problem. Even where input data are comprehensive and well-constrained, the relevance and accuracy of model results represent at best a general and simplified approximation to the complexity of natural hydrogeological and geochemical phenomena and their control on the surrounding environment. Therefore, it is essential to describe as clearly and precisely as possible, the nature of uncertainties in input data and parameters, as well as assumptions concerning boundary conditions and any limitations or bias in computational processes. When evaluating the need for performing numerical modelling, it is recommended to establish whether the precision and quality of the available data and modelling parameters are adequate for providing insights and information, which would not be otherwise obtained. Previous applications of modelling in relation to mining environments are numerous and can be found, for example, in the references given in Appendix 10.

Hydrogeological and geochemical modelling normally commences with definition of the problem and objectives, which are to be addressed. The next step involves formulation of a conceptual model or scenario, which is essentially a qualitative description of system architecture and stratigraphy, boundary conditions and behaviour, based on available information. Usually the conceptual model is a written summary supplemented with graphical representation of information derived from a combination of relevant background data, assumptions concerning parameters and boundary conditions and a range of modelling objectives or scenarios for numerical testing. Conceptual models are typically refined in an iterative manner as more data become available from field observations. Numerical process models are then run, based on input from the conceptual model, in an attempt to mathematically quantify and simulate in a predictive manner, the dominant features and processes affecting the behaviour of the system.

A more detailed description of hydrogeological and geochemical modelling procedures, the required background input data and a summary of available numerical modelling codes is given in Appendix 10.

5.7 STABILITY ASSESSMENT PROCEDURES FOR TAILINGS DAMS AND EMBANKMENTS AND WASTE ROCK MANAGEMENT FACILITIES

Inspection of the stability of embankments and dams and other earthworks is necessary to ensure that there is no risk of failure and to monitor earthen structures that are approaching their yield. Investigations usually employ so-called failure surface analysis, in which failure is assumed to occur along a single narrow zone of slip or shear plane.

In stability calculations the shear strength of a given material is compared with the maximum shear stress that can be sustained along real or theoretical planes subject to shear failure, or in other words the critical value of shear stress, which allows a dynamic equilibrium to be maintained. The relationship between these two values is known as the Factor of Safety (F) (Winterkorn 1975).

If the shear strength in the most vulnerable parts of the structure, where the Factor of Safety has its lowest value, is significantly greater than the limiting shear stress for maintaining equilibrium, such that $F > 1$, then failure is unlikely. If the Factor of Safety is near unity, then the situation is potentially unstable and failure is possible, while for $F < 1$, failure is highly likely. Where the Factor of Safety has a value less than $F = 1.8$-2.0, the structure is susceptible to deformation and limited displacement, creep or mass movement. Under these circumstances monitoring is advisable, particularly if the structure consists of diverse materials having significantly different yield strength characteristics.

With regard to site stability investigations during mine closure, the most relevant strength parameters are determined using the c-φ (cohesion–angle of internal friction) relation, according to which shear strength is calculated as a function of effective stresses (Suomen Rakennusinsinöörien Liitto 1989b). The same methods can be equally applied to different earthen structures (backfill in open pits, waste rock piles, tailings embankments) throughout the mine site.

5.7.1 Background information

Site stability investigations require prior knowledge of soil characteristics, the design and geometry of structures, pore water levels and distribution, and strength parameters for tailings and waste rock, as well as for underlying substrate and any other material used in construction. Most of the background information required for the closure investigations can normally be obtained from earlier geotechnical studies, including results of mine feasibility and planning investigations and ongoing construction and monitoring during the production phase. Information concerning soil characteristics, the geometry of earthen structures and the mechanical properties and behaviour of tailings and waste rock and other materials, should be compiled and evaluated, to assess the need for further studies.

Such background information is generally available for most of the mine structures requiring geotechnical stability assessment (open pit infill, waste rock storage facilities and dams and embankments). However, if this information is lacking, or considered insufficient, supplementary investigations are needed to accurately assess stability, with respect to foundations as well as structural earthworks. Additional information required typically includes the distribution of different types of materials within structures, and their unit weight, density, hydraulic conductivity or any other properties, which are subject to change over time.

Analysis of the geometry of mine structures is generally done shortly before closure, since during mining operations they are typically subject to continual modification. When assessing the final geometry, it is also important to taken into account the changes due to site closure, for example the covering of tailings and waste rocks.

Variations in depth to water table throughout the mine area, including pore water within tailings impoundments, represent one of the most significant factors to consider in relation to structural stability. Monitoring of water levels, as an integral aspect of the closure process, should continue in the same way as during active mining operations, particularly if closure procedures are not implemented immediately after shutdown. If necessary, a new network of observation wells for monitoring water levels and pressures should be installed, to ensure adequate information is obtained. If the provisional closure plan indicated that mining-induced changes in the water table are likely, then the post-closure monitoring process, including analysis of structural behaviour, is made easier, if a comprehensive groundwater observation array is in place from the beginning of mining operations.

The relevant material strength parameters required by the stability analysis are usually available from studies carried out during the mine construction phase as well as during subsequent operations, and from documents related to quality management and monitoring systems. If necessary, however, separate tests may be performed to better constrain material strength properties. Nowadays it is common practice to characterize tailings and waste rock in terms of geotechnical properties and behaviour, during or even prior to the production phase. However, considerable variation in physical properties and behaviour can occur, even in superficially similar tailings or waste rock materials, depending on their source and the ways in which they are generated. For example, the results of capillary flow tests (height of capillary rise) for tailings from five different mines show a range of values from 0.85–6.7 m, while hydraulic conductivity in the dense state varied between $10^{-5.8}$– $10^{-7.8}$ m/s and effective angles of repose ranged from 25.7°–41.3° (Ahonen 1997).

While existing material properties information for waste rocks, and other mining by-products, may be used in stability investigations, it is necessary to ensure that the data are both relevant and subject to validation. Investigations of material properties for waste rocks and tailings may have been focused on particular applications, whereas strength parameters in particular, but also other geotechnical properties, such as hydraulic conductivity, are very sensitive to variations in unit weight and water content. Material strength parameters and the determination of other geotechnical properties, including those of tailings, are treated in more detail in report dealing with mine site stability investigations, prepared during the TEKES Project 'Environmental Techniques for the Extractive Industries' (Juvankoski & Tolla 2004). The geotechnical properties of waste rock and tailings are considered in detail in connection with a specific project dealing with tailings dams and embankments, coordinated by the former National Board of Waters and the Environment, which was the predecessor to the current Finnish Environment Institute (Saarela 1990).

5.7.2 Required safety standards

Waste and mine embankments and dams in Finland fall under the jurisdiction of the Dam Safety Act (413/84) and the Dam Safety Decree (574/84), as well as the Mining Act (503/ 1965). An additional dam safety and monitoring code with guidelines for ensuring legal compliance were issued by the Ministry of Agriculture and Forestry (Maa- ja metsätalousministeriö 1997) in 1997. According to these guidelines, dams and retaining embankments are classified into four risk categories, namely P-, N- O- and T-dams, depending on the consequences of failure or breaching, and whether the dam is designed as a temporary or permanent structure. The safety code stipulates that for a dam subject to long-term pore water infiltration, the Factor of Safety (F) should be at least equal or exceed a value of 1.5 (Maa- ja metsätalousministeriö 1997). Relevant aspects of the safety code should be taken into consideration throughout the entire mining process, from designing and selecting suitable sites for mine embankments and impoundments, through the construction phase to ongoing site monitoring (KTM 2003b).

There are also a number of directives defining Factors of Safety for foundations in the housing and construction industries, which are also applicable to the design and safety management of dams and embankments. For example the Building Foundations Code, produced by the Finnish Association of Civil Engineers (Suomen Rakennusinsinöörien Liitto 1989a), sets a minimum Factor of Safety of F = 1.8 in relation to widespread failure of building foundations. Similarly, guidelines for excavations and earthworks (Suomen Rakennusinsinöörien Liitto 1989b), including situations involving long-term structural support of earth or rock masses, or prevention of slope failure (apart from cases where the excavation is of a transient nature, related to the construction program), also recommend a Factor of Safety F = 1.8. For material subject to collapse or slope failure during the construction phase, a value of F = 1.5 is sufficient, given that the excavations are not of a permanent nature.

5.7.3 Methods and software for calculating slope stability

In principle it is possible to use any of the currently available and approved geotechnical techniques for calculating slope stability and failure, depending on morphology of the sliding surface, such as straight failure surface, circular failure surface, multiple segmented failure surface, or free-formed failure surface methods or more sophisticated numerical techniques. In circumstances where the (rock) disposal heaps are essentially dry, analysis based on straight failure surfaces may be adequate (since the Factor of Safety is defined as the ratio of the tangent to the internal angle of friction and the angle of repose of the waste heap or embankment). For homogeneous dams and embankments and substrates, circular failure surface analysis may be more appropriate. In situations where material properties vary significantly through the structure, the multiple segment or free-formed failure surface approach is recommended. Stability assessment is in practice performed by computer programs, which ideally include a variety of separate algorithms capable of simulating safety factors based on different criteria. In addition, the software should be capable of analysis of failure surfaces with varying shapes. Various methods for calculating Factors of Safety are outlined briefly in the report dealing with mine site stability investigations, prepared during the TEKES Project 'Environmental Techniques for the Extractive Industries' (Juvankoski & Tolla 2004).

5.7.4 Enhancement of structural stability during mine closure

The most significant material properties controlling stability of earthen structures are shear strength (effective internal angle of friction (φ) and effective cohesion (c)), the angle of repose and height of the embankment or sloping surface, and the level of the water table (or boundary between the vadose and phreatic zone). In considering the various types of earthworks constructed during and after mining (open pit design and backfilling, waste rock facilities, tailings impoundment dams and embankments, and tailings covers), the most obvious and effective measure for enhancing stability is to reduce the angle of slope. This procedure is in principle applicable to all earthen structures, although in practice, there may be limitations imposed by lack of space. In such cases, terracing of the embankment slope may be an effective alternative.

Other options for enhancing slope stability include pumping to reduce pore water levels and pressures, and the addition of a supporting shoulder to buttress the outer slope of the embankment. Such supporting structures may also offer the additional advantage of forming hydrological barriers to arrest pore water infiltration and seepage (Saarela 1990). Properly de-

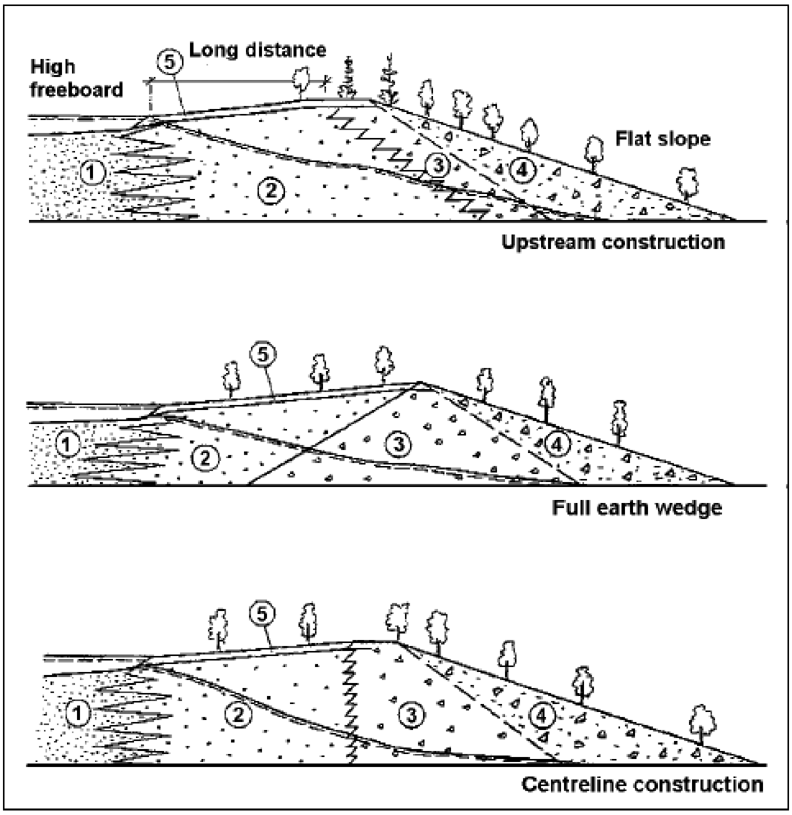


Figure 32. Alternative design options for embankments retaining tailings with permanent water cover. 1. Fine-grained tailings. 2. Coarse-grained tailings. 3. Supporting fill. 4. Supporting fill ensuring long-term stability. 5. Impermeable cover, preventing erosion (EC 2004).

signed drainage systems, as well as systematic planting with appropriate vegetation, will both assist in long-term stabilization of earthen structures, in terms of minimizing risk of slope failure, as well as erosion. These issues are also addressed further in report of the TEKES Project 'Environmental Techniques for the Extractive Industries' (Juvankoski & Tolla 2004).

Covering of waste rocks and tailings will also tend to promote an overall drop in the ambient water table over time, providing that the respective permeabilities of the cover materials are sufficiently low. This will also result in an improved Factor of Safety for the material in long-term. Figure 32 illustrates several common options for dam and embankment design, also showing the potential distribution of pore waters. As a general rule, the long-term stability of an earthen dam or embankment is assured with respect to internal erosional effects, providing that the slope of the hydraulic gradient is less than half of the internal angle of friction of the material in the structure (EC 2004).

When a decommissioned open pit progressively fills with water, conditions initially are the exact opposite of those in tailings impoundment embankments; in the latter case, the water level progressively decreases over time, whereas the converse applies to the open pit, leading to increased potential for slope instability. The risk of failure within the pit environment can be addressed in a pre-emptive manner by designing slopes that take into account changes due to the rising groundwater levels.

Where the open pit intersects the ambient water table in surrounding surficial deposits, discharge of groundwaters may lead to erosion of earthen slopes or backfill and retaining structures. Erosion intensity is controlled primarily by discharge rates and composition of the material. Evaluation of erosion risk is based on estimation of a critical flow velocity for groundwater discharge, with respect to entrainment of sediment particles of a given grain size. The critical velocity is essentially a function of both grain size and the degree of consolidation of the sediment. Analysis of the critical velocity concept and measures for mitigating erosion are dealt with in more detail in the report prepared for the TEKES Project 'Environmental Techniques for the Extractive Industries' (Juvankoski & Tolla 2004).

5.8 INVESTIGATION OF SITE CONTAMINATION AND REMEDIAL OPTIONS

5.8.1 Methods for investigating soil contamination

Where soil contamination is suspected, the first steps toward mitigation involve surveying background information and documenting the history and range of activities. When this process is undertaken in connection with mine closure, a general assessment of the state of environmental conditions and performance indicators is usually required, together with a review of mining operations and the mine planning process and collation of all other relevant information, in the form of maps and results of background information studies and geological and hydrological surveys. Baseline studies are usually made before the commencement of the mining activities and they include thorough documentation of the state of the mine environment prior to the mining operations, which can be used as a reference state for defining remediation objectives. When deciding the desired post-remediation outcome, it is, however, necessary to consider whether there have been other environmental changes which are not directly attributable to the mining process. It should be clear from documentation of the history of mining whether or not there have been any mining-related accidents or other incidents, and whether there have been previous assessments of site contamination or attempts at remediation. Mine records should generally also be an additional source of information in preparing a provisional assessment of the potential occurrence and nature of contamination or potentially harmful elements.

Mine planning documents and maps provide the basis for delineating the most likely sources of potential contamination of soil and surface- and groundwaters. Geological, geochemical and hydrogeological data can be used to define geochemical baselines in soil, sediments and groundwaters, pathways and direction of groundwater flow, surface drainage patterns, location of potentially contaminated areas and properties of surficial sediments and overburden which either enhance or inhibit contaminant transport. The detail, in which investigations can be planned from the outset, depends to a large extent on the amount and quality of available information. Where available background information is comprehensive, it is also easier to plan effective sampling programs for site evaluation and management.

Investigations of contaminated soil sites usually incorporate the following features (cf. SGY 2002):

- Tentative plan of sampling network, including preliminary amount and location of sampling sites

- Sampling methods (for example test pits, drilling, groundwater or surface water sampling)
- Desired depth of sampling sites (for example surface sampling, sampling to bedrock interface, or water table, or to a specific sedimentary horizon) and a preliminary indication of sampling strategy (at regular intervals, or from specific layers)
- Number of samples required and volume of sample (e.g. 100 g, 0.5 l)
- Selection criteria and number of samples collected for both laboratory and *in situ* measurements, and analytical requirements (characterization and abundances of contaminant species)
- Sample preparation and packaging in the field
- Sample storage and labelling procedures
- Timeframe of sampling and analysis
- Occupational health and safety issues (e.g. protective clothing and precautions during sampling)

When preparing strategies for assessing mine site contamination, it is advisable to address in particular those factors, which influence the overall extent of the investigations. Important considerations in the planning of contamination studies in relation to mine closure are the location of activities and operations that may lead to contamination, and the natural background levels of potentially harmful elements. Additional significant aspects to take into account are post-closure land use options and procedures, including for example, the possibility of using excavated materials, such as waste rock and tailings, either in site remediation or applications elsewhere. The appropriate regional environmental authorities should be informed of the intention to carry out studies of soil contamination, and a detailed investigation plan should be submitted for appraisal and comment.

After this process is completed, the investigations can be commenced, with sampling preferably undertaken by a certified expert, in order to ensure that the plan is followed in detail, and complies with standard sampling procedures and quality controls. All aspects of the sampling program should be recorded and documented, including deviations from the original plan, as well as descriptions of sampling sites, including information concerning the nature of the material sampled, groundwater and surface water conditions, sampling depth, sample colour, odour, moisture content, sediment or soil type, and weather conditions at the time of sampling. If necessary, *in situ* measurements may be undertaken during sampling (Figure 33). A report of investigation should be prepared on the basis of field and laboratory studies and measurements, including a standard risk analysis of the possibility and nature of contamination of surficial materials or groundwater and surface waters (refer to Section 4.2).

Figure 33. Preliminary in situ delineation of the nature and extent of contamination by inorganic substances can be facilitated by using a portable XRF analyzer.

According to Section 2 of the recently enacted Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007), (refer to Section 3.2), risk assessment should place particular emphasis on concentrations, total amounts, properties, baseline concentrations, and locations of harmful substances in soil. Attention should also be given to ambient environmental parameters (surficial material and groundwater conditions), current and future anticipated land use activities at and adjacent to the site, and the potential short-term and longer term risks to health, environment and safety. The risks arising from mining-related contamination should also be assessed in relation to contamination from other sources in the vicinity or any other factors. Based on the Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007) the possible contamination of soil and the need for remediation should be assessed if the legally prescribed threshold value is exceeded by one or more contaminant. In areas where the geochemical baseline is higher than this statutory threshold value, the assessment should take into account the natural background concentration as well. Following evaluation of overall risk and extent of contamination in and around the mine environment, the need and urgency for remedial action or other measures is assessed and reported. A copy of this report should also be submitted to the relevant regional environmental authorities, who make the final assessment concerning site remediation requirements or the need for further investigations.

5.8.2 Remediation of contaminated soil sites

If the need for certain soil remediation is indicated by the risk assessment process, the remediation program must be planned and implemented such that, within a particular degree of certainty, there is no significant risk of adverse effects on health, safety or the natural environment, even over the long-term and irrespective of potential post-closure land use options. Preparation of an appropriate plan for remediation includes an outline of the need for clean-up of soil or groundwater, the objectives of the project and the nature of the proposed treatment technologies and methods. The Finnish Environment Institute (SYKE) has produced a general guide to planning and implementation of remediation projects in relation to contaminated soils (Alanko & Järvinen 2001). The guidelines are comprehensive and can be used as a basis for planning remedial action for complex sites. In simpler cases the contents of the plan can be modified to meet specific site requirements and remedial action. It is recommended that these guidelines be followed for both planning and reporting of the remediation program (Alanko & Järvinen 2001). A general plan for remediation of contaminated soil sites should be submitted to the appropriate regional environmental authorities for approval.

Remediation of contaminated soil requires an environmental permit or that appropriate environmental authorities are informed of the intention to carry out remediation (refer to Section 3.2). Responsibility and accountability in relation to remediation of contaminated soil sites is dealt with in detail in Section 3.2.

The report produced for VTT by Mroueh *et al.* (2004), dealing with quality management of contaminated soil remediation programs, presents guidelines on appropriate treatment practices for the most common contaminated soil remediation methods. In Finland, the most common remediation method is excavation, off-site treatment and relocation of contaminated material. Treatment methods commonly used in Finland include stabilization/solidification, thermal desorption, soil washing, composting, soil vapour extraction and containment and isolation. Vegetation may also be used for remediation (phytoremediation, see Section 6.2.3). Contamination by organic compounds can also be dealt with using a range of biologically based techniques, such as bioventing and enhanced *in situ* biological remediation.

Groundwaters are often cleaned-up by using so-called pump and treat methods, in which contaminated groundwater is pumped to the surface for processing in a customized treatment plant and then either returned to the site or released into the surrounding watershed, or else transferred onwards for further treatment at another waste water management facility. Other remedial options include aeration of groundwater, natural biodegradation techniques and construction of reactive barriers and membranes, where contaminated groundwater is directed through a permeable barrier, in which contaminants are either contained and adsorbed, or broken down via chemical reactions. Acidic mine waters are typically treated by neutralization, or by construction of limestone drains or artificial wetlands (refer to Section 6.2.1).

The most widely used remediation method in Finland is the excavation and removal of contaminated material for treatment elsewhere, and replacement with clean fill. However, because this process does not physically remove the contaminant from the excavated material and does not strictly qualify as an acceptable remedial option, it is necessary to carefully plan the final location of excavated material and to choose options to ensure that there will be no adverse environmental consequences. Alternatively, soil contaminated with organic compounds may be treated, for example with soil vapour extraction prior to removal. Where the degree and extent of contamination is low, and depending on the nature of the contaminant, it might be possible to use the material for covering and landscaping municipal waste sites, or as foundation fill in road construction. Where contamination is caused by high concentrations of organic compounds, these should be removed, for example by combustion, prior to final relocation of the soil. Some contaminated material may be relocated as waste fill directly, without the need for treatment. However, it should be noticed that the treatment and recycling of contaminated soil is always case-specific and in most cases an environmental permit is required (Environmental Protection Act, Sections 28 and 78). In connection with mine closure, it should be established whether the amount of contamination is sufficiently low that the material can be used in site remediation for covering tailings or, if the source of contamination is exclusively metallic in nature, whether contaminated material can be used underground as backfill. In such cases, however, it is necessary to thoroughly investigate the risk of potential transport of metal contaminants into surrounding surface- and groundwaters, or indeed the atmosphere.

All measures and activities undertaken in relation to mine closure and remediation should be carefully documented and filed as a report to be archived on site for the duration of the remediation program. Such reports should be regularly updated and be available for inspection by relevant authorities, as and when required. Directions concerning reporting procedures and requirements should also be included in the general remediation plan for the contaminated soil site. When the remediation program is deemed complete, a final report is prepared, evaluating the implementation and success of the project and outlining the need for further monitoring or restrictions on land use. This final report should be submitted to the relevant regional environmental authorities.

5.9 SELECTION AND SOURCE OF SUITABLE EARTH MATERIALS FOR MINE SITE REHABILITATION

The mine closure process will usually require a source of earth materials for a variety of remediation measures, such as stabilizing and landscaping tailings and waste rock areas and open pits. Additional material may be needed for mitigation of acid production from tailings and waste rock or for providing backfill or structural support for underground mine workings. The amount and quality of materials needed clearly depend on the precise nature of the site or structure and the overall purpose and objectives of the closure. For these reasons it is necessary to firstly document all of the potential areas for remediation and estimate the volumes of landfill and covering material required, before attempting to establish whether a suitable and sufficient source can be identified.

In many instances it is possible to use material available or stored on the mine site, such as fine-grained till or stockpiles of overburden stripped prior to mining, for remediation purposes; subject to quality considerations, tailings and waste rock may also be used (refer to Section 6.1). If however, there is insufficient suitable material available at the mine site, it must be sourced from elsewhere. In such situations surficial geological maps of the surrounding areas may be referred to, if available, for locating suitable materials, or else appropriate surveying techniques may be used (as described in Section 5.1). When conducting such investigations outside the mining concession however, it is important to remember that excavation of test pits requires permission from the appropriate landowner, while extraction of materials requires a permit from relevant permitting authorities (Section 4 of the Land Extraction Act 555/1981). Detailed information relating to surficial geology may also be available from within the boundaries of the mining lease, either from previous regional mapping surveys, or through drilling and other site investigations undertaken in connection with mining.

Geophysical techniques (for example, electrical resistivity measurements, as described in Section 5.5) may be used to survey and assess the suitability of overburden stockpiled during mining operations, supplemented by drilling or excavation of test pits. When a potential resource for extraction of material has been identified, whether in undisturbed surficial deposits, or within overburden stockpiles on site, a representative range of samples is taken for laboratory analysis. Material is usually assessed for grain size, although permeability should be also measured for at least some, if not all samples. Selection of appropriate samples for laboratory analysis is based on field observations of the structure of surficial deposits. When waste rock and tailings are sampled, the leachability of potentially hazardous compounds should also be tested, in addition to measuring grain size distribution and permeability; waste rock grain size analysis is usually performed on crushed samples.

In order to obtain optimum material compositions and properties for remediation purposes, it is commonly necessary to mix material of varying origin. In such situations, the proportions of different components are selected according to grain size distribution curves of each material. For example, mixing of crushed waste rock with a sediment having a mean grain size corresponding to fine-grained till, can yield a material that has an enhanced load-bearing capacity, while retaining a relatively low permeability, making it more suitable for covering of tailings or other applications where a compacted structural layer is required. There may be considerable benefits in undertaking a detailed assessment of the potential for using mixtures of on-site materials, rather than sourcing remediation material from elsewhere, for example in terms of both transport and environmental considerations.

6. MINE CLOSURE STRATEGIES

The following sections describe mine closure procedures, and present examples of risk management strategies such as options for water treatment, covering of tailings and waste rock areas, and landscape restoration. The final section of the chapter deals with issues related to public relations, transfer of ownership and long-term sustainable use of the former mine site.

6.1 MINE CLOSURE AND INFRASTRUCTURE DECOMMISSIONING – PLANNING AND OBJECTIVES

Although some generic standards and guidelines can be defined, it is important to appreciate that the precise design and implementation of closure procedures will vary according to the nature and scale of operations and environmental considerations at individual mines. These variations will also be reflected in the choice of appropriate technologies (cf. EC 2004). It is also advisable, and in many cases advantageous, to anticipate and commence dealing with closure issues during active mining operations.

Comprehensive closure planning must in general include the following aspects of mining:

- underground operations,
- open pits and quarries,
- waste rock piles and topsoil or other overburden stockpiles,
- tailings areas,
- concentrating plant,
- other buildings and infrastructure,
- mining machinery and other equipment,
- landfills and wastes, as well as
- contaminated soils and polluted surface- and groundwaters.

A specific strategy must be formulated for each of the above points, taking into consideration general safety issues, as well as environmental and potential land use criteria. For some of the of the mining activities and legacies outlined above, strict procedural guidelines are prescribed by mining and environmental legislation, whereas in other situations, it may be necessary to apply best available technologies (BAT), or otherwise follow best practice principles, according to specific circumstances and requirements. The purpose of the following sections is to review each aspect of mining activity in relation to closure objectives, and present model examples of closure implementation, some of which are summarized in Tables 20–24. These tables also provide information on significant physico-chemical and land use risk factors relevant to mine closure. However, because the closure procedures need to be designed according to individual case requirements, the examples considered below are not intended to be exhaustive.

6.1.1 Underground workings

An underground mining operation involves a system of declines, ramps and tunnels, providing access to stopes and galleries, as well as areas allocated to service and maintenance, storage and social and mine safety activities. In addition, mining requires infrastructure including electricity, communications systems, water supply and ventilation, including pressured air systems, and pumps for removal of groundwater. Depending on the type of ore and mining methods, exploited stopes may be backfilled during mining, to prevent collapse of pillars and galleries. Alternatively some stopes and galleries and access ramps may remain open and are potentially available for later disposal of suitable materials.

When mining operations cease, irrespective of whether mining was above or below ground, the mine site must meet the criteria set for public safety, in compliance with Section 51 of the Finnish Mining Act 503/1965. In practice this means that declines, mineshafts and ventilation shafts are effectively closed so as to prevent access, and that areas susceptible to subsidence or collapse are surrounded by fencing and erecting clearly marked warning signs (Ministry of Trade and Industry Decision 921/1975). Access to the former mine site can also be restricted by resorting to road closure.

Entrances to declines can be blocked with local waste rock, while ventilation shafts may be capped with reinforced concrete. If open galleries and stopes remain after mining has ceased, the risk of subsidence or collapse may be minimized by filling with waste rock or tailings, and by constructing adit plugs to provide structural support. The use of tailings or waste rocks is contingent on their being non-reactive, posing no risk to ambient surface and groundwaters, and may therefore require permitting and approval from environmental authorities (see Section 3.1.1). The use of rockfill and other earthworks needs to be considered carefully if subsequent land use at the mine site includes construction of public roads or other permanent infrastructure. As well as reducing subsidence risk, the use of adit plugs can prevent the migration of the backfill in the mine, if it becomes flooded with water. Adit plugs or retaining embankments are commonly made impermeable using concrete. The use of adit plugs and rockfill is not generally recommended in declines and shafts, in case the mine is reopened at some future date; Section 47 of the Mining Act (503/1965) refers specifically to the need to ensure that none of these activities endanger or impede any future attempts to exploit raw materials from the site.

When delineating and fencing off areas at risk of subsidence or collapse, or planning for subsequent forms of post-closure land use, it is also important to take into account a possible subsidence due to longer term settling, for example where mine tailings have been used as backfill.

All built infrastructure existing at the mine site, including equipment, stairways and ladders constructed exclusively for mining purposes, and which contribute to mine safety, must be left in place, unless specific permission for removal is granted by the Ministry of Trade and Industry (Mining Act, Section 51). Wooden or concrete structures housing workshops for machinery maintenance, or social facilities including canteens and cafeterias should also be left in place, unless there are justifiable reasons for them to be demolished or relocated. Removal of equipment and machinery as well as facilities, materials and infrastructure that are not related to mine safety, including pipes, cables, and electrical and other essential equipment, may be negotiated under appropriate circumstances (Figure 34). However, nothing should be removed if dismantling in itself constitutes a safety risk, or if it can be used during subsequent mining activity. On the other hand, all waste, and all materials, which have the potential to pollute groundwaters, when the mine is flooded with groundwater, must be removed, in accordance with Section 8 of the Environmental Protection Act (86/2000). Sorting of material to be removed from the site should be carried out during the decommissioning and dismantling phase, to facilitate later reuse and recycling. Material constructed from wood can generally be left at the site, since it rarely poses a contamination risk, to groundwater for example. Moreover, it may provide a source of nutrients for activating bacterial sulphate reduction, if this is adopted as a method of water treatment (cf. Section 6.2.1).

After closure, when water is no longer pumped out of mines, infiltration and recharge from both groundwater and surface flow progressively restore the water level to that of the ambient water table. The rate at which this occurs depends on the type of mine and local hydrological parameters and in some cases

Figure 34. Underground mines typically have service and maintenance and storage depots, as well as social and medical facilities, (as in the examples shown from the Hitura Ni mine, Nivala, Finland). After decommissioning, most of these facilities, apart from supporting structures, are removed.

may take tens of years. Flooding of the underground workings may occasionally lead to contamination of surrounding groundwaters as well as surface flow. For example, exposed rock faces in sulphide mines will inevitably, through oxidation of sulphide phases, lead to acidification, which will promote further metal leaching. However, once submerged beneath water, more reducing conditions prevail and sulphide oxidation is consequently diminished, or may even cease altogether. Therefore, one way to minimize the problem of water contamination driven by sulphide oxidation is to accelerate the flooding of the mine by pumping fresh or treated water into the mine. In practice, however, there are seldom sufficient quantities of water in close proximity to the mine site and a separate permit would be required for pumping surficial waters (Water Act 264/1961, Section 9.2). Furthermore, since the pumping might result in deterioration of groundwater quality, it is prohibited under the Environmental Protection Act (Section 8). If necessary, a separate study of site hydrology and groundwater characterization can be undertaken, in order to anticipate potential effects of post-closure mine-influenced waters on surrounding water quality.

Flooding rates and evolution of water quality after mine closure can be assessed with hydrogeological and geochemical models (see Section 5.6). If the risk of contamination of surrounding surface water or groundwater seems likely, then options for water treatment and management need to be considered as part of the closure strategy, in line with environmental legislation directives. For example, it is possible to reduce metal and sulphate abundances in mine waters through the controlled use of sulphate-reducing bacteria (cf. Mustikkamäki 2000). Further methods for water treatment are described in Section 6.2.1. Compared to sulphide ores, there is usually less need for water treatment where industrial minerals or carbonate is mined.

Before underground workings are closed, or pumps shut down, it is required by law (Mining Act) to produce a detailed map of the mine as specified in Decision 1218/1995 of the Ministry of Trade and Industry (Sections 5 and 6). It is advisable to indicate the locations of proposed retaining barriers and other closure structures on the map. This map must be presented to the Safety Technology Authority of Finland, prior to approval being given for commencing the closure program (Mining Act, Section 51). The map should be

Table 20. Examples of risk factors, rehabilitation objectives and recommended remediation strategies for underground mining operations (modified after UNEP/WHO 1998).

Potential risk factors	Rehabilitation objectives	Examples of remediation methods
PHYSICAL STABILITY ISSUES		
Safety (mineshaft, raises, ventilation shafts)	• Compliance with safety requirements	• Prevention of public access • Permanent sealing of shafts and entrances (covering by concrete or filling with waste rock) • Periodic inspections
Collapse or underground cave-in	• Collapse avoidance or minimization	• Structural reinforcement or infilling tunnels with waste rock
Surface subsidence or collapse	• Stabilization of land surface • Strengthening underground structures	• Prevention of public access • Structural reinforcement at surface, tunnel backfilling, landscaping and channelling to conform with future land use, demarcation of subsidence-prone areas behind fencing with clearly marked warning signs
CHEMICAL STABILITY ISSUES		
Generation of acid mine drainage and/or leaching of contaminants (particularly mining of sulphide ores); leaching of residual processing chemicals and other pollutants from backfill	• Compliance with quality objectives for surficial and groundwaters	• Sealing of tunnels, shafts and drill holes, containment; active or passive treatment of mine drainage; regular monitoring of water quality during mine flooding and follow-up analysis of water chemistry and migration control
Leakage of oil from machinery and equipment remaining in mine	• Leakage avoidance	• Removal of equipment from underground workings, removal of oil or oil-contaminated material
LAND USE ISSUES		
Permanent abandonment of mine site; Negative aesthetic impact; Impact on surface drainage, infiltration and groundwater recharge	• Allowing sustainable future land use • Management of surface waters and assurance of groundwater recharge and quality	• Landscaping and infilling depressions, sealing mine shafts and entrances, revegetation programs

accompanied by thorough documentation outlining the geophysical maps and surveys, drill core logging data, including descriptions of rock types as well as chemical analyses, together with any other data related to the ore deposit (Ministry of Trade and Industry Decision 1218/1995). The map and documentation can be submitted to the Safety Technology Authority of Finland in electronic form in addition to a paper copy format (Ministry of Trade and Industry Decision 1218/1995). A duplicate copy of the map may also be submitted to the Central Archives of Finnish Business Records, at Mikkeli. Representative sections of drill core and logging reports related to mining activity should also be delivered to the national drill core depot of the Geological Survey of Finland, located at Loppi (Mining Act, Section 19).

6.1.2 Open-cut workings

The legacy of open-cut mining is, depending on the nature and scale of operations, a pit of variable size and depth to width ratio (Figure 35). As for underground workings, closure strategies for open-cut workings require that the area meets the legal requirements for general public safety (Mining Act, Section 51). This means in effect that public access to the open pit is restricted and unstable slopes surrounding the pit are landscaped and stabilized. Steep or vertical pit walls should be made safe and they should be modified to gentler slopes where they remain above estimated final water level, or if they are susceptible to failure and slip.

Public access to the site is restricted by erecting a safety fence around the open pit, with clearly visible warning signs (Figure 15), in accordance with the Ministry of Trade and Industry decision (921/1975, Section 129). Relevant factors to consider in relation to fencing include the location of mine, stability and quality of pit edges, equilibrium water levels and fluctuation range, and the suitability of the water for use by humans and animals (Ministry of Trade and Industry Decision 921/1975, Section 129). Positioning of the fence is largely determined by identifying the limits of ground potentially subject to subsidence or collapse. An additional measure for preventing public access is to close all roads leading to the mine. However, possible use of the road network by other business activities in the region needs to be taken into consideration.

Landscape restoration around open pits should anticipate potential erosion and subsidence risk and likely variations in level of water table after mining and pumping has ceased (refer to Section 5.7.5). In

Figure 35. Lahnaslampi open-cut talc mine, Sotkamo, Finland. Waste rock and magnesite tailings from the new mine scheduled to open nearby will be transported to the pit after mining operations have ceased.

more vulnerable areas, erosion can be minimized by replanting appropriate vegetation (refer to Section 6.2.3), which has the additional advantage of enhancing aesthetic and ecological values at the same time. In some cases, natural regeneration is an acceptable strategy. Another important aspect of landscaping is stabilization of pit edges and rock faces, to prevent collapse. Waste rock may be used for landscape restoration and stabilization, as well as for backfilling the open pit, so long as it is environmentally non-reactive. In some cases, usage of waste rocks may require environmental permitting (refer to Section 3.1.1).

Similar to underground mining, closure strategies for open pits require the removal of any materials that could conceivably cause contamination of surface and groundwaters or soil, as defined under the Environmental Protection Act. As long as dismantling does not cause any safety hazards, all steel structures, pipes and hoses, and electrical and communications cables and wiring should be removed from the site. Concrete and wooden structures can normally be left untouched, if there is no evident risk to the surrounding environment. Any other materials stored around the open pit should also be removed.

Current practice in Finland is that open-cut mines and surrounding areas affected by mining are designated as special areas within municipal building code registers. This means that in addition to the normal building application process through local municipal authorities, approval needs to be sought from the current holder of the mining rights to the area or, if mining rights have lapsed, from the last operator recorded in the mining register (cf. Section 3.5). A working group appointed to review the Mining Act (KTM 2003a) has also recommended that municipal government authorities consult with mining authorities (i.e. Ministry of Trade and Industry) whenever construction or other activities are being planned in former mining areas. Delineation of the area, formally classified as affected by mining activities, is usually accomplished during final technical inspections by the Safety Technology Authority of Finland (TUKES). It is increasingly common in Finland for ownership of the mining lease to be retained by the operator after formal mine closure, particularly if the land was actually purchased during mining operations.

If it were necessary to pump during mining operations, then after closure, the pit will normally fill with water, due to precipitation and surface runoff, as well as groundwater infiltration. Eventually the open pit may come to resemble a natural lake, especially after revegetation. Monitoring of water quality is however, advisable to ensure that there is no ongoing risk of contamination. For example, where mining of sulphide ores has occurred there is a greater possibility for contamination of surrounding groundwaters or surface runoff with acidic mine-influenced water containing elevated metal and sulphate abundances. Hydrogeological and geochemical modelling can be used to provide predictive estimates of pit filling rate, and evolution of water chemistry of the final pit lake (refer to Section 5.6). If the results of such studies indicate that adverse effects on surrounding water quality are likely, preventative measures, such as treatment of the pit water or sealing structures for overflow, are required under the Environmental Protection Act to ensure that there is no risk of overflow or leakage of water from the mine site. Methods for treatment of mine waters containing excess metal and sulphate abundances, including bacterial sulphate reduction (Figure 36), are discussed further in Section 6.2.1.

As in the case of underground mining, a detailed map of the open pit must be presented to the Safety Technology Authority of Finland, prior to implementation of mine closure and rehabilitation, in accordance with Section 51 of the Finnish Mining Act 503/1965. Supplementary information relating to mining, which should also be submitted, is detailed above in Section 6.1.1.

Figure 36. When mining ceases and pumping stops, water progressively fills the open pit. Various options are available for water treatment, if necessary. At the former Hammaslahti Cu-Zn open pit (Finland), shown here, water chemistry is modulated by bacterial sulphate reduction, with addition of farm manure as one mechanism for promoting bacterial activity.

Table 21. Examples of risk factors, rehabilitation objectives and recommended remediation strategies in relation to open-cut mining operations (modified after UNEP/WHO 1998).

Potential risk factors	Rehabilitation objectives	Examples of remediation methods
PHYSICAL STABILITY ISSUES		
Safety issues related to steep slopes and rockfaces, deep water and water-filled spaces	• Compliance with safety requirements	• Prevention of public access; fencing off dangerous areas, displaying clear warning signs; closure of access roads
Collapse, subsidence and landslips	• Avoidance or minimization of subsidence and collapse	• Landscaping and stabilization of steep slopes by reinforcement, or revegetation; fencing off dangerous areas, displaying clear warning signs • Periodic safety inspections
Impact on surface drainage, infiltration and groundwater recharge	• Management of surface water drainage and runoff, assurance of groundwater recharge and quality	• Landscaping and furrowing
Erosion, siltation	• Prevention of erosion or siltation	• Revegetation, ditching, landscaping
CHEMICAL STABILITY ISSUES		
Generation of acidic groundwaters and/or leaching of hazardous metals (particularly mining of sulphide ores)	• Compliance with quality objectives for surficial and groundwaters	• Containment and active or passive treatment of mine-influenced waters; intensive monitoring of water quality during flooding and periodic follow-up inspection and analysis • Monitoring and management of water chemistry and hydrology
LAND USE ISSUES		
Negative aesthetic impact; Limitations on post-closure activities	• Restoration to natural state, with recreational value	• Landscaping and infilling depressions, revegetation programs

6.1.3 Waste rock management

Mining inevitably generates variable amounts of waste rock, which is essentially defined as rock material, with or without low grades of ore, which cannot be mined and processed profitably, but which must be removed to exploit the ore (Figure 37). Waste rock is usually assigned to stockpiles in close proximity to the mine, unless it can be used in conjunction with mining, for example in backfilling. The size of waste rock piles varies according to ore to gangue ratio and scale of operations, typically ranging from several to hundreds of hectares in extent. Therefore, if waste rock cannot be used during mining, it may have a significant impact on the surrounding landscape. In addition to ameliorating any adverse visual or land use impact, there is a legal obligation on cessation of mining activities to ensure that the waste rock piles complies with general safety requirements (Mining Act, Section 51), and that there is no risk of slope failure (Ministry of Trade and Industry Decision 921/1975, Section 130). It is also necessary to ensure that there is no environmental or health risk due to pollutants entering surficial or groundwaters, or from wind-borne dust ablation (e.g. Ministry of Trade and Industry Decision 921/1975, EC 2004, Environmental Protection Act).

Waste rock can commonly be used in road construction or other earthworks on site during active mining operations, or may be sold for use as aggregate in a variety of applications, including general road making, as construction material for the building industry, or as material for landfill or in embankments designed for mitigating traffic noise. Such practices and procedures are usually an acknowledged entitlement under the Mining Act. Thus the concession holder is not required to apply for a special permit for extraction of aggregate according to the Land Extraction Act (555/1981). However, terms for compensation need to be negotiated and specified when drafting the concession rights, or else separately, with the landowner, if the mine operator does not actually own the land. Waste rock can also be used, subject to certain restrictions, as backfill during mining or during rehabilitation after closure. In the former case, waste rock is immediately used to stabilize pit walls or tunnels and to backfill stopes and galleries. The value of waste rock can be enhanced if it is first sorted on the basis of environmental constraints and geotechnical properties and rock type, prior to transfer to separate waste rock piles. The use of waste rock within the mine area may require environmental approval permit and a specific utilization plan (refer to Section 3.1.1). A further condition is that the rock material satisfies both geotechnical criteria and is environmentally benign; waste rock must not, for example, be a source of potential contamination, as defined by the Environmental Protection Act. Use of waste rock outside the mining concession may be

Figure 37. Waste rock generated during mining varies greatly, from dust and sand-sized particles through to large boulders.

subject to additional, case-specific environmental approval (cf. Section 3.1.1) and economic considerations may also be relevant, if transport distances are significant. The Finnish National Road Administration has documented the potential uses of rock aggregate material (Tiehallinto 1994, 1999).

Ideally, if waste rock can be exploited, it is best to commence utilization as early as possible during the mining process, for this reduces the volume of material that needs to be dealt with at mine closure, and hence may also accrue financial benefit in terms of reduced closure expenditure. Minimization of mine waste prior to disposal is a high priority objective for management of waste rocks in the BAT reference document (EC 2004), as discussed in Section 3.4, and an essential feature of current general waste legislation in Finland, as well as of the waste management directive for the extractive industries of the European Parliament and the Council (2006/21/EC). The volume of waste rock requiring final disposal can be reduced by use in landscaping and stabilizing pit walls after mine closure, or in some cases in the neutralization of acidic groundwaters generated in the pit itself (EC 2004). However, infilling of an open pit may prove prohibitively expensive in terms of transport costs. Furthermore, even if there are no adverse environmental consequences (cf. EC 2004), it may be undesirable, if there is some possibility of reinitiating mining operations in the future.

If it is not possible to make use of waste rock either during mining operations or in relation to closure, final placement must be determined in accordance with current waste legislation (refer to Section 3.1.1). Planning and implementation of disposal of waste rocks both need to evaluate and anticipate long-term behaviour of the material and any safety risks associated with the disposal sites (cf. EC 2004, and Mining Act, Section 23). Current practice usually involves such assessment of short term and longer term issues relating to waste rocks prior to commencement of mining, which routinely includes evaluation of the following parameters and material properties (EC 2004):

- volumes of rock to be mined and assigned to waste rock piles,
- chemical and mineralogical composition,
- acid generation potential,
- leachability of potential contaminants,
- long-term behaviour and responses,
- physical and technical properties,
- hydrological parameters and
- grain size distribution.

It is also necessary to define these properties if the intention is to use the waste rock for other purposes. For effective risk assessment and management, it is also important to understand soil structure and hydrologic conditions at the disposal site (cf. Chapter 5). In practice these investigations are carried out prior to the commencement of mining, as an integral part of a baseline study or any environmental impact assessment (EIA) process (cf. Section 4.1).

The long-term chemical behaviour, acid generation potential, and metal leaching capacity of waste rocks can be studied in the laboratory using static and kinetic tests and selective extractions, while current environmental impact at the site can be evaluated by analysis of drainage channel and seepage water quality, supplemented by hydrogeological and geochemical modelling. Analytical and modelling techniques for evaluating long-term behaviour are described in more detail in Chapter 5 and in reports produced for the TEKES project 'Environmental Techniques for the Extractive Industries' (Kaartinen & Wahlström 2005, Kumpulainen 2005a and 2005b). Sulphide-bearing waste rocks are particularly susceptible to acid production as a result of sulphide oxidation, and thus have the potential for causing the release of acidic, metal-bearing waters into the surrounding environment.

If research findings indicate that waste rock is relatively reactive and has the potential for releasing pollutants into either surficial or groundwaters, which then constitute a wider environmental or health risk, then it is necessary to consider covering the rock pile with a dry or wet cover as a precautionary measure (EC 2004, refer also to Section 3.1.1). A range of covering options exists for impeding infiltration of oxygen or water into the waste rock pile, and thus inhibiting mineral weathering and acid production; these techniques are described in further detail in Section 6.2.2. In addition to, or in conjunction with covering of waste rocks, the possible need for treatment of mine waters should be assessed. Planning for monitoring procedures and for construction of a system of containment and drainage channels, if required, should also be undertaken (EC 2004; see also Sections 6.2.1 and 7.1).

Water quality problems may be addressed using either passive or active treatment methods, the latter tending to be more expensive to implement, and requiring more monitoring and maintenance. Passive techniques, such as the use of wetlands or limestone drains have gained wide acceptance in recent years for treating water discharge from waste rock piles and tailings areas. This approach and other methods for water treatment are described further in Section 6.2.1. All of these processes have the aim of purifying water to the extent that it can be ultimately released into the surrounding environment. Contaminated water is first channelled through a drainage network to the treatment area, making sure that there is no risk of runoff or infiltration and mixing with uncontaminated surface or groundwaters. The need for treatment ought to be evaluated on the basis of local conditions, because not all mine environments share the same attributes and potential for contamination risks.

If it can be established that waste rock is not inherently reactive and that there is no evident risk of contamination from waste rocks, then the closure program with respect to waste rock disposal sites can focus more on avoidance of physical safety factors, such as mitigating subsidence, slope failure and erosion (due to wind, water and temperature extremes), reducing dust generation, and evaluation of landscaping and revegetation requirements (EC 2004). Compliance with waste legislation requirements should also be addressed (refer to Section 3.1.1). The same procedure and risk management considerations apply to assessment of closure strategies at mines where waste rocks are demonstrably reactive.

Safety risk can be substantially reduced by landscaping waste rock piles and by preventing public access, by fencing, with appropriate warning signs, and by closing roads leading to the stockpiles. Restriction of access is not necessary if other measures have been implemented, both to reduce safety hazards and to facilitate multiple forms of post-closure land use. A prime consideration in landscape restoration is stability analysis (cf. Section 5.7), taking into account not only susceptibility to erosion and slope failure or subsidence, but also the likely impact of extreme weather events, such as storms and floods. It is also expedient to make use of topsoil or other overburden removed in connection with mining in the concession area, providing that they are geotechnically suitable and that they do not themselves pose any environmental risk (refer to Sections 5.9 and 6.1.4). Waste rock piles can be further stabilized with the aid of revegetation programs, which simultaneously reduces dust hazards. Natural

Table 22. Examples of risk factors, rehabilitation objectives and recommended remediation strategies with respect to waste rock (modified after UNEP/WHO 1998).

Potential risk factors	Rehabilitation objectives	Examples of remediation methods
PHYSICAL STABILITY ISSUES		
Subsidence and slope failure, erosion, impact on surface runoff and groundwater infiltration	• Mitigation of slope instability, erosion and siltation	• Landscaping with slope reduction and furrowing, drainage systems, settling ponds, earthen and rock retaining walls, revegetation programs, site monitoring
Safety	• Compliance with established safety guidelines	• Prevention of public access; fencing off dangerous areas, displaying clear warning signs
Disruption of surface runoff and groundwater infiltration and migration	• Management of surface water drainage and runoff, ensure effective groundwater recharge	• Landscaping and furrowing, containment and drainage channel systems
CHEMICAL STABILITY ISSUES		
Generation of acid mine drainage and/or leaching of metals or contaminants	• Compliance with water quality objectives	• Containment and active or passive treatment of mine-influenced waters; monitoring drainage water quality; using impervious cover on waste rock pile; elevation of water table (anoxic conditions), ongoing site monitoring • Monitoring and management of water chemistry, hydrology and potential pollutant migration
LAND USE ISSUES		
Negative aesthetic impact; Limitations on post-closure activities	• Restoration to natural state, other forms of land use compatible with sustaining natural ecosystem diversity • Utilization of waste rock	• Landscaping and slope reduction, revegetation programs, use of waste rock as mine backfill and/or in earthworks

regeneration may be appropriate and efficient in some instances but in other cases, establishment of floral diversity may require a layer of topsoil or mulch to be spread over the waste rocks. Suitable plants and planting strategies are discussed in more detail in Section 6.2.3. Landscaping and revegetation can in principle be carried out concurrently with mining, assuming that the waste rock will not be used for other purposes, which has the additional advantages of mitigating safety hazards at the same time as restoring landscape values and providing a better opportunity for maintaining ecological integrity.

6.1.4 Topsoil and overburden

Topsoil and overburden represents unconsolidated material excavated and removed at the commencement of mining. The amount of overburden removed obviously depends on depth to bedrock and scale of the mining operations. It is customary to store this material in proximity to the mine for rehabilitation purposes after mine closure, for example in covering waste rock piles and tailings, or for general landscaping, although it can also be used in earthworks during mining operations. Utilization of overburden material does not require a separate extraction permit according to the Land Extractive Act (555/1981), since the right to extract and exploit overburden within the concession areas is conferred by the Mining Act (503/1965). However, a separate utilization plan may need to be prepared to satisfy waste legislation (refer to Section 3.1.1). In addition, compensation arrangements, in the event that the mining concession holder does not own the land, will need to be mediated with the landowner.

A storage strategy for overburden should be implemented at the commencement of mining, so as to allow for material to be accessible for use both during mining and after closure. Ideally, different types of material should be stored separately, on the basis of compositional and geotechnical properties, and a map showing soil type and location within the storage area should be prepared. This procedure ensures that an adequate utilization plan is already in place at the commencement of mining activities. If the overburden is unsuitable for site remediation purposes, for example due to geotechnical reasons, then their final disposal must be carried out in accordance with waste legislation directives (refer to Section 3.1.1). Mine closure procedures also require that any remaining overburden heaps are stabilized to meet safety requirements (Mining Act 503/1965, Section 51), and landscaped appropriately. In general, landscape restoration can be addressed in an ongoing manner during mining.

6.1.5 Tailings areas

In addition to the quarrying of waste rock, some mines produce tailings as a waste product from enrichment of ore in concentration plants. Tailings consist primarily of gangue minerals, although they may also contain some potentially recoverable minerals, and are usually transported as slurry to an impoundment known as tailings area. The volume of tailings generated at a mine depends on the size of the deposit and the efficiency of extraction and concentration. Similar to waste rocks, tailings must meet general safety standards after mine closure, as required by law (Mining Act, Section 51, Ministry of Trade and Industry Decision 921/1975). If the tailings are still in slurry form at the close of mining operations, measures must be taken to dry the wet area, or to mark the area with warning signs and if necessary, surround it by fencing (Ministry of Trade and Industry Decision 921/1975). In addition, closure strategy must ensure that the tailings area is not a source of contamination and risk to the environmental or public health, through erosion, dust ablation, or migration of pollutants in surface waters or groundwater (as stipulated by Ministry of Trade and Industry Decision 921/1975, EC 2004, and the Environmental Protection Act). A further important objective of the closure strategy is to restore the area through landscaping and other appropriate measures to a condition in which a variety of alternative land use activities are permissible, particularly in areas where there is already considerable demand on land availability.

The primary objective with respect to treatment, management and remediation of tailings is to minimize the amount requiring final rehabilitation (e.g. EC 2004; Waste Act, Section 6.1.3). It is generally more difficult to utilize tailings during mining operations, for example compared to waste rock, partly due to its finer grain size. Nevertheless, tailings can be selectively used in earthworks and road construction at the mine site or in other applications, for example in raising the height of impoundment dams (Figure 38). Providing that it is chemically non-reactive, tailings may also be used in various ways outside the mine environment, in earthworks, and even as a fertilizer or supplement to enhance soil quality. If tailings are chemically reactive, they are clearly less amenable to such uses, either due to unsuitable geotechnical properties or because of their potential environmental impact.

Just as with waste rocks, utilization of tailings at the mine site may require permit from environmental authorities and preparation of a plan detailing specific activities, prior to commencement of mining. Likewise, environmental permits will be required for transport and use of tailings beyond the limits of the mining concession area (refer to Section 3.1.1). Tailings may also be used for backfill at the mine workings after closure, providing that there is no attendant risk of groundwater or surface water contamination. Commonly however, such large volumes of tailings are generated during operation that it is difficult to find sufficient economically viable applications in reasonable proximity to the mine, even if the tailings are useable from a technical or environmental viewpoint. Therefore, remaining tailings must be dealt with in a manner, which complies with waste legislation (refer to Section 3.1.1).

Prior to the commencement of mining, a utilization plan for tailings should be drafted, together with a tailings management and final placement strategies, including a closure and after-care procedure plan. The BAT reference document, which deals specifically with mine-related tailings and waste rocks (EC 2004), recommends that the following items and actions be considered in relation to tailings when planning closure strategies:

- mineralogical, chemical and geotechnical characterization of tailings properties
- water management and possible treatment strategies
- revegetation of the tailings impoundment
- environmental impact assessment
- site monitoring after closure
- liability and security
- proposed closure techniques and procedures
- post-closure land use options

The physical and chemical stability and behaviour of mine tailings over the longer term are determined by their mineralogical, chemical and geotechnical properties (Figure 39). Characterization of tailings according to these parameters is therefore central to defining and implementing effective closure strategies that comply with legal requirements. In order to adequately ascertain the likely long-term behaviour of tailings, assessment of the following parameters and properties is recommended (EC 2004):

- annual and cumulative volumes of tailings generated during mining,
- grain size distribution,
- density of solids, pulp density (% solid matter),
- stability and plasticity,
- porosity and compaction,
- mineralogical and chemical composition,
- acid generating potential,
- pore water chemistry,
- leachability of potential pollutants, and
- hydrological properties.

Figure 38. Tailings can be used for various purposes during mining, such as increasing the height of retaining embankments surrounding tailings impoundments.

Behaviour of tailings after mine closure and responses to change over the longer term should be studied as a routine aspect of the overall mine planning process (cf. EC 2004). This enables potential environmental impacts to be anticipated and assists in planning optimum location and structures of tailings impoundments and potential utilization of tailings in earthworks and as landfill. It is particularly important to carefully plan the placement and storage of chemically reactive tailings; this requires an additional understanding of soil structure, composition and hydrology at the proposed storage site, which nowadays tends to be an integral part of standard baseline studies or the EIA process (refer to Section 4.1).

Long-term behaviour of tailings can be assessed through empirical testing of samples in the laboratory or with the field studies, and also by using geochemical and hydrogeological numerical modelling. These methods are reviewed in detail in Chapter 5 and in working reports of the TEKES project 'Environmental Techniques for the Extractive Industries' (e.g. Heikkinen *et al.* 2004, Heikkinen 2005, Kaartinen & Wahlström 2005). One of the most important objectives of assessing long-term chemical behaviour is to determine the potential for tailings to generate acid mine drainage, or for release of metals or other pollutants into surrounding water systems, and if so, whether these processes constitute an environmental or health risk. The potential for discharge of acidic mine-influenced waters is mainly related to tailings generated from concentration of sulphide ores (cf. Section 6.2.1), compared for

a)

b)

Figure 39. Mineralogical and chemical composition of tailings exerts a strong influence on long-term behaviour. a) Sulphide-bearing tailings exposed to the atmosphere are susceptible to oxidation, which may generate acidic, metal-rich runoff and seepage. b) Tailings at carbonate mines tend to be more chemically non-reactive.

example, to quarries in carbonate rocks, where water in tailings ponds is typically near-neutral. Once the long-term behaviour of tailings has been established, it is possible to assess whether or not they need to be covered after mine closure, and the extent to which mine waters may require treatment.

The purpose of the various alternative methods of covering is to physically and chemically isolate sulphide-bearing waste in order to prevent oxidation of sulphide minerals and consequent discharge of acidic waters. Therefore, it is advisable to initiate the covering program while mining is in progress, or as soon after closure as possible. Acid generation can also be minimized during mining by refining the tailings to more effectively separate out and recover sulphide minerals, by storing sulphide-bearing waste separately from other tailings, or by mixing tailings with material having a pH buffering capacity, such as carbonate minerals (EC 2004). An alternative strategy for isolating tailings is to construct a wetland environment on top of the impoundment, or to elevate levels of water saturated zone close to the surface of the tailings impoundment (EC 2004). The effect of discharge from the tailings impoundment on water quality downstream can be further mitigated in a pre-emptive way by implementing various forms of passive and active water treatment. It should be noted that tailings contain large amounts of pore water, and that natural, unassisted drainage of the impoundment may take several decades. For treatment, surface runoff and groundwater discharge from the tailings is first directed through a network of channels surrounding the impoundment. The quality of the water released into the watershed downstream of the mine must be carefully measured, in accordance with a detailed monitoring procedure (refer to Section 7.1). Further detailed description of techniques for covering tailings areas and methods of water treatment are given in Section 6.2.

If routine or other environmental monitoring reveals evidence of groundwater contamination by tailings during mining operations, then under the Environmental Protection Act, there is an immediate obligation to determine the precise source and pathway of contaminant discharge and prevent any further release. The problem can be investigated using a range of geological, groundwater and geophysical techniques, supported as necessary by hydrogeological and reactive transport modelling, as discussed further in Chapter 5. Possible mitigation measures include the use of compacted clay or equivalent material at the site of discharge (e.g. Salonen *et al.* 2001), in order to provide an impermeable seal (Figure 40). An alternative approach is to construct a permeable reactive barrier, which allows discharge to continue, while water quality is assured. Progress and success of these remedial procedures requires continual monitoring of groundwater chemical parameters (refer to Section 7.1).

If the tailings are chemically non-reactive and there is no demonstrable environmental or health risk, then the main emphasis of closure strategy is on ensuring the long-term physical stability of the reclaimed environment, such as prevention of subsidence, erosion and dust ablation, or the ecological restoration through landscaping and revegetation programs. Obligations under waste legislation will also need to be observed (cf. Section 3.1.1). The same requirements apply to closure situations where tailings are of a chemically reactive nature, in addition to evaluating the need for covering of tailings and water treatment programs.

Long-term physical behaviour and response can be evaluated by stability calculations based on a range of physical parameters (refer to Section 5.7). These estimations also need to consider the effect of natural phenomena, such as rainfall, vegetation cover, and extreme weather events on erosion and slope stability. The stability of tailings impoundment dams can be enhanced by decreasing slopes and buttressing, by decreasing pore water pressure in the impoundment, either through pumping water out or by decreasing surface water infiltration with a cover layer. Additional measures include furrowing to arrest erosion on steeper slopes and directing runoff into drainage channels, as well as stabilization with vegetation cover. The stability of tailings impoundments can also be improved by drainage of settling ponds and removal of any retaining structures that are no longer required. However, drainage of settling ponds is always subject to environmental constraints and the final disposal site for sludge remaining after draining needs to be assessed within the framework of best practice and relevant mining and environmental legislation (refer to Chapter 3). It is also necessary to define a utilization strategy for material remaining after demolition of embankments and other earthworks. Stability calculations and methods for improving stability are discussed in detail in Section 5.7 and also in a working report compiled for the TEKES research project 'Environmental Techniques for the Extractive Industries' (Juvankoski & Tolla 2004). If the possibility of slope failure or subsidence remains at the site, despite due efforts at enhancing stability, or if other potential hazards occur (for example if tailings are saturated and at risk of liquefaction), then the area should be fenced off and clearly marked with warning signs prohibiting entry (cf. Ministry of Trade and Industry Decision 921/1975). Monitoring of structural stability and integrity should also continue on a periodic basis after mine closure and relinquishment (refer to Sections 5.7 and 7.2).

Figure 40. If a tailings impoundment is constructed over a permeable substrate, there is an enhanced potential for groundwater contamination. Site remediation measures may include arresting discharge of water from the impoundment by addition of impermeable compacted materials in various ways. The example shown here involves the use of compacted clay directly overlying bedrock. The location of tailings impoundments should only be decided after thorough characterization of soil structure, with areas underlain by coarse, poorly consolidated materials to be avoided.

Covering of tailings may be required if the area is susceptible to raising of dust by wind ablation, or if the establishment of desired vegetation demands landscaping and improvement of soil quality. As in the case of managing waste rock, it is most expedient to make use of material stockpiled on site, in particular overburden and topsoil, providing they are appropriate in terms of environmental and geotechnical considerations (cf. Section 5.9). If the purpose of covering is primarily to mitigate the effects of dust, as well as landscape restoration, then a relatively thin layer of topsoil or mulch and humus is adequate, and less attention needs to be given to permeability than in situations where the intention is to isolate sulphide-bearing tailings to prevent oxidation (EC 2004, refer also to Section 6.2.2). Normally, the thickness of the cover depends on local circumstances, including the risk of erosion and post-closure land use scenarios. In some cases, there may be no need to apply a layer of topsoil at all, and vegetation may be established directly over the tailings. Generally, systematic planting of seedlings or application of seed from rapidly growing grassy species accelerates the regeneration (EC 2004). It is usually possible to com-

Table 23. Examples of risk factors, rehabilitation objectives and recommended remediation strategies for mine tailings (modified after UNEP/WHO 1998).

Potential risk factors	Rehabilitation objectives	Examples of remediation methods
PHYSICAL STABILITY ISSUES		
Safety of tailings dams	• Factor of safety > 1.5 for static conditions • Resistance to erosion, including extreme events	• Landscaping, particularly of sloping surfaces; drainage systems; retaining embankments; contoured furrowing to arrest erosion; revegetation; regular inspections and monitoring
General safety	• Compliance with safety requirements	• Prevention of public access; fencing off dangerous areas, displaying clear warning signs • Periodic inspections
Dust generation, winnowing and accumulation of silt or slime	• Prevention of dust ablation and erosion	• Revegetation programs, settling ponds, contoured erosion furrows
Disruption to surface runoff and groundwater recharge	• Management of surface water in and around tailings area	• Landscaping and drainage channels
CHEMICAL STABILITY ISSUES		
Generation of acid mine drainage and/or leaching of hazardous metals; Leaching of residual processing chemicals and other pollutants	• Compliance with water quality objectives	• Containment and active or passive treatment of mine-influenced waters; covering tailings with impermeable compacted layers; monitoring of drainage water quality; raising water table (anoxic conditions), ongoing monitoring • Monitoring and management of water chemistry and hydrology
LAND USE ISSUES		
Negative aesthetic impact; Limitations on post-closure activities	• Restoration to functional ecosystem, with recreational value	• Landscaping of impoundment surface and embankment slopes; revegetation programs

mence landscaping and revegetation programs during mining, which enhances the potential for the area to revert to a functional ecosystem as rapidly as possible following mine closure, and thereby allowing a wider range of post-closure land use options.

After site rehabilitation and landscaping, tailings areas can be used for a variety of purposes, such as for example, golf courses. However, during any post-closure land use activity and development, it is necessary to remain aware of all procedures and earthworks carried out during the closure process. Care must be taken that future activities do not disrupt the former tailings area, to the extent that there could be any form of renewed environmental contamination or health risk. It is therefore both practical and advisable to assign a separate status to the area for the purposes of urban or other municipal land use zonation and to come to a formal agreement with subsequent landowners and stakeholders concerning the nature of any proposed developments and associated responsibilities and liabilities for compensation (refer to Sections 3.5 and 6.3).

6.1.6 Decommissioning and demolishing buildings and other infrastructure

A mining concession area contains numerous buildings and infrastructure directly related to extraction and processing of ore (for example head frames, crushing plants and concentrators, concentrate storage facilities), as well as offices and laboratories, maintenance, service and storage depots and workshops, and other buildings used by subcontractors (Figure 41). Additional infrastructure may include roads and railways, electrical cables and transformers, other pipes and cables, various storage facilities for diverse materials and in some cases settling ponds.

The legal requirement to ensure that the mine site presents no risk to public safety (Mining Act, Section 51) also applies to infrastructure at the site. This effectively requires the demolition and removal of buildings considered unnecessary or whose condition has deteriorated beyond repair, an assessment of options for ongoing utilization of remaining buildings and structures, and general cleaning of the site. According to the Mining Act (Section 51), the concession holder retains the right to keep the buildings and facilities remaining above ground at the mine site for a period of up to two years following formal relinquishing of mining activities, after which ownership of the structures is transferred, without compensation, to the landowner. An exception to this is made, however, in the case of ladders and stairwells in mine workings which are retained to ensure safe access to the mine, and concrete headframes and related facilities which can only be used specifically for the purposes of mining. These structures should be left in place, unless a special ex-

Figure 41. The mine site contains a number of specialized buildings and structures, such as the crushing mill shown here, at the Hitura Ni mine, Nivala, Finland. In general, such infrastructure is dismantled during mine decommissioning and closure, if they cannot be used for other purposes or for processing ore from nearby deposits.

emption granting their removal is made by the Ministry of Trade and Industry (Mining Act, Section 51).

During the demolition and removal phase of mine closure, opportunities for re-use and recycling of materials, as well as their potential as energy sources needs to be assessed, in accordance with relevant waste legislation. Some buildings may be suitable for sale, and either re-occupied on site, or dismantled and relocated elsewhere. There are also examples where mine buildings and infrastructure are of cultural and historical significance and are maintained as mining museums, as in the case of the Outokumpu mine, or have heritage listing under the Finnish Building Protection Act (60/1985), as in the case of the Keretti head frame, also at Outokumpu. In general however, decommissioning mine buildings and structures are seldom suitable for alternative use or occupancy. Moreover, mines are commonly situated in remote locations, making demolition the most practical alternative. The possibility of selling buildings should nevertheless be considered early during the closure process, so that issues related to ongoing land management and liabilities can be negotiated with prospective buyers and, if necessary, agreed to in a written contract.

During the demolition of buildings and other mine facilities the opportunity should be taken to salvage and sort materials for re-use or recycling, especially metal, stone and concrete, wood and other combustible material, as well as plastic and glass for salvaging. Dismantled steel structures for example can be sold as scrap metal, which may contribute towards offsetting closure costs.

Due care should also be exercised during decommissioning and demolition to avoid generating any additional environmental or health hazards; for example asbestos in older buildings may be a potentially severe problem. Other materials that may require careful handling include linoleum sheeting and flooring, thermal insulating material around hot water pipes and boilers. Settling ponds associated with concentration facilities may also be present, with accumulation of insoluble, metal-bearing residue, which may therefore also require removal and disposal. Any remaining materials, which cannot be effectively used or recycled should be properly disposed of or taken to a landfill site or to a hazardous waste treatment plant for appropriate treatment and disposal.

Table 24. Examples of risk factors, rehabilitation objectives and remediation strategies for decommissioning and demolition of mine buildings and other infrastructure facilities (modified after UNEP/WHO 1998).

Potential risk factors	Rehabilitation objectives	Examples of remediation methods
PHYSICAL STABILITY ISSUES		
Safety of buildings, other mine and other infrastructure and facilities, and roads	• Maximizing re-use and recycling of materials from dismantled structures; ensuring upkeep and maintenance of remaining facilities; clear assignment of accountability • Compliance with safety requirements	• Determine which roads, buildings and structures are retained, and assign future use options (such as museum status); devise site maintenance plan; plan and implement immediate demolition and dismantling of other facilities; restriction of public access • Assignment of accountability • Periodic inspections
Disruption to surface runoff and groundwater recharge	• Management of surface water	• Drainage systems; ongoing maintenance of retaining embankments and ensuring unobstructed flow in pipes, drainage channels and road culverts
CHEMICAL STABILITY ISSUES		
Environmental hazards due to building materials, contaminated soils and chemical storage depots; general safety risks	• Mitigation of environmental hazards and ensuring safety	• Determine extent of contamination; responsible removal and disposal of chemicals and contaminated materials, remediation of contaminated soils; removal of underground storage tanks
LAND USE ISSUES		
Options for ongoing use of buildings and roads	• Maximum utilization of any remaining infrastructure and facilities	• Ascertain potential options for utilizing buildings and roads
Negative aesthetic impact; Limitations on post-closure activities	• Development of functional ecosystem, with recreational value	• Landscaping; revegetation programs; demolition and removal of unnecessary infrastructure

6.1.7 Machinery and equipment

All mining machinery and equipment, including those used in crushing and concentrating, are removed from the mine site, when mining ceases. The Mining Act also identifies certain equipment related to mine safety and applicable only to mining operations that require an additional permit from the Ministry of Trade and Industry for removal from the mine site (Mining Act, Section 51). As in the case of buildings and infrastructure, the potential for redeployment or sale and/or recycling of machinery and mining equipment, either for materials or energy purposes, needs to be established (refer to Section 6.1.6). For example, mining equipment and mill and concentrator machinery can be purchased by other mining operations if in good condition, or sold as scrap metal if in poor condition (Figure 42). The concentrating plant can also be sold in its entirety, in which case the only equipment that needs to be removed from the mine site is that directly related to mining. The removal of machinery and equipment should be conducted in a manner that does not pose any environmental or safety risk. Any equipment or materials, which cannot be effectively recycled or used, should be transported to a landfill site or to a hazardous waste treatment plant, if necessary, where it can be disposed of in an appropriate manner. In accordance with Section 51 of the Mining Act, the concession holder may remain surficial equipment or machinery at the site for a period of up to two years after formal mine closure. After this time, the ownership of the equipment is transferred to the current landholder, without any obligation for compensation.

6.1.8 Contaminated soils

Contamination of soil may occur within the mine area itself, or in proximity to the concentration plant. Contaminant sources can include ore, waste rock, tailings and concentrate, all of which release diverse mineral particles, metallic complexes, and chemical compounds that could be dispersed throughout the mine area, by wind, surface runoff or migration through porous sediment. Spillage of oil and other petroleum products and processing chemicals can also occur during routine transport, refuelling and storage, as well in accident situations. Depending on soil permeability and its other properties, such contaminants may spread laterally over significant distances and potentially migrate into surrounding aquifers.

According to Section 90 of the Environmental Protection Act (86/2000), the mine operator remains responsible for prevention of pollution and for determining and monitoring the impact of the operations, in accordance with permit regulations, even after mine closure. Upon closure, the operator is likewise obliged

Figure 42. All mining equipment and machinery must be removed from underground locations during the mine closure process.

to ascertain and report any evidence of contamination of soils, surface water or groundwater that might have occurred in relation to mining, enrichment or other activities, if this was not already adequately investigated and monitored during the operations. If it is suspected that contamination is present, the relevant authorities should be contacted to determine an appropriate response (cf. Section 3.2).

Under Sections 7 and 8 of the Environmental Protection Act, the mine operator is responsible for ensuring that waste or other substances shall not be left or discharged on the ground or in the soil such that any resultant deterioration of soil or groundwater quality could endanger or harm health or the environment, substantially impair the amenity of the site or cause comparable violation of the public or private good (cf. Section 3.2). In accordance with Section 18 of the Environmental Protection Decree (169/2000), monitoring of activities and their potential impacts on the surrounding soil and groundwater should be carried out as described in the environmental permit if applicable. In addition, an emergency response plan should be prepared, if applicable, in anticipation of the event of accidents, for example. If an accident or another exceptional situation does occur, relevant authorities should be notified immediately, following the procedure specified in Section 24 of the Environmental Protection Decree, and remediation actions need to be implemented without delay (Environmental Protection Act, Section 62).

According to the recently enacted Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007), natural baseline concentration levels should be taken into account while assessing the soil contamination and remediation needs among other things. This applies particularly in the case of toxic metallic elements, since baseline concentrations in the mine environment may naturally be rather high. New decree involves soil quality guidelines for about 50 chemicals and chemical groups. The case specific risk assessment of soil contamination and remediation needs has an essential role in this decree (cf. Section 5.8). An example of the approach that might be taken in investigating site contamination and monitoring the progress of site remediation is given in Appendix 11.

After case specific risk assessment of possible soil contamination in the mine area and its surroundings has been undertaken, and the need for remediation has been recognized, appropriate treatment practices should be selected, using best available technology (BAT). If the contaminated soil is excavated and replaced with clean soil the possibility of using this excavated soil for covering tailings could be considered. Alternatively, if the contamination is entirely inorganic in nature, it may be possible to use the contaminated soil as backfill in an underground mine. According to Section 78 of the Environmental Protection Act, remediation of contaminated soil usually requires an environmental permit although under some circumstances it may be sufficient to notify local environmental authorities as described in Sections 24, 25 and 28 of the Environmental Protection Decree. Further information concerning alternative methods of remediation, and permitting procedures is given in Section 5.8.

6.2 RISK MANAGEMENT STRATEGIES FOR MINE CLOSURE

In the following section examples are given to illustrate risk management procedures in relation to water treatment and restoration, covering of waste rock piles and tailings areas, and landscaping of mine sites.

6.2.1 Water management and treatment

A crucial aspect of risk management after mine closure is the treatment and control of mine waters that may pose a risk to environment of public health (cf. Section 6.1). Base metal and coal mines are particularly prone to generating acid sulphate and metallic ion waters, which thus require careful monitoring and treatment. The formation of acidic mine influenced waters is less likely where industrial minerals and limestone are quarried. Instead, depending on the precise mineralogy of mined material, waters both in the mine or quarry, and in associated waste rock and tailings areas, will tend to be near neutral or somewhat alkaline. It is still possible however, that contamination by powder from explosives for example, is present or that water contains significant amounts of solid matter, which precludes direct release into the surrounding environment. In the following discussion, the focus is primarily on water treatment in relation to sulphide-bearing mining activities.

Mining of sulphide ores typically generates waste rock and tailings, which are usually disposed in close proximity to the mine itself. Through exposure to weather, combined with microbial activity, near-surface tailings or waste rock tend to become oxidized. Acid mine drainage is generated when oxidized sulphide grain surfaces come into contact with water during weathering, leading to leaching of metals and sulphate, and potential transport into surrounding surficial and groundwaters. Acid mine drainage may also form in underground and open pit mining operations. The following reactions, which are typical in the mining environment, describe the weathering of pyrite (FeS_2) under oxidizing conditions (Kleinmann *et al.* 1981):

Mine-influenced waters may be highly acidic, with pH < 3, associated with elevated sulphate (SO_4^{2-}) and metal and metalloid (Cu, Fe, Zn, Al, Pb, As, Cd) concentrations (Fortin *et al.* 1995). Conversely, in some mine environments, neutral to slightly alkaline waters may be present, depending on the abundance of sulphides relative to carbonate and silicate minerals, such as calcite or serpentine, which tend to have a neutralizing effect. While the process of formation of acid mine drainage is now well understood, there is nevertheless considerable variation in drainage quality between individual mine sites, depending on water flow regimes, mineralogical composition of tailings and host rocks, climatic conditions and even the strategy adopted for closure (Baker and Banfield 2003).

Where site rehabilitation is unable to prevent the formation of acidic drainage or surface flow, or water composition differs from those in the ambient environment, a separate treatment program is generally called for. It is therefore important that the waters in the potential discharge zone are carefully characterized, to better anticipate likely changes and hence treatment strategies. This process involves assessment of standard parameters, such as BOD, COD, nutrient and elemental abundances, as well as physical variables, notably redox state, which has an important effect on metal cation and ligand behaviour. A range of active and passive forms of water treatment are available, as summarized in Table 25, including chemical methods and its applications aimed at neutralizing water pH, for example by flow through anoxic or oxic limestone drains (ALD or OLD) – excavated channels filled with crushed carbonate. Alternative schemes involve microbial or microbiological treatment in anaerobic wetlands and bioreactors, and filtration through permeable reactive barriers and leach beds. Additional procedures such as settling ponds may also be used, for removing suspended matter. A more detailed description of these methods and their applicability to various situations is presented in Appendix 12.

$$2\,FeS_2\,(s) + 7\,O_2\,(aq) + 2\,H_2O \rightarrow 2\,Fe^{2+}\,(aq) + 4\,SO_4^{2-}\,(aq) + 4\,H^+\,(aq)$$

$$4\,Fe^{2+} + O_2\,(aq) + 4\,H^+\,(aq) \rightarrow 4\,Fe^{3+} + 2\,H_2O$$

Different procedures have been developed for different water compositions (cf. Table 25). Individual mine sites need to be assessed accordingly, taking into consideration both water chemistry and flow rates in order to ascertain likely contaminant loading. Enhanced results are commonly achieved by combining several treatment processes, or through multiple cycling through a single process. For example, iron concentrations can be reduced initially by flow through aerobic wetlands (Figure 43), before neutralization of waters by passing them through an open limestone channel (OLC) system, thereby avoiding a loss of neutralizing potential by precipitation of iron compounds on carbonate surfaces. Similarly, wetlands will perform better if inflowing waters have already been subjected to oxygenation and passed through settling ponds.

Choice of appropriate processes is not only dictated by the amount and composition of water but also by the residence time required for effective treatment. In some passive applications, for example, wetlands or permeable reactive barriers, a minimum residence time is required to facilitate the necessary reactions. Important additional criteria to consider when choosing treatment strategies are balancing implementation and management costs against remediation requirements, the effect of seasonal fluctuations in water flux and pollutant concentration, and intrinsic factors including climate, topography and soil type. During the planning stage it is also advisable to test the efficiency of alternative treatment methods for the selected mine site in the laboratory or undertake pilot studies on site. Pilot studies furthermore provide an opportunity for estimating the real cost of the remediation program and for avoiding mistakes in defining the necessary scope of the program and the parameters for design and sizing of the treatment system, the geochemical approach to be used and the practical design of ongoing monitoring and management.

In closure planning, attention must also be given to drainage patterns and hydrology of the rehabilitation site, so that contaminated waters can be contained and directed to treatment areas, and that treated water can be released into the surrounding catchment area in a controlled manner. In general it is desirable to avoid mixing of contaminated and clean or treated waters, for example by diverting clean waters away from and around the mine site. It is also common practice to ensure containment of runoff and groundwater percolation by excavating adequate trenches around tailings impoundments (Figure 44). Assessment of the necessity for water treatment and management should be made not only for discharge from tailings areas but also for waters from waste rock piles, or overflow from closed mineshafts and open pits, with a view to the potential for extreme events occurring over long timescales. Only by adopting this comprehensive approach will minimization of risk to the surrounding environment be assured.

Figure 43. Aerobic wetlands are highly suited to treatment of near-neutral (pH > 5) waters containing elevated Fe and Mn. Precipitation of Fe and Mn compounds reduces trace metal abundances in the water, while vegetation modulates flow rates and promotes retention of precipitates within the confines of the wetland basin (Hammaslahti Cu-Zn mine, Pyhäselkä, Finland).

Table 25. Examples of water treatment methods for different types of mine drainage.

Method	Treatment mechanism	Appropriate applications	Advantages	Disadvantages	References
Neutralization	• Addition of alkaline material causes increase in pH • Metallic cations precipitate as (oxy)hydroxides and carbonates	• All acidic mine waters	• Efficient at increasing water pH	• Need to physically remove and dispose of metallic precipitates • High cost of chemicals and monitoring	Ledin & Pedersen 1996; MEND 1994
Open limestone channel (OLC)	• Limestone added to mine water outflow drainage systems • pH of water increases, causing metal precipitation as (oxy)hydroxides and carbonates	• Acidic mine waters with relatively low metal concentrations	• Effective increase in water pH • Straightforward implementation	• Requires regular replenishment of limestone • Tendency for reactivity to decline due to precipitation on limestone surfaces • Loss of limestone at high flow rates	Ziemkiewicz *et al.* 1997
Anoxic limestone drainage (ALD)	• Anoxic mine water channelled through buried and sealed cells of limestone • Carbonate dissolution increases pH of water and enhances buffering capacity	• Moderately acidic mine waters, with dissolved O_2 < 1mgL^{-1}; Fe^{3+} < 2 mgL^{-1}; Al^{3+} < 2 mgL^{-1}; SO_4^{2-} < 2000 mgL^{-1};	• Produces good quality water • Effective for long time period (> 10 years) • Requires only small area to operate effectively • Cost-effective compared to traditional neutralization techniques	• Susceptible to blockage of drainage channels • Stringent requirements on composition of inflow water • Requires additional anaerobic or aerobic treatment for removal of metallic pollutants	MEND 1996; PIRAMID Consortium 2003
Reducing and alkalinity producing systems (RAPS)	• Analogous to limestone drainage system • Water passes through compost layer overlying limestone layer • Compost layer reduces oxygen and metal abundances in mine waters	• Moderate acidic mine waters	• Effective in small areas • No problem with precipitation • Cost-effective compared to traditional neutralization methods	• System must be located at least 2.5 m below level at which mine waters are produced • Requires additional anaerobic or aerobic treatment for removal of metallic pollutants	PIRAMID Consortium 2003
Aerobic wetlands	• Aqueous oxidation reactions mediated chemically and biologically cause precipitation of metallic hydroxides and oxyhydroxides • Accumulation of precipitates at bottom of wetland	• Iron-enriched and alkaline mine waters	• Efficient removal of metals from solution • Cost-effective, subject to site-specific considerations	• Oxidation reactions tend to decrease water pH • Effectiveness sensitive to temperature and compositional fluctuations • Potential formation of undesirable flow channels	MEND 1996; Gazea *et al.* 1996; PIRAMID Consortium 2003
Anaerobic wetlands	• Sulphate-reducing bacteria cause shift in redox state, raising water pH and precipitating metal sulphides • Source of organic carbon added to system to promote bacterial activity	• Acidic mine waters with SO_4^{2-} > 300 mgL^{-1}	• Highly efficient • Cost-effective, subject to site-specific considerations	• Usually requires supplementary aerobic treatment • Effectiveness sensitive to temperature and compositional fluctuations	MEND 1996; Gazea *et al.* 1996; PIRAMID Consortium 2003
Bioreactors	• Sulphate reduction in reactor raises water pH and leads to metal precipitation as sulphides • Requires addition of carbon source and nutrients to activate sulphate-reducing bacterial population	• Acidic mine waters with SO_4^{2-} > 300 mgL^{-1}	• Small space requirements • Easy to activate and adjust operations	• Expensive monitoring and maintenance • Suited to relatively small volumes of water	MEND 1996
Open pit and mine shaft bioreactors	• Relies on addition of carbon source and bacterial strain to promote bacterially mediated sulphate-reduction • Bacterial activity raises alkalinity and promotes metal sulphide precipitation	• Acidic mine waters with SO_4^{2-} > 300 mgL^{-1}	• Mine waters treated efficiently before release into ambient environment • Virtually negligible cost • Negligible monitoring and management requirements	• Mineshaft needs to be sufficiently deep • Effectiveness sensitive to temperature and compositional fluctuations	Mustikkamäki 2000
Permeable reactive barriers (PRB) and leach beds	• Mine water flow is channelled through permeable reactive barriers, either above or below ground • Sulphate reduction within reactive material increases pH and leads to metal sulphide precipitation • Hydraulic conductivity of reactive material must exceed that of surrounding soil material	• Acidic mine waters with SO_4^{2-} > 300 mgL^{-1}	• Efficient • Cost-effective, subject to site-specific considerations • Relatively long (> 10 year) operational time • Negligible monitoring and management requirements, and thus appropriate in remote locations	• Risk of sealing and clogging reduces flow and renders process ineffective • Effectiveness sensitive to water temperature and compositional fluctuations • Suitable for relatively small flow rates	Waybrant *et al.* 1998; Mustikkamäki 2000

Figure 44. Potential seepage of water through tailings dams is contained by an effective system of trenches, which also channels water for further treatment as necessary (Zinkgruvan Zn-Pb mine, Sweden).

6.2.2 Procedures for covering tailings and waste rocks

It is difficult to provide generic guidelines for covering procedures of waste rock and tailings management facilities. Overall, objectives and requirements need to be determined case-specifically, based on assessment of a range of criteria, including the nature of the tailings and waste rock materials and the cover material, hydrological and soil parameters and attributes at the rehabilitation site, and consideration of future land use requirements, as well as any technical difficulties that might arise, related to location, and availability of suitable covering material. Depending on the above site-specific characteristics, objectives of the covering program may be to:

- prevent wind ablation of tailings or waste dumps and hence airborne transport of pollutants into the surrounding environment
- ensure that the site remains inert over the long term
- prevent or minimize the formation of acid mine drainage, by excluding transport of oxygen into the tailings or waste rocks
- prevent leaching of metallic and other pollutants from the tailings and waste rocks by preventing the water infiltration into the materials
- promote the establishment of a viable ecosystem in harmony with the surrounding environment

The nature of tailings, waste rocks and mine host rocks varies considerably, depending on whether the mine has been exploiting industrial minerals, sulphide ores or various other metals. Conditions and requirements for covering also vary further within these groups. Therefore, it is important to characterize the properties of the material to be covered in order to assess both the potential environmental impacts and risks related to the material, prior to deciding implementation strategy.

It is also important to appreciate that extraction and transport of cover material to the site of rehabilitation may in itself have a significant impact on the surrounding environment and should therefore be incorporated into the decision-making process. In many instances, a reasonable solution, both financially and in terms of minimal environmental impact, is the temporary storage of topsoil and other material in close proximity to the mine in a manner that promotes their utilization. A flow chart depicting the process of design and implementation of a covering program is shown in Figure 45.

When prescribing specific remediation programs, compliance with closure legislation (cf. Chapter 3) should be given first priority. Application of best practice technologies and solutions will presumably receive even more attention in the future. For example, the recently published EC mining industry guidelines on management of tailings and waste rocks (EC 2004) place particular emphasis on analysis of the whole mining process, from planning to decommissioning and rehabilitation. While BAT reference documents are important, other sources of information contained in research and technical reports should also be used in deciding whether a given strategy is appropriate.

There are essentially two options for isolating tailings and waste rock – burial beneath a layer of overburden, or covering with water, although the possibility of leaving tailings exposed may also be considered.

Options for leaving tailings uncovered

The simplest procedure is to landscape the closed mine environment in whole while leaving tailings and waste rock areas uncovered. This may be acceptable if it can be shown that the tailings and waste rock management facilities are stable and pose no health risk or safety hazard to humans or wildlife through groundwater contamination or dust ablation. It is nevertheless necessary to take measures against the possibility of erosion over the long-term, by establishing vegetation, or controlling the flow of water through the area.

Dry cover layers

Covering tailings or waste rock with a dry layer of overburden is an effective way of mitigating generation of dust, water infiltration and oxygen diffusion. At the same time, this approach generally provides enhanced conditions for plant growth, reduces the risk of erosion and can be integrated with landscape restoration. Prior to covering it is customary to dewater the tailings, and to allow consolidation of tailings. Some form of temporary covering measure may be required at this stage, to prevent dust ablation. It is also necessary to deal with potential erosion and ponding of surface waters in the management facilities, by designing slopes with an appropriate angle of repose and using furrowing to and channels to arrest and divert water runoff (EC 2004).

The thickness, structure and material properties of the cover layer will be determined by the nature of the tailings and other site characteristics, including the local water table, and the availability of and access to source material, all of which need to be considered thoroughly. If the material to be covered is reactive or susceptible to acid production, and the intention is to isolate the tailings from oxygen diffusion and water infiltration, the following features should also be examined carefully (Naturvårdsverket 2002):

- The potential for interaction between the atmosphere and tailings or waste rock, for example via plant root systems or disruption of surface integrity by subsidence or some other mechanism
- The possibility that seasonal temperature and rainfall fluctuations induce frost heave or desiccation cracking and thereby affect the effectiveness of the covering layer
- Measures to mitigate the effect of erosion should also take into account extreme and unlikely events, such as flooding, or freezing and blockage of drainage networks

The risk of excessive acid production can be addressed by moderating the pH of the material to be

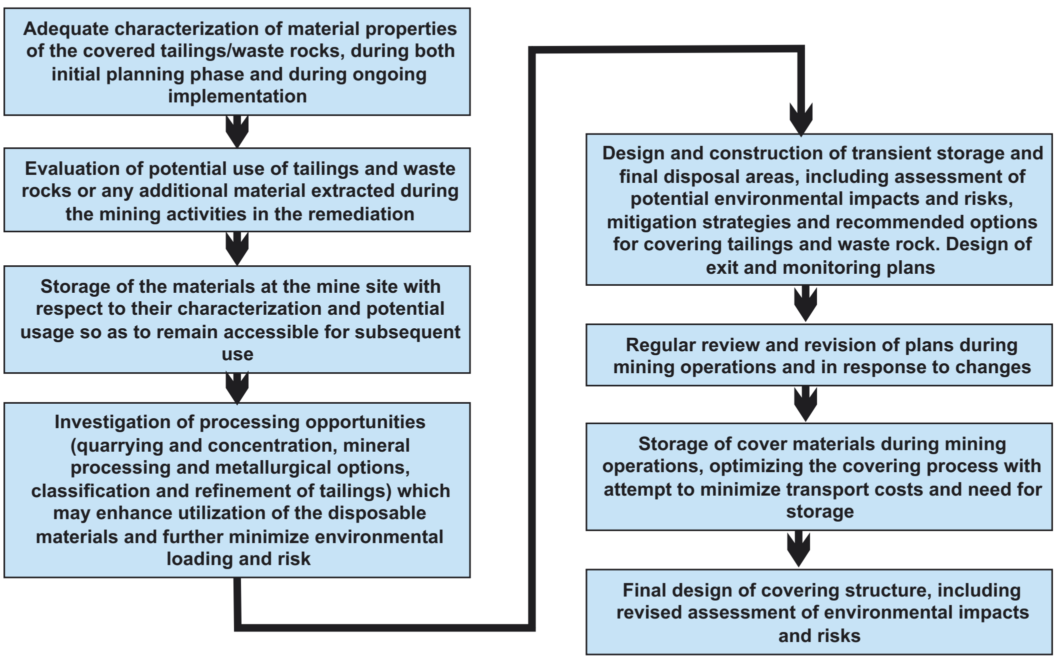


Figure 45. Designing the covering of the tailings and waste rock areas.

covered by addition of lime, crushed limestone or fly ash, prior to covering.

The most straightforward method is to spread the cover material without any attempt at compaction or consolidation. This is appropriate in situations where there is no need to prevent the water infiltration into the covered material. If the covering material is inherently relatively impermeable, then it is possible to make an effectively impervious barrier by spreading and compacting two or more layers. Oxygen diffusion can be dealt with by designing the system such that the water table lies within the cover layer, but in this case it is necessary to ensure that there is no possibility of accidental release of acidic waters or solid waste material.

A more effective approach to prevention of oxygen and water infiltration is by spreading two separate layers, a sealing layer (for example compacted impervious clay) and the surface layer. The upper layer thus protects the lower layer against the effects of erosion and structural degradation due to seasonal dehydration or freezing, as well as minimizing direct interaction with humans and other animals, plants and microbial activity. Moreover, this layered structure both disrupts upwards capillary flow and favours retention of any metal complexes transported by pore waters.

The EC's BAT reference document (EC 2004) also describes a further option in which the compacted layer is overlain by another layer intended to prevent the water infiltration and to promote drying of the substrate. However, excessive drying and potential desiccation of the surface layer may lead to oxygen infiltration to deeper levels. Moreover, in the long-term, the geotextile between the layers may deteriorate, leading to mixing of the layers and reduction of the effectiveness of the desiccation layer.

In oxygen consuming cover layer a water-saturated, relatively impermeable structure also acts as an effective barrier to oxygen diffusion, since breakdown of organic matter in the surficial layer consumes oxygen. However, if organic matter promotes biologic reduction of iron, there is an increased risk of metal leaching. Conditions might also be favourable for bacterial sulphate reduction, although so far, neither of these processes has been documented during site monitoring.

Dry cover methods have been widely used in mine site rehabilitation in the Nordic countries, for example at Enonkoski and Keretti (Outokumpu) in Finland and at Viscaria in Sweden. Further examples of this approach are listed in Appendix 13.

The use of water covers

The use of water cover is appropriate in situations where the aim is to prevent oxygen infiltration into tailings that are susceptible to acid production, the main reason being that oxygen diffusion rates are four orders of magnitude lower in water than in air (Robertson *et al.* 1997). However, covering by a layer of water requires that the following conditions are met:

- Water must be available, even if the area is subject to seasonal dryness, in sufficient amounts to ensure that both the water table and water chemistry remain stable
- Dams and impoundments are structurally stable over the long-term
- Outflow channels are stable and with a capacity designed for coping with isolated extreme flood events, and also other eventualities, such as ice dams and log jams
- Water depth above the tailings is deep enough such that wave action does not cause erosion or hydraulic separation and concentration of tailings.

The impoundment will function best if it is integrated with the surrounding watershed and is fed by inflow from a natural stream. This accelerates the restoration of a natural ecosystem by supplying organic matter, nutrients, and aquatic biota. Moreover, influx and deposition of sediment enhances the existing barrier to oxygen diffusion within the underlying tailings. The greatest uncertainties with respect to this approach lie in ensuring the long-term stability of the impoundment dams and that an adequate supply of water is maintained over the longer term, even after monitoring of the site has ceased. Appendix 13 documents examples of water-covered tailings schemes in Sweden.

6.2.3 Revegetation programs in landscape restoration

Revegetation programs not only provide aesthetic enhancement of former mining sites, but also mitigate any adverse effects associated with tailings and waste rock areas and closed open pits and quarries, whether due to drainage issues or slope instability. Vegetation cover also effectively isolates potentially hazardous materials from contact with humans, animals and surface waters and prevents potential dust hazards, by a combination of binding soil and overburden and disrupting the effect of wind at ground level. Careful regeneration of vegetation also provides the opportunity for reversion to a balanced and viable ecosystem approaching that prior to the commencement of mining, which in turn enhances the value of the site, both aesthetically and in terms of alternative land use activities. Plants also have the capacity to bind toxic compounds in root systems and foliage, thereby reducing their bioavailability and uptake into the surrounding environment (EPA 2000).

Vegetation cover also inhibits the formation of acidic complexes, at least those of biological origin, through uptake of oxygen and moisture by root systems, which thereby reduces activity of bacteria whose metabolism generates acidic compounds (Ledin & Pedersen 1996). This effect will be further enhanced in the presence of heterotrophic bacteria and fungi, which also utilize oxygen and increase carbon dioxide levels in soils.

The choice of appropriate plant species for regeneration requires consideration of soil attributes and climatic factors, as well as evaluation of future options for land use (see Table 26). Tailings and waste rock are generally poor in nutrients and organic matter and lack normal soil microbe populations, while tending to be acidic, and with elevated concentrations of potentially toxic elements. Waste rock heaps are also characterized by coarser rock fragments than in most soil substrates, and slopes may be steep. Therefore, ideal species for revegetation are opportunistic varieties, which germinate efficiently and grow rapidly, forming an effective ground cover and which are also capable of establishing themselves on a nutrient-poor, and porous, or rocky substrate. Ideally, such plants would also be tolerant to extremes of heat, frost and wind, and promote formation of humus, as well as being efficient in nitrogen fixation and transpiration. However, survival of an individual species is not as important as promoting the progressive establishment of a naturally viable vegetation regime. While natural regeneration would be ideal, in practice it is commonly necessary to undertake a systematic planting program, preferably with endemic species. The problem of erosion can be minimized by channelling runoff away from the area to be revegetated, and by firstly stabilizing the area with grasses and other forms of rapidly colonizing groundcover, before establishing larger shrubs and trees.

Table 26. Recommendation of planting strategies according to intended land use (Karjalainen 2003).

Type of land use	Revegetation strategy
Plantation forestry	• Recommended, if intention is economically viable forest production • Fast growing plants with high yield
Recreation	• Plants resistant to physical impact, such as turf for sportsgrounds and playing fields • Slow-growing ground cover species
Agriculture or grazing	• Requires careful risk assessment and monitoring during and after rehabilitation • Plants susceptible to uptake of toxic compounds
Natural landscape with no specific commercial or conservation objectives	• Facilitate rapid colonization of vegetation by endemic species
No specifically defined land use	• Species that rapidly stabilize the site, including commercial grass varieties
Nature conservation	• Maximize floral diversity in accordance with original ecosystem

Selection of suitable species for revegetation

A number of taxa in Finland are well adapted to relatively acidic natural conditions, including grasses of the family Poaceae, such as *Deschampsia flexuosa* (wavy hair-grass), and members of the Polygonaceae, Caryophyllaceae and Asteraceae, including the common sorrel *(Rumex acetosa)*, sticky catchfly *(Lychnis viscaria*) and golden rod *(Solidago virgaurea).* Some conifers and herbaceous and woody shrubs are also tolerant of relatively low pH soils (Karjalainen 1993), although the majority of plants used in site revegetation are best suited to pH levels in the range 5–7.

Most species are also tolerant of modest amounts of soil contaminants, with trees in particular being able to survive anomalous concentrations up to 2 orders of magnitude above background levels (Dickinson *et al.* 2000). Other plants that are resistant to elevated substrate trace metal concentrations include the grasses of the Poaceae family, *Festuca ovina* (sheep's fescue), and *F. rubra* (red fescue), and members of the genus *Agrostis,* notably *A. capillaries* (colonial bentgrass), as well as the common sorrel *(Rumex acetosa)*, *Deschampsia cespitosa* (tussock grass) and *Anthoxanthum odoratum* (sweet vernal grass). Other tolerant taxa include plantains *(Plantago spp.),* field penny-cress *(Thlaspi arvense)* and sea sandwort (*Honckenya peploide)*. The alpine catchfly *(Lychnis alpina)* appears to be particularly tolerant of elevated copper abundances, while the common ox eye daisy *(Leucanthemum vulgare)* and yarrow *(Achillea millefolium)* are suited to a wide range of conditions.

The first tree species to colonize tailings and waste rock piles are typically birches (*Betula spp.*), willows (*Salix spp.*), and aspen *(Populus tremula)* (Figure 46). Replanting programs in Finland should ideally be of mixed species, including spruce *(Picea abies)* and birch (*Betula spp.*), interspersed with scattered rowan *(Sorbus aucuparia)*. It is important that root systems do not penetrate too deeply, so as to avoid significant disturbance to soil structure, or infiltration of oxygen and water. For these reasons, aspen *(Populus tremula),* alder *(Alnus spp.),* pine *(Pinus sylvestris)* and members of the willow family (Salicaceae) are not recommended (Naturvårdsverket 2002). Conversely, the fact that these species have deep root systems makes them ultimately more resilient. Moreover, roots systems of pine trees are known to sequester at least lead and arsenic, thus potentially reducing the bioavailability of these elements.

Revegetation of steeper slopes can be facilitated by the use of mulch or other binding agents and the construction of terraces and retaining walls to prevent erosion. In such situations, willows (*Salix spp*. and *Populus spp*.) and alders (*Alnus spp*.) are ideal, since their efficient evapotranspiration also acts against water infiltration and may thus reduce erosion. Other plants that are similarly effective in water uptake are clovers (*Trifolium spp*.), wood angelica *(Angelica sylvestris),* coltsfoot *(Tussilago farfara),* and the common clubrush (*Schoenoplectus lacustris).*

Optimizing conditions for revegetation

The lack of nutrients in reclaimed ground may be addressed by addition of slow release chemical and organic fertilizers, while pH may be increased through the use of lime. Legumes, such as lucerne (*Medicago sativa*), clovers (*Trifolium spp.*), vetches (*Vicia spp.*), and lupins (*Lupinus spp*.) can also be used to permanently enhance nitrogen levels in soil, although these species tend to be sensitive to pH levels less than 6.0.

In some situations it may be possible to plant directly on waste rocks or tailings, by covering them with a thin veneer of mulch or compost or by using species that are especially tolerant to elevated metal concentrations. Under more demanding circumstances, it may be necessary to spread a layer of topsoil first. However, if this layer consists primarily of clay and peat, it will be vulnerable to excessive drying in the summer months. Therefore the substrate should ideally be both more water-retentive and enhance stabilization, and of sufficient thickness to deal with susceptibility to erosion and depth of root penetration.

The use of vegetation in soil rehabilitation

Vegetation can also be used in the remediation of degraded or contaminated soil. Several plants can decrease the number of contaminants in soil and their transport by breakdown or through uptake either into root systems below ground or woody tissue and foliage above ground. The potential for this approach is widely recognized, although as yet there are no clearly defined guidelines in place. It is therefore recommended that site-specific pilot investigations should be undertaken wherever possible.

The use of vegetation may be appropriate in mitigating the effects of certain metals, petroleum-based products, chlorinated hydrocarbons, and PAH compounds, providing that the following factors are taken into consideration:

Figure 46. Progressive colonization of reclaimed tailings area by birch (Betula spp.), willow (Salix spp.), Scots pine (Pinus sylvestris) and various grasses. Where conditions for regrowth are less favourable, an extra layer of topsoil may be needed.

- The site in question needs to be well characterized in terms of hazardous compounds and their respective concentrations, soil pH, nutrients and organic matter content, the nature and proximity of surrounding activities and prevailing light intensity and aspect, moisture conditions and wind patterns.
- Plants must be selected which are appropriate for both the types of hazardous compounds and anticipated growing conditions. Recommended species include the willows (Salicaceae*),* field penny-cress *(Thlaspi arvense)*, dandelions *(Taraxacum officinale),* common ragweed *(Ambrosia artemisiifolia)*, red-root amaranth (*Amaranthus retroflexus*), aspens and poplars *(Populus spp.)*, wild mustard *(Sinapis arvensis)*, sunflowers *(Helianthus annuus),* and clover *(Trifolium spp.).*
- Root systems must not form pathways for water infiltration and metal transport.
- Ensuring that the addition of fertilizer does not lead to changes in pH that might liberate or leach metals or other hazardous compounds.
- Plants that accumulate hazardous compounds can be periodically cut or removed from the reclamation site, which may therefore require additional disposal in a designated hazardous waste facility.

A checklist outlining strategies for designing and implementing revegetation programs is presented in Appendix 17.

6.3 POST-CLOSURE LAND USE AND TRANSFER OF OWNERSHIP

6.3.1 Alternative options for land use following mine closure

The mine operator commonly retains the land ownership rights on a mining concession after mining activities have ceased, unless there is a compelling reason for all or part of the area to be sold. While open pits, tailings impoundments and areas prone to subsidence are subject to environmental monitoring and risk management, the mine operator is still responsible for the area and it is therefore advisable to relinquish ownership only when the mine site is considered to pose no environmental or safety risk. Even then it is normal practice for certain fenced off areas, such as pits susceptible to slope failure and rock falls, or in some cases tailings impoundments, to remain as the permanent property of the last operator of the mine. In contrast, land suited to agricultural purposes, with the exception of areas that may have been affected by contamination, is usually sold. If possible, any mine infrastructure that remains after decommissioning can be used by other businesses and industries, which also requires that roads in the mine area are upgraded or modified for improved public access. Depending on location, the former mine site can be developed to suit a variety of recreational uses. For example, in Finland, the tailings area at the former Keretti mine has now become the Outokumpu golf course (Figure 47), while the former tailings impoundment of the Virtasalmi mine now serves as a racing track.

If the mine operator does not actually own the land, the area of the mining concession reverts to the original owner as soon as the operator relinquishes mining rights (Mining Act, Section 51). In such circumstances it is recommended that negotiations concerning future land use options and possible restrictions involve local municipal authorities as well as the mine operator and landowner. It is also advisable to reach a formal agreement on potential land use restrictions where the mine operator sells all or part of the land to an outside party. Particular attention should be given to tailings

Figure 47. After landscaping and rehabilitation, the former tailings impoundment of the Keretti mine (Finland), now functions as the Outokumpu golf course.

impoundments and waste rock disposal sites, to areas subject to collapse or slope failure, and any earthworks or drainage systems related to water containment, channelling and treatment. A written contract should be drafted between both or all parties, clearly defining proposed activities, any areas to be excluded, and a mutual agreement apportioning responsibility and accountability for safety and environmental issues. The contract may also specify that any excavation, quarrying, or earthworks carried out within the former mine area must be negotiated with the last mine operator. Local government planning authorities also have the right to impose building or land use restrictions at the site and register it into the local building code, should this be deemed necessary (cf. Section 3.5).

6.3.2 Relinquishment and transfer of ownership and liability

Relinquishing operating rights

When the rights to conduct mining activity are transferred to another operator, the transaction must be recorded in the original mining certificate. The new custodian, or party responsible for negotiating the transfer, is then required to inform the Ministry of Trade and Industry within 60 days, so that the change of ownership can be duly recorded in the mining register. The transfer of ownership becomes legally binding from the date that the Ministry of Trade and Industry receives written notification of the transaction, although in the case of a *bona fide* third party, the transfer becomes valid from the date of entry in the register (Mining Act, Section 54). The new custodian is further required to inform the Ministry of the Environment of the transfer of ownership and environmental permits (Environmental Protection Act, Section 81).

Responsibility for any adverse environmental impact at the mine site (excluding that caused by any activities prior to 1.6.1995), is also transferred to the new operator if he or she was aware of, or should have been aware of, the problem when the transfer of ownership took place (Environmental Protection Act, Section 7). It is advisable to commission an environmental due diligence survey prior to relinquishing mining rights, as in transferring ownership of real estate. A formal contract drawn up between the two parties, also enables mutual responsibilities to be agreed upon, such as liability for specified activities carried out at the site or exemption of certain areas from the agreement restriction although under common law such agreements are not binding with respect to third parties. Likewise, it is normally not possible to transfer any statutory obligations under the Environmental Protection Act, for example, responsibility for preventative measures against environmental or safety risks, remediation of contaminated soil, or for removal of waste from the site, in a way which could be seen as binding with respect to regulatory and other authorities.

It is advisable for both parties to agree on who will be liable in the event of future pollution of soil or groundwater, which can be directly attributed to materials or actions related to mining activity (cf. Section 3.2). It must be noted that an exemption clause of this nature is only binding for the parties to the agreement, and that supervising authorities may intervene and assign responsibility as is deemed appropriate. It is also important to agree on a course of action, if the extent of contamination proves to be greater than the estimate made at the time of drafting the contract, and how both anticipated and unforeseen expenses will be shared. It is also advisable to define an upper limit for expenditure, and to agree on a course of action if this limit is exceeded.

Relinquishing title to land, buildings and infrastructure

Transfer of title and ownership on relinquishment must comply with the Environmental Protection Act and the Real Estate Code (540/1995), including the requirement for accurate reporting of the state of the site by the seller (Environmental Protection Act, Section 104) and, subject to certain conditions, responsibilities that the new title holder may have for any future site remediation activities (Environmental Protection Act, Section 75). The previous title holder, whether operating the mine as a landowner or under a leasing arrangement, must provide a report to the new title holder or owner, detailing all activities carried out at the site, with a comprehensive description of all materials and waste that has the potential to cause contamination of soil or groundwater. The purchaser, or new title holder, is also responsible for obtaining all available information concerning previous operations and potential environmental, health, and safety risks at the site. The new owner may actually be liable for remediation and reasonable compensation, if it can be shown that he or she knew, or should have been aware of, potential risks at the site at the time of transfer of title and ownership (Environmental Protection Act, Section 75).

According the Real Estate Code, parties to the transfer of ownership must reach agreement concerning the precise nature and contents of the sale. If a discrepancy between the contents of the document and the actual real estate is subsequently found, and an error of omission is acknowledged, negotiations are required to establish which aspects of the omission can be interpreted as agreed to in the sale and which can be otherwise agreed upon. Depending on its severity, and whether the extent was acknowledged at the time of signing the contract, site contamination may be viewed as a serious hidden or quality defect under Section 17 of the Real Estate Code. The seller is required to provide information that is both accurate and sufficient concerning the nature and quality of the real estate involved in the transaction, including any hidden factors which might conceivably affect overall value. Conversely, the buyer cannot appeal to ignorance with respect to a particular defect or omission, if it falls into the category of matters which any responsible title holder should be aware of. The nature and extent of possible defects is determined according to the condition of the real estate at the time of sale, which means that the seller is responsible for the consequences of any defect which existed at the time of sale, even if it were not evident at the time (Real Estate Code, Section 21). The buyer is similarly obliged to investigate and document the condition of the real estate prior to the sale and cannot interpret a problem as a defect if it is clear that it was recognized and acknowledged at the time of sale (Real Estate Code, Section 22). The possibility of unidentified contamination being present at the site, and the cost of any investigations and remediation that might subsequently be required, can, however, be made a condition of sale.

Transactions and mergers

Relinquishment of corporate ownership is more complex, and may involve direct transfer of shares, consolidation through company mergers and acquisitions, or alternatively divestment of assets and establishment of subsidiary companies. Transfer of shares, in part or entirety, is usually straightforward with respect to existing permitting commitments and obligations; as the new title holder remains a distinct legal entity under corporate law, there is no effective change from the perspective of regulatory authorities. Corporate mergers do not necessarily cause disruption to permitting obligations either, since the companies involved in the amalgamation are replaced by a newly defined company that assumes responsibility. Company mergers may also take place such that shares are held in joint ownership. In this case the existing company structures are retained as legal entities, until such time as a formal merger is implemented, and from a legal perspective this arrangement does not differ from that involving direct transfer of shares.

From the viewpoint of permitting and regulatory authorities, procedures during partitioning or diffusion of a larger corporation into smaller companies resemble relinquishment of business activities, in that it generally unites a broad but related range of activities under the collective responsibility of a single legally defined company. Under these circumstances, the new title holder is required under Section 81 of the Environmental Protection Act to inform the relevant authorities of the transfer of ownership. From the perspective of the Mining Act, the transfer of ownership to such a company is classified as a transaction which needs to be entered in the mining register.

Financial security and solvency issues

In the event of bankruptcy of the mine operator, the company board is replaced by a body of trustees appointed to act on behalf of the company. If a decision is not made to immediately sell all assets related to mining activity, or if the trustees do not decide in favour of continuing mining operations, then standard mine closure procedures, obligations, and strategies will apply as normal.

Insolvency issues nevertheless inherently contain a degree of uncertainty and it is, therefore, advisable for the trustees administering the mine, either on their own initiative, or in conjunction with relevant authorities, to reassess the most important issues relating to permitting and environmental and safety responsibilities. Safety issues are dealt with by the Safety Technology Authority of Finland and require a commitment to maintaining safety standards at the site and regular inspections. Obligations and responses required under environmental legislation need to be established and agreed upon in consultation between the administrators and relevant authorities. Separate inspections may be carried out by officers from the appropriate Regional Environment Centres, after which report should be prepared, defining those issues requiring immediate attention and for example, a revised ongoing monitoring and due diligence plan.

Should the trustees decide in favour of continuing business operations, there is also an ongoing obligation to meet environmental legislation requirements. The estate under the administration of the trustees must, therefore, assume responsibility for any contamination resulting from continued activities and for arranging appropriate management of waste. The total assets and liabilities of the bankruptcy estate must also be declared, as well as the level of insurance taken out and the amount of any pledged collateral or guarantees. After judgment has been officially handed down concerning the value and distribution of estate assets, the trustees can ascertain the resources available for any closure-related procedures that might be necessary, such as fencing or excavation and removal of contaminated material, or for post-closure site monitoring. However, it is not possible to assign funds from the estate specifically for remediation of contaminated soil or groundwater, if no separate guarantees exist, or if they are considered inadequate to cover remediation costs. It is therefore important that bankruptcy proceedings are attended by an appropriate representative of the government, to ensure that financial provisions are sufficient to meet any such obligations.

The mine operator, as the holder of a permit as defined in law, is required to allocate a specified amount of money, in proportion to total company turnover, as a contribution towards insurance against environmental risk or damage (Environmental Damage Insurance Act 81/1998). Funds received in this way are intended for use in compensation for environmental incidents and damage, in cases, where the perpetrator is unknown, or financially insolvent.

Land tenure after the operations

If custodianship of the mining concession reverts to the landowner from whom it was leased during mining, then any equipment or facilities remaining on site after a period of two years has elapsed, automatically becomes the property of the landowner, as discussed in Sections 6.1.6 and 6.1.7 (of the Finnish Mining Act, Section 51). According to both the Mining Act and legislation covering damage liability (Tort Liability Act 412/1974), the mine operator remains responsible for any damage related to mining activities. If contamination due to mining is observed at the site after closure and relinquishment, but there is no longer any mine operator to assume responsibility, the current landowner may be liable for compensation and implementation of remedial measures, simply on the basis of ownership status. However, it appears, when considering the outcome of past legal proceedings and individual examples, that prosecution of the landowner in such cases would be highly improbable. Regulations concerning contaminated soil are described in more detail in Section 3.2.

Insurance against post-closure environmental damage

Although it is possible to take out insurance against the possibility of environmental damage during or post-closure, in practice this may prove to be prohibitively expensive. While the general intent of insurance would be to cover compensation for damage or contamination due to an unanticipated event or accident, in reality most environmental problems are seen to be a consequence of longer term activity.

6.4. INFORMING REGULATORY AUTHORITIES AND THE GENERAL PUBLIC CONCERNING MINE CLOSURE

Mine operators generally have a preferred option for communicating to the public and stakeholders concerning developments or changes, and the issue of mine closure can be dealt with in the same way. While there is no legislative requirement for informing the general public of mine closure, the operator may be guided by a company public relations and environmental policy that favours transparent engagement with the surrounding community and regulatory authorities. There are, however, some additional statutory obligations, (for example under the Accounting Act 1336/1997, and Companies Act 734/1978) to inform various stakeholders, such as shareholders, auditors, employees, concerning closure and relinquishment plans, and any attendant changes in company operations or ownership.

A distinction is made here between general comments made in public and official applications, proposals and statements submitted to regulatory authorities and other third parties, in compliance with legal commitments, or to stakeholders ("… whose interests and rights may be affected by …"), and employee representatives or others who are affected by company decisions ("… opportunity to express opinions on proposed…"). Section 3.6 provides more detailed information on requirements and procedures in relation to regulatory authorities.

It may be necessary to have a statement drafted and issued according to a standard procedure and format under official or legal guidance. If the statement or submission process is incomplete or misleading, there may be a delayed response or requirement for resubmission, if not outright rejection. The mine operator may also concurrently issue separate statements of a public nature, in relations to proposed activities and mine closure, but must take care to ensure that a clear distinction is made between formal negotiation process and informal public announcements.

7. MONITORING OF MINE SITE REHABILITATION PROGRAMS – REQUIREMENTS AND PROCEDURES

The primary reason for ongoing monitoring of the mine site following closure is to ensure that remediation measures, including earthworks, water treatment, and drainage systems, function as intended and in accordance with closure criteria. In addition, site surveillance may be necessary to demonstrate that the mine site remains safe and poses no environmental or health risks. Regular monitoring also allows for a proactive response where the rehabilitation process is found to be deficient, or in the event of structural failure. Mandatory monitoring requirements during active mining, as well as following cessation of operations and closure, are specified in environmental legislation (refer to Section 3.1.3).

The type of monitoring required is determined at each mine according to the specific nature of the mining process, with an appropriate emphasis on those issues, which the risk assessment process has identified as potentially problematic in terms of either safety or contamination. For example, if it can be demonstrated that discharge from waste rock areas or tailings is unlikely to represent a contamination risk, it is generally not necessary to keep water quality at the site under close surveillance. Instead, the monitoring program may focus on the structural integrity and stability of the tailings impoundment.

Typical features that can be routinely monitored following closure may include:

- the state of fencing and warning and prohibition signs,
- the stability of embankments and tailings impoundments and other areas potentially subject to slope failure,
- flooding of the mine workings and evolution of water quality,
- chemical stability of tailings and waste rocks, evaluation of the success of the assessment of their long-term behaviour, and the long-term performance of the applied wet/dry covers,
- functionality of water treatment and drainages systems, and
- success of revegetation programs.

Each of these features may be monitored based on the following attributes and procedures:

- visual inspection of embankments and tailings impoundments, assessing extent of erosion or changes in morphology and water level,
- measuring volumes and quality of water discharge from tailings areas and waste rock disposal sites,
- measurement of physical and chemical parameters of surficial waters both upstream from the mine and at downstream discharge sites,
- assessing state and viability of surrounding aquatic ecosystem, including measurement of physical and chemical properties of water,
- physical and chemical characterization of groundwaters in surrounding watershed, and
- monitor revegetation rates, biodiversity and density of vegetation cover.

A comprehensive monitoring plan should be drafted, at the latest in conjunction with the final closure plan, for submission to the relevant environmental authorities. Some elements of the monitoring program will inevitably be based on the requirements and recommendations contained within environmental permits. Final details will however, vary according to specific assessment of environmental impacts at a given mine and the most appropriate remedial measures. It is advisable to consult with local environmental authorities concerning the main features of the envisaged monitoring plan and attendant procedures, prior to formal drafting and submission.

A typical monitoring program accompanying a mine closure plan would include features such as:

- what is to be monitored (what processes are being measured; what variables are being monitored),
- how is monitoring implemented (sampling and analytical techniques used in monitoring),
- a description of establishing and maintaining a follow-up system or surveillance network,
- frequency of monitoring (schedules and timing of sampling intervals),

- duration of monitoring (estimate of total time required), and
- responsibility for monitoring (who will undertake the monitoring and ensure compliance).

The following sections provide specific and detailed examples of planning and implementation of post-closure monitoring of surficial and groundwater quality and geotechnical specifications for mine embankments and tailings and waste rock areas.

7.1 POST-CLOSURE MONITORING OF SURFACE WATER AND GROUNDWATER

The underlying aim of monitoring surface water and groundwater quality after mine closure is to ensure that there is no pollutant discharge into the surrounding environment or, if contamination does occur, to facilitate rapid detection and response, thereby minimizing any adverse health and environmental consequences. Monitoring also provides valuable reference data for authorities in subsequent decision-making and in refining environmental permitting procedures or land use planning. The requirement for monitoring water quality may be negotiated on a case-by-case basis, if for example, it can be demonstrated that mining activities do not adversely affect water in surrounding areas.

However, when planning monitoring strategies in areas where closure is imminent, or where operations have already ceased, it is essential that adequate background information is available. In general this requires knowledge of the following:

- precise extent and boundaries of surrounding catchment areas;
- nature of bedrock, including rock types, and characterization of faults and fracture zones in terms of location, orientation and extent;
- surficial and regolith geology, including thickness of overburden, stratigraphy, results of any additional regional studies such as drilling or geophysical, seismic and radar surveys;
- precipitation;
- location of surface water bodies, including lakes and wetlands, rivers and streams;
- whether or not the area contains significant aquifers and is classified, or protected, as a source of groundwater (Britschgi & Gustafsson 1996);
- hydrology of surface drainage, extent of watershed which may potentially be affected by mine water outflow, absolute amounts and potential variations in volume of water bodies (refer to Section 4.1.1);
- seasonal fluctuations in depth and absolute range of groundwater table, and possible variations in groundwater flow paths;
- location of groundwater discharge zones, with flow rates, and locations of groundwater monitoring sites and wells;
- results of groundwater investigations carried out in the area, including reports relating to the installation of observation wells and information concerning flow rates during pumping tests;
- chemical composition of water, including data on seasonal variations and sampling under variable climatic conditions, as well as data on surface and groundwater samples from different sources and depths;
- documentation of the status of water prior to commencement of mining and any changes observed during mining, and
- usage of surface and groundwater in proximity to the mine site, including surface storage or groundwater extraction, either for nearby communities or for individual households.

The nature of post-closure water treatment and drainage systems and processes affecting the composition of mine waters throughout the mine site, but particularly in relation to tailings and waste rock areas, should be understood prior to preparation of the monitoring plan. The number and locations of monitoring and sampling sites required for groundwater investigations are determined by local hydrological conditions and the relative importance of the area with respect to groundwater recharge and storage. Furthermore, the possibility of whether or not aquifers are exploited for domestic or other forms of consumption has to be taken into account. Monitoring of surface waters should be carried out both upstream from the mine site, to determine baseline levels, and downstream of discharge sites. In practice, this usually means sampling from streams flowing through the mine site, or from drainage systems and channels designed to capture all surface waters at the site (Hatakka & Heikkinen 2005).

A comprehensive description of methods for investigating groundwaters can be found in a manual published by the Water Association Finland (Suomen Vesiyhdistys 2005). Groundwater volumes are estimated and monitored from productivity/yield- and

a)

b)

Figure 48. Groundwater samples for monitoring purposes can be taken from (a) existing domestic wells, or (b) from observation wells.

flow-rate measurements made at selected discharge sites, combined with water table data from specifically drilled observation wells and existing productive wells. Groundwater quality can be monitored by sampling from natural springs and productive or observation wells (Figure 48). All sampling sites should meet standard requirements with respect to their general condition and material properties in order to ensure representative sampling.

If there are no suitable observation wells in the area, sufficiently dense network of observation wells must be established, with careful attention given to installation, construction and documentation. Depth of observation wells varies according to local site conditions but it is usual to penetrate as far as the bedrock interface, with the screened interval including the entire depth of groundwater body. The natural fluctuations of the water table must be taken into account before installing the screen. It is also important to consider both the pipe diameter and material composition; the inner diameter of the observation well should be sufficient enough to allow insertion of standard measuring and sampling instruments, for example, pumps with sufficient suction capability. Likewise, the pipe must be made of an inert material to avoid sample contamination. In some cases, groundwater monitoring may include sampling from wells drilled into bedrock, especially if these are used as domestic water sources, or if the bedrock is highly fractured and the possibility of infiltration by contaminated mine waters is suspected. The most relevant parameters for analysis and measurement are generally determined on the basis of previous investigations, but may also include some additional variables that relate more specifically to environmental risks identified at the site. In addition to assessing the presence of specific contaminants, the monitoring program can also involve measuring variables which affect metal solubility, such as pH and dissolved oxygen, chlorides, sulphates and nitrates. The range of variables chosen for analysis depends on site-specific conditions and circumstances. Comprehensive analysis of water chemistry should ideally be repeated on an annual basis, even though only few metals are present in anomalous concentrations. Chemical analysis of surface water may be supplemented by monitoring of biological indicators.

Figure 49. Following mine closure, monitoring of surface and groundwater quality involves in situ measurement of certain parameters, such as pH, electrical conductivity and oxygen, in addition to laboratory analyses.

It is recommended that certified personnel (SFS-EN ISO/IEC 17024) collect samples using appropriate and approved methods. Careful documentation of the sampling procedure is necessary to ensure reproducibility and verification of time series comparisons. Samples should be analyzed in an independent accredited laboratory using officially certified procedures. However, for some parameters, such as pH and electrical conductivity, the most reliable results are obtained by *in situ* measurement at the field (Figure 49, and see also Paukola *et al.* 1999 and Suomen Vesiyhdistys 2005).

The level of the water table and discharge are also routinely measured in connection with sampling. Surface water samples can be taken using bailers beneath the surface or by retrieving a suite of samples from different depths (see also Mäkelä *et al.* 1992). The pumps used in groundwater sampling from observation wells need to be sufficiently efficient. In case the monitoring site consists of soils with low permeability, it may be necessary to pump the observation wells dry a day or so prior to sampling, in order to obtain samples from fresh water. In such cases the samples are usually taken using bailers. It is also advisable to collect duplicate and blank samples for quality control purposes. The proposed sampling strategy should also be included within the monitoring plan submitted to the environmental authorities. Sampling frequency will vary depending on site-specific hydrology and is, therefore, determined on a case-by-case basis. If the area includes significant groundwater resources supplying surrounding communities, or if there are individual wells and natural springs used by households in the immediate vicinity, sampling should be undertaken on at least a quarterly basis. Seasonal variations are also monitored by taking samples during spring maxima, summer minima, autumn maxima, and winter minima. In Finland this means sampling during February–March, May–June, August–September and November–December. If there has been previous indication of deterioration in yield or quality of well water, sampling should be undertaken more frequently and extended to include all wells that might conceivably be subject to contamination or flow disturbance. If, however, the area surrounding the mine site is uninhabited, and not used for any other commercial or recreational activities, less frequent monitoring is sufficient. Even then, however, sampling should be undertaken at least twice a year, preferably so as to coincide with the spring maximum in May-June and summer minimum in August-September. If there is no human activity whatsoever in the area, sampling on an annual basis may be adequate. If the rehabilitation site is in proximity to areas listed for protection under the Natura 2000 program, such as wetlands and springs, consultation concerning more stringent monitoring is inevitably required.

Sampling frequency of surface waters varies according to choice of parameters. According to the European Water Framework Directive (2000/60/EC), biological parameters should be measured at intervals varying from 0.5–3 years, while physical and chemical parameters should be monitored more frequently, at intervals of 1–3 months (European Parliament and Commission, 2000, Appendix V, Section 1.3.4). These monitoring guidelines are however negotiable, if it can be shown that the reliability and precision of site surveillance will not be compromised by less frequent sampling.

Although statutory limits can not be imposed for the duration of mine site surface water and groundwater monitoring programs, in each case a specific timeframe can nevertheless be stipulated, after which the situation is subject to further review. If, during systematic monitoring over a period of at least 3-5 years, there are no detectable adverse effects on surrounding water quality, then the frequency of monitoring may be reduced. Conversely, if appreciable changes in water quality or yield are observed, surveillance requirements may need to be reassessed. A comprehensive list of guidelines and procedures for systematic monitoring of surface and groundwaters is given in Appendix 17.

7.2 GEOTECHNICAL SURVEILLANCE OF MINE EMBANKMENTS AND TAILINGS AREAS

The purpose of systematic geotechnical monitoring at the mine, following closure, is to ensure that the structural integrity of earthworks is maintained according to plan, and that potential risk factors are identified in time to initiate an appropriate response. Design of a geotechnical monitoring plan should be undertaken by an accredited professional specialised in construction of mine embankments and impoundments.

To a large extent, post-closure surveillance is a continuation of monitoring processes initiated during mining activities, ensuring that earthworks are constructed in a stable manner. Therefore, monitoring criteria developed during mining can usually be applied to the post-closure phase as well.

Typical features included for regular and routine assessment in such surveillance programs include:

- visual inspection of the overall mine site and earthen structures
- assessment of the level of pore waters and surface waters
- determination of pore water content and seepage in embankments and other earthworks
- measurements of potential surface deformation, mass movement or failure.

The monitoring program needs to be designed specifically to meet the attributes and remediation requirements of individual mines. Qualitative visual inspection includes:

1) **Inspections of a general nature**
   - general condition of fencing enclosing the site, and
   - general condition and functionality of monitoring equipment.

2) **Open pits and waste rock disposal areas**
   - evidence for erosion or mass movement and slumping of sloping embankments and retaining barriers, and
   - effectiveness of measures implemented for draining and drying the mine site.

3) **Embankments and impoundments**
   - evidence for slope instability and creep at the base of embankments and retaining barriers,
   - evidence of erosion of embankments by surface water overflow or pore water seepage,
   - evidence of differential compaction and cracking or fissuring in terraces and embankments,
   - effectiveness of drainage systems, including state of open channels,
   - success of slope stabilization by vegetation cover (plant survival and growth, extent of cover, presence of oversize trees),
   - evidence of surface subsidence or cracking and breaching of tailings covers
   - effectiveness of drainage and drying procedures in tailings covers
   - effectiveness of vegetation colonization of tailings covers

Visual inspection and comparisons of changes over time may be facilitated by filming or photographing the site.

After mining operations have ceased, systematic measurement of pore water levels and pressures is necessary along profiles through embankments and retaining barriers, while groundwater discharge can be measured by installation of specifically designed water gauges (Figure 50). Measurements are primarily

Figure 50. Seepage water discharge rates from waste rock areas and tailings impoundments can be monitored effectively by installation of standard V-shaped water gauges (Vee-weir) at outflow locations.

made from the existing observation points, but depending on the requirements of the monitoring plan, it may prove necessary to increase the number of measuring points. For example, where tailings impoundments are only covered in part (with the central area remaining exposed), it is likely that the groundwater level will be lowered towards the embankment margins. It is, therefore, recommended that monitoring instruments are installed along at least one profile across the covered part of the impoundment, as well as on the embankment slope. To monitor the behaviour of pore water levels over time, and anticipate potential lateral mass movement, it is advisable to install borehole inclinometers along one or two profiles across the embankment, in which the safety factors are lowest. Practical procedures for installing and using inclinometer are described in the report published by the Finnish Road Administration (Tiehallinto 2000).

It is both advisable and practical to perform visual inspections concurrently with more quantitative monitoring methods, such as pore pressure measurements. At the Hitura nickel mine, for example, it has been customary in recent years to determine pore pressures within embankments and barriers at a rate of ten times per year. Accordingly, it might be anticipated that at least during the initial stages of the post-closure monitoring program at Hitura, qualitative visual inspections would be carried out at monthly intervals. It is also necessary to assess the integrity of earthen structures immediately after exceptional rainfall events. Frequency of monitoring should also be greater during and immediately after construction of embankments and other earthworks, and while covering tailings impoundments. Progress of water filling abandoned open pits and workings should also be subject to close surveillance until conditions approach a dynamic equilibrium. As waste rock areas, embankments and other structures progressively stabilize, monitoring frequency can be steadily decreased such that waste rock disposal sites that have shown no evidence of surface deformation or slope failure over extended periods, and which are not subjected to further loading during closure, need only sporadic monitoring. Further specific recommendations concerning nature and frequency of site surveillance following closure are given in the EC's BAT reference document (EC 2004).

All instruments deployed in the field during the monitoring program should be clearly marked and protected for accidental or deliberate interference and damage. In the case of monitoring surface deformation and mass movement, it is also necessary to ensure that benchmarks and survey points still remain in place and accessible after site monitoring has ceased. The precise locations of monitoring systems must be documented carefully, as well as the results of measurements, and recorded in notebooks and databases. It is desirable to present results in graphical format as well, to allow evaluation of changes in material parameters and behaviour along specific profiles over time. Such an approach allows potential departures from expected behaviour to be identified at an early stage and hence to anticipate the need for any further risk management and mitigation. To ensure that this process is effective, regular inspection and appraisal of surveillance results by a nominated person is required.

A detailed list of criteria and procedures for monitoring geotechnical stability of earthworks and other structures is outlined in Appendix 17.

8. RESERVE PROCEDURE, PLEDGING A GUARANTEE AND COST ESTIMATES IN MINE CLOSURE

A mine closure cost estimate contains the costs of the component actions included in the closure plan and the cost effects of implementing the entire plan. For the mining company, the mine closure costs constitute a significant item over the life-cycle of a mine.

Funding a mine closure by entering annual reserves in the balance sheet is consistent with good reporting and closure practice. The purpose of entering these reserves is to ensure that mine closure costs have been taken into account as accurately as possible in the company's bookkeeping so as to avoid the costs being too much of a financial burden on the company towards the end of the mine's life-cycle, at which time the profitability of the mine tends to be decreasing too. Both voluntary and compulsory reserves entered in the final accounts are used.

The environmental permit procedure (Environmental Protection Act, Section 42, and 1999/31/EC) requires that a guarantee be pledged to ensure waste management. In the extraction industry, this usually applies to actions taken at closure regarding the disposal areas for tailings and waste rock classified as waste. The main purpose of the guarantee is to ensure that society can cover the costs of normal waste management measures foreseen at the moment of the environmental permit being granted, in case of the insolvency of the operator.

The guarantee is pledged to the environmental permit authority or the supervising authority. The guarantees required have ranged from less than one to dozens of Euros *per* square metre of tailings area. The size of the guarantee, its accumulation, the inspection interval, dismantling of the deposit or guarantee, and the specific arrangement of the guarantee vary by site, area and depending on the solvency of the operator. It should be noted that a reserve in bookkeeping, even a compulsory reserve (Accounting Act 1336/1997, Section 5.14), is not accepted as a guarantee in this sense; it must be a bank deposit, an absolute guarantee, guarantee insurance, etc. The guarantee is dismantled once the aftercare actions have been acceptably completed. Part of the guarantee may be withheld for unforeseen future work (see Ministry of the Environment instructions, Dnro YM2/401/2003, Kauppila & Kosola 2005, and Section 3.1.1).

The guarantee procedure causes indirect additional costs to the company due to reduced borrowing potential and possibly increased loan management costs. The procedure has been in use in Finland only for a few years, and there is as yet no accurate conception of its details, its indirect cost impact on companies, or recommended bookkeeping practices (see Appendix 5).

A closure plan drawn up at the beginning of the life-cycle of a mine is, naturally, fairly inaccurate, and thus the related cost estimate is also inaccurate. Accordingly, the costs should be regularly reappraised as mine operations progress, as processes develop, as statutory objectives change, as environmental investments affecting closure costs are being made, and as prices change. Costs are dependent in many ways on the location of the production and the production processes: the target state of closure, land use, the physical and chemical properties and volumes of the waste rock and tailings, material processing problems, etc. The cost variance depends on the level of reliability or certainty sought; this variance can be significantly reduced by using risk management methods to identify and prioritize uncertainties. The risk management costs of low risks are usually reasonable, and the cost variance may be +/- 25% or 30%. The risk management costs of high risks are not only higher but more difficult to estimate too, and the cost variance may be +/- 100% or even more.

In the following, it will be summarized how the cost responsible body is determined, and how the closure costs are roughly estimated and scheduled. These are indicative and tentative examples; individual cases may differ greatly. The estimates given are based on the closure of a medium-sized sulphide ore mine in Finland.

Responsibilities

The costs of mine closure are the responsibility of the last mine operator or the owner of the area if ownership of the area is transferred when mine operations are discontinued. The mine operator may be liable for aftercare costs if the new owner is unable to fulfil his responsibilities. It should be noted that the guarantee procedure only covers the rehabilitation of the disposal areas for waste rock and tailings classified as waste.

Cost timing

The major closure costs are usually caused by actions that cannot be taken before the mine operations are discontinued. A rough estimate is that only about 10% of the costs of closure are realized while the mine is in operation, while 50% to 60% of the costs are realized during two or three years following the discontinuation of operations, the remaining 30% or 40% being distributed over the following several years, depending on the site. Nevertheless, variances of the given figures may be considerable.

Cost by measure

The largest costs are usually caused by the covering of the tailings area. Depending on the structure of the covering layer, the availability of the material and the location of the site, the costs may be between EUR 5,000 and EUR 25,000 per hectare and may constitute up to 50% to 75% of all closure costs. Significant cost variance in earthwork can be introduced by cyclical fluctuations in the construction market and the location of the mine.

Demolishing a concentrator costs between EUR 100,000 and 300,000, depending on its size and the price, and volume of recyclable scrap. In some cases, the value of the scrap steel alone is enough to offset the cost of demolition. Other structures may cost EUR 50,000 to 200,000 to dismantle and move. Tidying up the site and disposing of demolition materials cost EUR 100,000 to 200,000, while water treatment arrangements may cost EUR 50,000 to 200,000 depending on the water quality and local conditions. Further costs can be caused by the rehabilitation of the soil in the concentrator and industrial areas.

The cost of dismantling the mine itself is EUR 100,000 to 400,000 depending on the equipment to be removed, tunnels to be filled in, and access holes to be closed. Open pit closure involves evening out slopes, dismantling equipment and structures, and erecting a fence. The shaping and possible covering of waste rock piles is also a significant expense, totalling some EUR 1,000 to 20,000 per hectare.

Mine closure may also require several official permits which may cost EUR 10,000 to 30,000 to obtain. Fulfilling the permit requirements may sometimes require further investigations, which can easily cost EUR 50,000 to 100,000 depending on their extent.

Personnel costs depend on the number of people dismissed, the notice period, personnel service years, age structure (pension costs), the size of the company, training needs, and relocation costs. Some of the personnel can be employed in the aftercare work.

Aftercare and monitoring costs

The costs of aftercare and monitoring depend largely on how the water flowing from the site needs to be monitored, how the safety monitoring of the site has to be organized, and how dams need to be monitored. Permit requirements related to closure often require samples to be taken, laboratory tests to be conducted, results to be analysed, and reports to be written. The annual cost can be EUR 5,000 to 20,000 depending on the extent of the area and the permit requirements.

Using cost estimates in prioritizing alternatives

The purpose of mine aftercare is to return the area to a state required by law. It is also important to do the job properly the first time so as to avoid costly rework. Comparing the costs of various options with their benefits, and assessing the consequences of each environmental risk and the costs of reducing that risk through risk assessment, result in an identification of the best options. Risk assessment also helps analyse any overlapping effects of planned actions.

Communications on the cost estimate and actual costs are of great importance in maintaining relations with the community.

9. DEFINITIONS

Acid Mine Drainage (AMD), Acid Rock Drainage (ARD)
Acidic Drainage stemming from open pit, underground mining operations, waste-rock or tailings facilities that contain free sulphuric acid and dissolved metals sulphate salts, resulting from the oxidation of contained sulphide minerals or additives to the process. The acid dissolves minerals in the rocks, further changing the quality of the drainage water.

Acid Potential (AP)
Maximum potential acid generation of the material.

BAT Reference Document (=BREF –document)
The EU member states' competent authorities and industry co-operate on the development of BAT reference documents for each of the industries listed in Annex I of the IPPC Directive (96/61/EC). These documents describe the techniques, which it is agreed that can be defined as BAT, as well as the agreed indicative emission levels to be applied when such techniques are used.

Best available techniques - BAT
Best available technique refers to methods of production and treatment that are as efficient and advanced as possible and technologically and economically feasible, and to methods of designing, constructing, maintenance and operation with which the contaminative effect of activities can be prevented or most efficiently reduced; (Section 3, Environmental Protection Act).

Concentrate
The valuable minerals/marketable products extracted from the ore in mineral processing.

EIA -procedure
Procedure for environmental impacts assessment based on Act on Environmental Impact Assessment Procedure (468/1994).

Gangue
The part of an ore that is not economically desirable but cannot be avoided in excavation.

General plan for mine operations
Based on Decision of Ministry of Trade and Industry (921/1975) a general plan has to be delivered to Safety Technology Authority of Finland prior to commencement of mining operations. General plan should cover aspects related to organizing and commencement of excavations; describe locations of activities at mine site, and present a schedule for mine construction (Sections 2 to 4, Decision 921/1975).

Hazardous waste
Waste materials listed as hazardous waste in the annex of the Ministry of the Environment Decree on the list of the most common wastes and of hazardous wastes (1129/2001)

Industrial minerals
Geological materials, which are mined for their commercial value, which are not fuel (fuel minerals or mineral fuels) or gemstones and are not sources of metals (metallic minerals). They are used in their natural state or after beneficiation either as raw materials or as additives in a wide range of applications.

Inert waste
Waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater. (1999/31/EC)

Landfill
Waste disposal site for the deposit of the waste onto or into land (i.e. underground), including:
- internal waste disposal sites (i.e. landfill where a producer of waste is carrying out its own waste disposal at the place of production), and
- a permanent site (i.e. more than one year) which is used for temporary storage of waste,

but excluding:
- facilities where waste is unloaded in order to permit its preparation for further transport for recovery, treatment or disposal elsewhere, and
- storage of waste prior to recovery or treatment for a period less than three years as a general rule, or
- storage of waste prior to disposal for a period less than one year (1999/31/EC).

Each landfill is classified in one of the following classes:
- landfill for hazardous waste,
- landfill for non-hazardous waste,
- landfill for inert waste (1999/31/EC).

Metallic ores, metalliferous ores
Metal-bearing; pertaining to a mineral deposit from which a metal or metals can be extracted by enrichment or metallurgical processes.

Mine
Facility that produces exploitable minerals through excavating the earth crust and by extracting the valuable minerals from unexploitable rock.

Mine closure
Permanent cessation of mining operations and all subsequent activity related to decommissioning and site rehabilitation or ongoing monitoring.

Mineral processing, mineral dressing
Mechanical, physical and/or chemical processes applied to produce marketable mineral products (concentrates) from ore.

Neutralization potential (NP)
Material’s capacity to neutralize acidity.

Natural stones
Term “natural stones” refers to rocks that have been formed through geological processes and have economic value. According to Natural stone Handbook (Kiviteollisuusliitto ry 1994, in Finnish) Finnish Natural stones are classified into four main categories: 1) igneous rocks, 2) schists and quartzites, 3) marbles, as well as 4) soapstones and serpentinites. Natural stones are commonly used as architectural rocks, in environmental planning and in interior decoration.(Aatos 2003).

Non-hazardous waste
Waste not regarded as hazardous waste (1999/31/EC).

Ore
Naturally occurring material from which a mineral or minerals of economic value can be extracted at a reasonable profit.

Overburden
Unconsolidated earth material on top of the orebody. In case of open pit mining operations, it is removed prior to extraction of the ore and deposited at the mine site. In Finland, term overburden is mainly used for soil materials.

Plan for the exploitation of the concession and auxiliary area
A plan for the exploitation of the concession and auxiliary area included in the concession application defined in the Mine Act (503/1965). Plan should include a report on the factors that determine the extent and shape of the concession area, including a description of the locations of overburden, waste rock and tailings facilities in the concession or auxiliary area.

Rehabilitation, reclamation
Activities taken to restore the mine site into condition that poses no hazard to human health or environment after the ore is extracted.

Rock material of secondary quality
Residue rock formed in soapstone production composed of poor quality soapstone invalid for production.

Stakeholder
A person, group or organization with the potential to be affected by the process of, or outcome of, mine closure.

Tailings
Those portions of washed or milled ore that are regarded as too poor to be treated further, as distinguished from the concentrate, or material of value. Tailings consist mainly of gangue and may include process water, process chemicals and portions of the unrecovered minerals.

Tailings area, tailings pond, tailings impoundment
Engineered structure designed for managing tailings and for clearing and recycling the process water.

Waste rock, barren rock, surplus stone
Part of the orebody, without or with low grades of ore, which cannot be mined and processed profitably, but is needed to remove to exploit the ore. Waste rock is commonly either deposited in stockpiles at the mine site or utilized as backfilling in mining or in earth construction at or outside the mine site.

10. SOURCE MATERIAL

10.1 Statutes and regulations

Reference: FINLEX Data Bank – Electronic Statutes of Finland (www.finlex.fi); EUR-Lex – Electronic Data Bank of European Union Law (http://eur-lex.europa.eu/)

2003/33/EC: Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC

Accounting Act (1336/1997)

Act on Compensation for Environmental Damage (737/1994)

Act on Environmental Impact Assessment Procedure (468/1994) (in Finnish)

Act on Implementation of the Legislation on Environmental Protection (113/2000)

Act on the Protection of Buildings (60/1985)

Act on the Safe Handling of dangerous Chemicals and Explosives (390/2005) (in Finnish)

Act on Water Resources Management (1299/2004) (in Finnish)

Antiquities Act (295/1963) (in Finnish)

Chemicals Act (744/1989) (in Finnish)

Code of Real Estate (540/1995)

Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

Council of State Decision on the protection of groundwater against pollution caused by certain substances dangerous for health and the environment (364/1994) (in Finnish)

Dam Safety Act (413/1984) (in Finnish)

Dam Safety Decree (574/1984) (in Finnish)

Decision of the Ministry of Trade and Industry on safety regulations in mining (921/1975) (in Finnish)

Decision of the Ministry of Trade and Industry on mine maps (1218/1995) (in Finnish)

Decree on the Industrial Handling and Storage of Dangerous Chemicals (59/1999) (in Finnish)

Decree on Environmental Impact Assessment Procedure (713/2006) (in Finnish)

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

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.

Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

Environmental Damage Insurance Act (81/1998)

Environmental Protection Act (86/2000)

Environmental Protection Decree (169/2000)

Forest Act (1093/1996)

Government Decision on approval of Finland's proposal for the European Union's Natura 2000 network 20.8.1998

Government Decision on landfills (861/1997); Government Decision (1049/1999) on an amendment to the Government decision on landfill sites (in Finnish)

Government Decision on the discharge into the aquatic environment of certain substances posing a hazard to the environment and to health (363/1994) (in Finnish)

Government Decision to supplement Finland's proposal for the European Union's Natura 2000 network 25.3.1999

Government Decision to supplement Finland's proposal for the European Union's Natura 2000 network 8.5.2002

Government Decision 22.1.2004 on sites returned by the Supreme Administrative Court for reconsideration of Finland's proposal for Natura 2000 network

Government Decree (889/2006) on an amendment of the Environmental Protection Decree (in Finnish)

Government Decree on the discharge into the aquatic environment of certain substances posing a hazard to the environment and to health (1022/2006)

Government Decree on the assessment of soil contamination and need for remediation (214/2007) (in Finnish)

Government Proposal (84/1999) to Parliament on reform of environmental protection and water legislation. (in Finnish)

Health Protection Act (763/1994) (in Finnish)

Land Extraction Act (555/1981)

Land Use and Building Act (132/1999)

Mining Act (503/1965) (in Finnish)

Nature Conservation Act (1096/1996)

Nature Conservation Decree (160/1997)

Penal Code (39/1889)

Radiation Act (230/1989) (in Finnish)

Tort Liability Act (412/1974)

Waste Decree (1390/1993)

Waste Management Act (673/1978)

Waste Act (1072/1993)

Water Act (264/1961)

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10.3 Photographs

Hitura mine: Photos 1, 2c, 12, 34, 38, 40, 41, 42

Päivi M. Heikkinen: Cover photo and photos 3a, 3b, 6, 9, 13, 16, 17 (larger), 23a, 23b, 27a, 27b, 28a, 28b, 35, 36, 39a, 43, 44, 48a, 48b, 50

Jaana Jarva: Photo 33

Tommi Kauppila: Photos 5, 15, 17 (smaller), 24, 25

Kirsti Korkka-Niemi: Photo 49

Ulla-Maija Mroueh: Photos 14, 47

Esa Mäkelä: Photo 46

Elina Vestola: Photos 2b, 37, 39b

Geological Survey of Finland: 2a

11. APPENDIXES

APPENDIX 1. CHEMICAL AND PHYSICAL IMPACTS RELATED TO MINING AND MINERAL PROCESSING

Table 1. Chemical impacts of different types of mining and mineral processing operations (Ashton et al. 2001)

Operation	Chemical treatment?	Acid mine drainage	Alkalinity	Radio-activity	Arsenic	Mercury	Heavy metals	Cyanide
Diamonds (m)	yes	no	no	occasionally	no	no	no	no
Diamonds (a)	no	no	no	occasionally	no	no	no	no
Gold/silver (m)	yes	yes	no	yes	occasionally	no	occasionally	yes
Gold (a)	yes	no	no	occasionally	no	yes	occasionally	no
PGE (m)	yes	yes	no	occasionally	no	no	yes	no
PGE (s)	yes	yes	no	occasionally	no	no	yes	no
Iron (m)	no	yes	no	no	no	no	yes	no
Iron (s)	no	yes	no	no	no	no	yes	no
Chromium (m)	no	no	yes	occasionally	no	no	yes	no
Chromium (s)	yes	yes	no	occasionally	no	no	yes	no
Wolfram (m)	no	no	no	yes	no	no	yes	no
Ni-Co (m)	yes	yes	no	occasionally	occasionally	no	yes	no
Ni-Co (s)	yes	yes	no	occasionally	occasionally	no	yes	no
Copper (m)	yes	yes	no	occasionally	no	no	yes	no
Copper (s)	yes	yes	no	occasionally	no	no	yes	no
Pb, Zn, Sb, Sn (m)	yes	yes	no	no	no	no	yes	no
Pb, Zn, Sb, Sn (s)	yes	yes (Zn)	no	no	no	no	yes	no
Building stone (q)	no	no	no	no	no	no	no	no
Coal (m,q)	no	yes	no	occasionally	no	no	no	no
Sulphur/pyrite	yes	yes	no	occasionally	no	no	yes	no
Manganese	no	no	occasionally	no	no	no	occasionally	no
Vanadium	yes	yes	no	no	no	no	yes	no
Phosphate*	yes	yes	no	occasionally	no	no	occasionally	no
Andalusite	no	no	no	no	no	no	no	no
Fluorspar	yes	no	occasionally	no	no	no	no	no
Other industrial minerals (q)	no	no	occasionally	occasionally	no	no	no	no
Vermiculite	yes	no	occasionally	occasionally	no	no	no	no
Chrysotile-asbestos	yes	no	occasionally	occasionally	no	no	occasionally	no
Gemstones (m,q)	no	no	no	no	no	no	no	no
As, Bi, Cd, Hg, Sb	yes	yes	no	occasionally	occasionally	occasionally	yes	no
Other metals	occasionally	yes	no	occasionally	no	no	occasionally	no

m = mine, a = alluvial, s = smelter, q = quarry
PGE = platinum group elements
* The most significant environmental impacts in phosphate quarrying are commonly related to exploitation of sedimentary deposits.

Reference

Ashton, P.J., D. Love, H. Mahachi, P.H.G.M. Dirks 2001. An Overview of the Impact of Mining and Mineral Processing Operations on Water Resources and Water Quality in the Zambezi, Limpopo and Olifants Catchments in Southern Africa. Contract Report to the Mining, Minerals and Sustainable Development (SOUTHERN AFRICA) Project, by CSIR-Environmentek, Pretoria, South Africa and Geology Department, University of Zimbabwe, Harare, Zimbabwe. Report No. ENV-P-C 2001-042. xvi + 336 pp. http://www.iied.org/mmsd/mmsd_pdfs/SthAfrica_word_PPT/06_FinalReport.doc

Table 2. Physical impacts of different types of mining and mineral processing operations (Ashton et al. 2001)

Operation	Salinization	Siltation of water courses	Use of water	Area affected**	Large pits	Diversion of water courses	Impacts on vegetation
Diamonds (m)	possible	yes	medium	local	locally	locally	no
Diamonds (a)	possible	yes	medium	local	locally	yes	yes
Gold/silver (m)	possible	yes	large	local	locally	locally	no
Gold (a)	possible	yes	low	regional	locally	yes	yes
PGE (m)	possible	possible	medium	mine site	no	no	no
PGE (s)	possible	possible	low	local	no	no	no
Iron (m)	possible	possible	medium	local	yes	no	no
Iron (s)	no	no	medium	local	no	no	no
Chromium (m)	no	no	medium	mine site	locally	no	no
Chromium (s)	no	no	medium	local	no	no	no
Wolfram (m)	possible	possible	low	mine site	locally	locally	no
Ni-Co (m)	possible	possible	large	mine site	yes	locally	no
Ni-Co (s)	no	no	medium	local	no	no	no
Copper (m)	possible	possible	large	mine site	yes	locally	no
Copper (s)	no	no	medium	local	no	no	no
Pb, Zn, Sb, Sn (m)	possible	possible	large	mine site	locally	locally	no
Pb, Zn, Sb, Sn (s)	possible	possible	low	local	no	no	no
Building stone (q)	no	yes	low	local	yes	yes	yes
Coal (m,q)	yes	possible	medium	local	yes	yes	no
Sulphur/pyrite	possible	possible	medium	local	no	no	no
Manganese	no	yes	medium	mine site	yes	no	yes
Vanadium	yes	yes	large	regional	locally	no	no
Phosphate*	yes	yes	large	regional	yes	no	no
Andalusite	no	yes	low	local	locally	no	locally
Fluorspar	yes	possible	low	local	locally	no	no
Other industrial minerals (q)	possible	possible	low	mine site	yes	locally	locally
Vermiculite	possible	yes	low	mine site	locally	no	locally
Chrysotile-asbestos	possible	yes	low	mine site	locally	no	no
Gemstones (m,q)	possible	possible	low	mine site	locally	locally	locally
As, Bi, Cd, Hg, Sb	no	possible	low	local	locally	locally	no
Other metals	no	possible	medium	mine site	locally	locally	no

m = mine, a = alluvial, s = smelter, q = quarry
PGE = platinum group elements
* The most significant environmental impacts in phosphate quarrying are commonly related to exploitation of sedimentary deposits.
** The area affected: mine site < local < regional

Chemical impacts relate mostly to waste rock and low-grade ore dumps, which are present at all sites, and to chemical treatment, with associated tailings dams, which are present at many mining sites. A wide variety of chemical impacts are possible and these can include acid mine drainage, the less common alkaline mine drainage, the release of highly toxic metals (most notably arsenic, antimony and mercury), the release of heavy metals, such as nickel, copper, cobalt, lead and zinc, and the release of cyanide from gold mining operations.

Physical impacts on water resources include the use of water for a variety of mining operations, siltation of water courses by contribution to suspended solids loads, salinization by contribution to dissolved solids loads, the creation of large pits (that act as rain water traps), diversions of watercourses and sometimes associated extensive deforestation or de-vegetation of mine sites with concomitant erosion problems. The area affected can be segmented into three typical classes or groups, namely: the mine environs only (typically consisting only of the mine property), the local area (one or more properties that are adjacent to the mine property), or more widespread (regional).

APPENDIX 2. QUESTIONS AND ISSUES TO CONSIDER WHEN EVALUATING THE CLOSURE PROCESS IN TERMS OF ECOLOGICALLY SUSTAINABLE DEVELOPMENT

The 7 Questions Model (MMSD 2002b) applied for the mine closure process.

1. Engagement and commitment

"Is there an appropriate process for engaging all relevant stakeholders and communities, to ensure that the planning and implementation of the closure process complies with sustainable development principles? If such processes and commitments exist, how adequate and effective are they?"

The focus here is on the effectiveness of communication and degree of interaction and commitment between the various stakeholders and interest groups involved with, and affected by, the mining and closure process. This is by nature a horizontal consultative process, whereas the subsequent issues in Questions 2 to 7 are addressed sequentially. (Note that the term 'project' is used here to refer to 'mine closure'). Specific subsidiary objectives include:

- Active recourse to communication and engagement mechanisms
- Agreed mechanisms for resolving differences
- Established procedures for reporting and independent verification
- Availability of relevant resources
- The project is carried out in an atmosphere conducive to transparency and rational assessment of factual data

2. People

"Will the well-being of affected communities be maintained (or preferably, further enhanced) following mine closure?"

For evaluation of human and environmental impact, the essential measure of success is whether the project is ultimately beneficial or detrimental to human communities and the ambient ecosystem, as determined by agreed performance indicators and criteria. Specific subsidiary objectives include:

- Communities are sufficiently organized to remain viable over the long term
- Social and cultural activities are maintained, or improved
- Public and occupational health and safety issues are addressed adequately and standards maintained
- Infrastructure of affected communities remains adequate for maintaining general well-being
- Potentially adverse and compounded effects, both direct and indirect, are anticipated and dealt with accordingly
- Realistic cost estimates are made for any social or cultural change and disruption
- Accountability for responsibilities, risks and related expenditures is precisely defined and audited
- Appropriate accounting and agreement on cost of closure, including financial provisions and securities
- The effects of cultural and social disruption are recognized and kept to a minimum

3. Natural environment

"Is the long-term integrity and stability of the surrounding biophysical environment assured?"

As with human impact, the essential measure of success is whether the project is ultimately beneficial or detrimental to the ambient ecosystem, as determined by agreed biophysical performance indicators and criteria. These issues are addressed widely elsewhere in the closure planning process, with specific subsidiary objectives including:

- There is no immediate or long-term threat to the stability and diversity of biophysical systems, or impediments to full ecosystem recovery
- Long-term ecosystem viability is not affected
- All possible costs, benefits and risks to the environment are documented and considered during decision-making processes
- Responsibilities, liabilities and financial provisions are precisely defined
- Adverse environmental affects are kept to a minimum and mitigation measures are implemented

4. Economy

"Have the costs of mine closure been adequately estimated in relation to the viability of mining operations? How will closure affect the local and regional economy?"

Economic aspects of the mining process, including closure provisions, as well as the relative contributions of the public sector and non-commercial activities, for example recreation, all need to be assessed to deliver the most favorable project outcome to financial stakeholders, communities and the environment. Specific objectives include:

- That financial provisions are adequate for the project
- The process is efficiently implemented
- Allocation of both responsibilities and benefits is just and in accordance with previously defined expectations
- Local and regional community economic objectives are attained
- The project is aligned with regional and national economic objectives and strategies

5. Cultural and natural heritage values

"Does the closure process either contribute to, or adequately address potential impact on traditional and non-commercial and recreational activities, interests and values in the region?"

The issues described above in relation to Question 4 are relevant here, with specific objectives including:

- Traditional and recreational activities are not restricted, interrupted or endangered
- Traditional lifestyles are maintained and sites of cultural heritage significance are preserved

6. Public sector institutions and governance

"Are legislative and institutional arrangements and resources appropriate and sufficient for ensuring that the closure process complies with best management practices?"

The issues described above in relation to Question 4 also apply here, with specific objectives including:

- The combination of appropriate legislation, market incentives, involvement of volunteer and non-government organizations, and acknowledgement of cultural values provides a basis for good management and governance
- Provision of resources is adequate and implementation is effective
- The closure project is designed, during the operations phase, to be implemented as a gradual, rather than abrupt transition.
- Mutual trust and respect exist between stakeholders and communities regarding closure commitments

7. Overall assessment

"When assessed on the basis of the various stakeholder viewpoints and interests, together with closure performance indicators, is the overall process seen to be beneficial or deleterious? Can the progress and success of the project be monitored in a dynamic way, so as to improve outcomes?"

This question is defined so as to integrate the issues represented by the preceding six questions, with a view to ongoing opportunities and challenges for improving the process. This new knowledge can then be applied at all stages of the mining life-cycle (exploration and delineation, beneficiation planning, planning of closure and post-closure activities). Specific objectives are:

- The full range of options for the project are recognized and evaluated
- Adequate assessment of various options at the strategic level
- Comprehensive synthesis of the whole process is prepared and available
- All stakeholders and affected communities and interest groups are committed to ongoing learning and improvement of the process

APPENDIX 3. INITIATIVES AND RECOMMENDATIONS PROMOTING SUSTAINABLE DEVELOPMENT IN THE MINERALS AND MINING INDUSTRIES

The table represents a compilation of project initiatives and recommendations for applying sustainable development principles and guidelines to the mining sector, including closure procedures. Most of these projects date from after the year 2000 and are broadly similar in scope. Industry appears to have favoured the ICMM guidelines and the number of companies adopting their recommendations is steadily increasing.

Initiative/Recommendation	Agency or organization	Purpose	Comments	Source
Extractive Industries Review (EIR)	Dr Emil Salim, EIR Secretariat Chair	Develop World Bank funding terms and guidelines	Emphasizes socio-economic impacts	http://go.worldbank.org/T1VB5JCV61
ICMM Sustainable Development Principles & GRI Guidelines	International Council for Mining and Metals (ICMM) and Global Reporting Initiative (GRI)	Commitment to sustainable production practices; requires compliance with GRI-2002 reporting procedures	Binding for 16 industry members and 23 organizations and agencies, including Euromines. Initiated by MMSD	www.icmm.com
Global Dialogue	Canadian and South African + 23 other governments	Commits governments to global challenges relating to the mining sector	Initiative of the UN/CSD and Johannesburg WSSD/P46	www.globaldialogue.info
Extractive Industries Transparency Initiative (EITI)	UK Government/DFID	Commits governments and other stakeholders to transparency of process	Supported by World Bank and IMF; instigated by Johannesburg WSSD/P46	www.eitransparency.org
Equator principles	Grouping of merchant banks	Ethical investment strategies and social responsibility	IFC supported	www.equatorprinciples.com
Mining Certification Evaluation Project (MCEP)	BHP, CSIRO, Newmont, Placer Dome, RT, WMC & WWF	Develop process for certification of mining industry according to social and environmental performance	WWF initiative parallel to fisheries and forestry certification schemes. Based on ICMM 10 Principles	www.minerals.csiro.au/sd/SD_MCEP.htm

DFID = UK Department for International Development
BHP = BHP Billiton, Co.
CSIRO = Commonwealth Scientific and Industrial Research Organization (Australia)
RT = Rio Tinto, Ltd.
WMC = WMC Resources, Ltd.
WWF = World Wildlife Fund
IFC = International Finance Corporation
IMF = International Monetary Fund
WSSD/P46 = World Summit on Sustainable Development Programme, Program Paragraph 46
UN = United Nations
CSD = UN Commission on Sustainable Development

APPENDIX 4. LEGISLATION APPLYING TO MINING

This is not an exhaustive list.

Relations with neighbors
- Adjoining Properties Act, 13 February 1920/26

Health protection
- Health Protection Act, 19 August 1994/763
- Health Protection Decree, 16 December 1994/1280

Environmental permit and environmental impact assessment
- Environmental Protection Act, 4 February 2000/86
- Environmental Protection Decree, 18 February 2000/169
- Act on the Implementation of the Legislation on Environmental Protection, 4 February 2000/113
- Act on Environmental Impact Assessment Procedure, 10 June 1994/468
- Decree on Environmental Impact Assessment Procedure, 17 August 2006/713
- Act on Environmental Permit Authorities, 4 February 2000/87
- Government Decision on Environmental Permit Authorities, 10 February 2000/128
- Ministry of the Environment Decree on fees payable to regional environment centres, 17 December 2003/1237
- Ministry of the Environment Decree on fees payable to environmental permit authorities, 17 December 2003/1238
- Ministry of the Environment Decree on fees payable to the Ministry of the Environment, 17 December 2003/1241

Water Act
- Water Act, 19 May 1961/264
- Water Decree, 6 April 1962/282
- Government Decision on the discharge into the aquatic environment of certain substances dangerous for health and the environment, 19 May 1994/363 repealed
- Government Decree on the discharge into the aquatic environment of certain substances dangerous for health and the environment, 23 November 2006/1022
- Government Decision on the protection of groundwater against pollution caused by certain substances dangerous for health and the environment, 19 May 1994/364
- Act on Water Resources Management, 30 December 2004/1299

Dams and controlled release
- Dam Safety Act, 1 June 1984/413
- Dam Safety Decree, 27 July 1984/574

Air pollution prevention and noise abatement
- Government Decision on air quality guideline values and sulphur deposition target values, 19 June 1996/480
- Government Decision on ozone-depleting substances, 2 April 1998/262
- Government Decision on guideline values for noise emission levels, 29 October 1992/993
- Government Decree on noise emissions level from equipment for outdoor use, 5 July 2001/621
- Government Decree on the sulphur content of heavy fuel oil and light fuel oil, 24 August 2000/766
- Government Decree on air quality, 9 August 2001/711

Radiation
- Radiation Act, 27 March 1991/592
- Radiation Decree, 20 December 1991/1512

Oil pollution prevention
- Act on Combating Oil Pollution on Land, 24 May 1974/378

Building
- Land Use and Building Act, 5 February 1999/132
- Land Use and Building Decree, 10 September 1999/895

Sanitation and waste management
- Waste Management Act, 31 August 1978/673
- Waste Act, 3 December 1993/1072
- Waste Decree, 22 December 1993/1390
- Government Decision on information to be provided on hazardous waste and on the packing and labelling of hazardous waste, 29 August 1996/659
- Government Decision on oil waste management, 30 January 1997/101
- Government Decision on landfill sites, 4 September 1997/861
- Government Decision on packaging and packaging waste, 23 October 1997/962
- Ministry of the Environment Decree on the list of the most common wastes and of hazardous wastes, 22 November 2001/1129
- Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC
- Government Decree on assessment of soil contamination and need for remediation 214/2007

Nature conservation
- Nature Conservation Act, 20 December 1996/1096
- Nature Conservation Decree, 14 February 1997/160

Mining
- Mining Act, 17 September 1965/503
- Mining Decree, 17 December 1965/663
- Ministry of Trade and Industry Decision on mining safety instructions, 28 November 1975/921
- Ministry of Trade and Industry Decision on mine maps, 27 October 1995/1218
- Government Decision on the ordinance for blasting and excavation work, 29 May 1986/410
- Shot firer Act, 25 February 2000/219
- Shot firer Decree, 25 February 2000/220
- 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

Chemicals, pesticides and explosive substances

- Chemicals Act, 14 August 1989/744
- Ministry of Trade and Industry Decision on explosive materials, 25 February 1980/130
- Ministry of Social Affairs and Health Decision on the list of hazardous substances, 24 February 1998/164
- Decree on the Industrial Handling and Storage of Dangerous Chemicals, 29 January 1999/59
- Explosives Decree, 28 May 1993/473
- Act on the Safe Handling of Dangerous Chemicals and Explosives, 3 June 2005/390
- Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC

Civil law

- Tort Liability Act, 31 May 1974/412
- Act on Compensation for Environmental Damage, 19 August 1994/737
- Environmental Damage Insurance Act, 30 January 1998/81
- Environmental Damage Insurance Decree, 2 October 1998/717

Environmental authorities

- Act on Municipal Environmental Administration, 24 January 1986/64
- Act on the Environmental Administration, 24 January 1995/55
- Government Decree on regional environment centers, 4 November 2004/950
- Government Decision on the boundaries of jurisdiction and locations of regional environment centers, 25 September 1997/909

Future legislation

- Draft Government Decree on the environmental protection requirements on rock excavation and rock crushing

APPENDIX 5. EXAMPLES OF PROVISIONS IN ENVIRONMENTAL PERMIT DECISIONS REGARDING MINE CLOSURE

Table 1. Metal ore mines

	Riddarhyttan Resources AB / Suurikuusikko gold mine and concentrator **Permit granted 1 November 2002, Northern Finland Environmental Permit Authority**	**Suomen Nikkeli Oy (Finn Nickel Ltd)/ Exploitation of nickel ore from the Särkiniemi deposit** **Permit granted 6 June 2005, Eastern Finland Environmental Permit Authority**	**AvestaPolarit Chrome Oy (now Outokumpu Chrome Oy) / Kemi chromite mine** **Permit granted 20 November 2002 (information in parentheses pertains to permit granted for a new tailings pond 6 February 2004), Northern Finland Environmental Permit Authority**
Guarantee to ensure/organize waste management	For the waste rock disposal areas, EUR 15,000 at the start of operations plus EUR 0.013 per each ton of waste rock excavated in the following year. For the tailings ponds, EUR 15,000 at the start of operations plus EUR 3.7 per additional sq.m in tailings pond 1, and EUR 15.6 per additional sq.m in tailings pond 2. Absolute bank guarantee with the Lapland Regional Environment Centre as beneficiary, bank deposit or other approved procedure. The guarantees are set so as to cover the shaping and closure costs for the tailings ponds and the waste rock disposal areas and also the costs of monitoring in a case where the operator itself cannot manage it.	EUR 100,000 For ensuring construction of the landfill structures and appropriate waste management of the temporarily dumped soil and rock materials. The guarantee can be partly returned once the North Savo Regional Environment Centre has approved the aftercare work carried out at the site; EUR 10,000 will be retained after this acceptance as guarantee to ensure monitoring and sufficient aftercare.	EUR 1,200,000 Bank deposit, bank guarantee or other approved procedure, with the Lapland Regional Environment Centre as beneficiary. (In the permit granted on 20 November 2002, the guarantee was considered sufficient to cover the decision concerning the environmental permit for the new tailings pond.)
Waste classification	Disposed waste rock, flotation tailings, neutralization sediments, mixtures of flotation tailings and neutralization sediments, and cyanide leaching sediments are classified as waste. Crushed waste rock or other rock which is delivered immediately or after a reasonably brief storage period for use in construction or other such operations is not considered waste, provided that the rock does not contain ore or have acid generation potential. Tailings and cyanide leaching sediments are classified as hazardous waste. The pond for flotation tailings and neutralization sediments, tailings pond 1, is classified as a hazardous waste dump. The pond for cyanide leaching sediments, tailings pond 2, is also classified as a hazardous waste dump. Waste rock is considered non-hazardous waste, though not inert waste, since some of the waste rock can be acid producing. The waste rock disposal areas are classified as non-hazardous waste landfills.	The mining waste generated in the operations is the waste produced in the excavation of metallic ores. Waste rock and basal moraine whose sulphur content exceeds 1.0% are considered non-hazardous waste. Soil and rock whose sulphur content is less than 1.0% are considered inert waste produced in the extraction of mineral ores and can be used for earthworks. Soil and rock used as they are for earthworks either in the mining district, or in road construction or improvement within 36 months of the mine operations being discontinued, are considered a by-product, not waste. A disposal area for materials that are considered permanently inert is considered an inert waste landfill. Because the dumped material is non-polluting soil (clay, peat) or inert waste produced in the extraction of mineral ores, the Government Decision on landfills does not apply.	Disposed waste rock, tailings and crushed rock from ore processing are classified as waste which must be treated or used in a place for which an appropriate permit or approval has been obtained. Crushed waste rock and similar materials consistent with the product properties of crushed stone, which immediately or after a reasonably brief storage period are delivered for use in construction or other operations, are not considered waste. Crushed rock from ore processing and waste rock can be used for earthworks or other construction at the mine site to replace natural materials. Tailings ponds and waste rock disposal areas are considered a repository of inert non-hazardous waste to which the Government Decision on landfills does not apply. The metals contained in the tailings are in poorly soluble form, and the tailings are not acid generating when disposed. (The tailings pond is considered a repository of inert non-hazardous waste to which the Government Decision on landfills does not apply.)

	Riddarhyttan Resources AB / Suurikuusikko gold mine and concentrator **Permit granted 1 November 2002, Northern Finland Environmental Permit Authority**	**Suomen Nikkeli Oy (Finn Nickel Ltd)/ Exploitation of nickel ore from the Särkiniemi deposit** **Permit granted 6 June 2005, Eastern Finland Environmental Permit Authority**	**AvestaPolarit Chrome Oy (now Outokumpu Chrome Oy) / Kemi chromite mine** **Permit granted 20 November 2002 (information in parentheses pertains to permit granted for a new tailings pond 6 February 2004), Northern Finland Environmental Permit Authority**
Landscaping and covering of waste rock piles and tailings ponds	In the landscaping of the waste rock piles and tailings ponds, particular attention must be paid to preventing acid generation by minimizing the amount of water and oxygen passing through the disposed material. A growth layer 0.5 m thick must be laid over the sloped and compacted surface of the waste rock areas, consisting of dense moraine on the bottom and peat and/or humus on the top. Tailings pond 1 must be covered at closure with a surface structure consisting of a seal course at least 0.5 m thick, with a water permeability of no more than 10^{-8} m/s. This must be topped with a drainage blanket at least 0.3 m thick, with good water permeability, and a growth layer 0.2 m thick. Tailings pond 2 must be covered with a watertight surface structure. Before building this, the water seeping from the pond must be recycled through a cyanide removal process until the WAD cyanide level of the water is less than 0.4 mg/l.	Waste rock and basal moraine whose sulphur content exceeds 1.0% must be permanently placed under water layer at the bottom of the open pit when operations are discontinued	The tailings ponds, filled to their final level, must be covered once most of the expected sinking of the tailings has occurred, though no later than two years after their use is discontinued. The surface structure must have a seal course at least 500 mm thick, with a water permeability of no more than $3*10^{-8}$ m/s. This must be topped with a growth layer of 50 mm, which must be immediately planted with grass. The surface structure must be sloped towards the edges of the pond with a slope of at least 1 in 200.[1] Disposal areas for waste rock and the minerals that cannot be used in the concentration process must be landscaped according to the landscaping plan at the latest when their maximum planned filling level has been reached. (The decision on the new tailings pond notes that the quality of the waste to be deposited in the new pond and the landscaping requirement for the pond cause no changes to the existing situation, referring to the permit decision of 20 November 2002.)
Party responsible for aftercare and monitoring	The permit holder, for the final repositories of waste rock, tailings and sediments, for as long as these can be expected to have potential harmful impacts on the environment, though for not less than 30 years.	Monitoring and landfill aftercare must be continued for at least 30 years after discontinuing operations, or until the environmental burden caused by the mine site can be considered to have ceased.	The only mention is that the permit holder is required to landscape the tailings ponds and the disposal areas for waste rock and crushed rock from ore processing.
Discontinuing operations, and aftercare	When operations are discontinued, all machinery, equipment, chemicals, fuels and waste that are potentially harmful to the environment must be removed from the site except for the waste that has a permanent repository at the site. Open pits and waste disposal areas must be left in a condition conducive to public safety.	The plan for discontinuing operations must be delivered to the North Savo Regional Environment Centre for inspection within one month of operations starting. The plan must cover at least the following: the disposal area and its foundation and surface structures; water collecting, treatment and conveying structures; and a detailed plan for organizing monitoring. The plan must be updated according to the current situation within one month of extraction being discontinued.	
Validity of environmental permit	A new application for reviewing provisions in the environmental permit must be submitted by 1 December 2007. The application must contain a detailed plan of the closure of the waste dumps and the removal of other functions, and also of monitoring after closure.	The decision is valid indefinitely. An application to review the permit provisions must be submitted by 20 December 2014.	The permit is valid indefinitely. An application to review the permit provisions must be submitted by 1 December 2008. (The permit is valid indefinitely. An application to review the permit provisions must be submitted by 1 December 2008, together with the 'main permit'.)

[1] Decision no. 28/05/1, Dnro PSY-2004-Y-148 (13 April 2005). Amendment to provision no. 9 in the environmental permit 77/20/1 issued to the Kemi mine of AvestaPolarit Chrome Oy on 20 November 2002.

Table 2. Industrial minerals mines

	Nordkalk Oyj Abp **Parainen limestone quarry waste rock disposal area, Hundbana** **Permit 4 July 2003, Western Finland Environmental Permit Authority**	**Nordkalk Oyj Abp** **Lappeenranta limestone quarry and calcite and wollastonite concentrators** **Permit 17 October 2002, Eastern Finland Environmental Permit Authority**	**Mondo Minerals Oy** **Lahnaslampi talc quarry waste rock disposal area extension** **Permit 23 September 2002, Northern Finland Environmental Permit Authority**	**Mondo Minerals Oy** **Lipasvaara talc and nickel mine** **Permit 16 November 2001, Eastern Finland Environmental Permit Authority**
Party responsible for aftercare and monitoring	After landfill use is discontinued, the area must be rehabilitated and landscaped as detailed in the permit application. The landscaping must be executed as the disposal proceeds, as far as possible. The maximum landfill volume is about 2,400,000 tons, the final height is about 60 m, and the slope is 1 in 1.5 or more.	The permit holder must manage aftercare for stripping soil and tailings areas for as long as these are found to cause harmful impacts on the environment, though not for more than 30 years after the operations at the site end. If the disposal areas are still causing harmful impacts on the environment 30 years later, the permit authority can rule that the aftercare responsibility will continue beyond that limit.	The permit holder, for as long as the area can be assumed to have a harmful impact on the environment, though not for less than 30 years.	Under the plan approved by the authorities, the impact on watercourses will be monitored until it is found that the disposal areas no longer have an impact on the environment.
Guarantee to organize/ ensure waste management	EUR 10,000 guarantee to the Southwest Finland Regional Environment Centre to ensure appropriate care and landscaping for the area. The guarantee only applies to the rehabilitation of tailings and waste rock areas classified as waste.	EUR 200,000 A guarantee approved by the Southeast Finland Regional Environment Centre (bank guarantee or deposit certificate) to ensure the fulfillment of the obligations regarding disposal areas and aftercare.	EUR 900,000 Absolute bank guarantee, with the Kainuu Regional Environment Centre as the beneficiary, or a bank deposit. The guarantee is set so as to cover the costs of landscaping and closure of the waste rock disposal area and monitoring during aftercare and costs in a case where the operator is unable to manage this.	EUR 500,000 As approved by the Regional Environment Centre.
Waste classification	The waste rock (waste title 010102) disposal area is considered a landfill for inert rock waste.	The stripping soil and waste rock are classified as non-hazardous, inert soil and rock waste. The tailings are classified as inert non-hazardous waste produced in the extraction and concentration of mineral ores, as referred to in section 2 of the Government Decision on landfills. The Government Decision on landfills does not apply to the stripping soil and tailings disposal areas. Waste rock, stripping soil and tailings must primarily be reused.	The disposed waste rock and soil are classified as waste (title 010101, waste produced in the extraction of metallic minerals). Mica schist which contains no sulphides and which is consistent with the product properties of crushed stone, and which is immediately or after a reasonably short period of storage delivered for use in construction or other operations is not considered waste. The waste rock disposal area is a non-hazardous waste landfill.	The provisions of the environmental permit stipulate further investigation of the composition of the waste rock, its solubility and other properties relevant to its disposal in a landfill. The waste classification and landfill disposal of the waste rock will be decided on the basis of this investigation.

	Nordkalk Oyj Abp **Parainen limestone quarry waste rock disposal area, Hundbana** **Permit 4 July 2003, Western Finland Environmental Permit Authority**	**Nordkalk Oyj Abp** **Lappeenranta limestone quarry and calcite and wollastonite concentrators** **Permit 17 October 2002, Eastern Finland Environmental Permit Authority**	**Mondo Minerals Oy** **Lahnaslampi talc quarry waste rock disposal area extension** **Permit 23 September 2002, Northern Finland Environmental Permit Authority**	**Mondo Minerals Oy** **Lipasvaara talc and nickel mine** **Permit 16 November 2001, Eastern Finland Environmental Permit Authority**
Discontinuing operations, and aftercare		Once the mine is closed, the site must be cared for so that it causes no danger or harm to the environment or to human health. If operations will be discontinued before the permit decision is revised, the permit holder must submit to the Environment Permit Authority an application with a plan on the aftercare measures required because of the discontinuation, at least eight months before the discontinuation.		Aftercare for the waste rock disposal areas must be continued for as long as they are found to have harmful impacts on the environment, though not for more than 30 years after operations are discontinued. If, after 30 years, the disposal areas are still found to have harmful impacts on the environment, the environment permit authority can rule that the aftercare responsibility will continue beyond that limit. Once the mine operations are discontinued, the site must be given aftercare so that within three years it is rendered into a state where it is no longer dangerous or harmful to the environment or to human health. According to the plan approved by the authorities, the settling ponds will be covered with dense moraine or converted into a wetland where vegetation will be used to bind any metals present.
Landscaping and covering of waste rock piles and tailings ponds	A record must be kept of waste rock disposed, showing the volumes and times of disposal. Rehabilitation and landscaping must be carried out as specified in the plan appended to the permit application. Slopes and levels will be covered with a 30-220 mm layer of gangue, topped with moraine with humus content or clay. Alternatively, compost peat from Paroc Oy Ab's rock wool plant can be used. Landscaping should begin from the bottom once the disposal has progressed so far that there is a sufficient amount of surface area available.	**Tailings pond:** The outer slopes of the perimeter dams must be landscaped to merge with the environment as the dams are raised. Once the dam reaches its final height of +82 m, trees and shrubs must be planted with a view to landscaping and dust binding. **Stripping soil:** The earthwork protecting the dumping area must be landscaped with trees and grass at the construction stage. The protective line of trees outside the earthwork must consist, at least in part, of coniferous and deciduous saplings grown to a minimum height of 4 to 5 m.* Once the dumping area reaches its final height of +82 m, the area must be shaped and landscaped with plantings to merge with the landscape and terrain. The surface must be covered with a sufficient growth layer and shaped so that no water-collecting depressions remain. Aftercare for the dumping area must be implemented stagewise as the area reaches its final height. *When the permit decision was granted, the neighbors voiced their unanimous opposition to planting trees, and the environmental permit authority entered in the inspection minutes that the area is to be landscaped using grass.		The waste rock disposal areas must be managed and landscaped by covering them with moraine and growth layers containing clean soils. The surfaces of the disposal areas must be shaped so that no water-collecting depressions remain. Slopes and terraces must alternate so that no slope is more than 40 m long. According to the approved plan, the moraine layer on the surface structure will be about 1 m, and the growth layer will be about 0.2 m thick. The aftercare for the disposal areas must be carried out within three years of the discontinuation of disposal. Aftercare for the northern disposal area must be conducted in stages while the disposal area reaches its final height, as far as possible.

Validity of environmental permit	The permit is valid indefinitely. An application to review the permit provisions must be submitted by 31 December 2010.	The permit is valid indefinitely. An application to review the permit provisions must be submitted to the environment permit authority by 30 September 2009.	A new application to review the provisions of the environmental permit must be submitted by 31 December 2003.	A new application to review the provisions of the environmental permit must be submitted by 31 October 2009. If operations will be discontinued before the permit decision is revised, the permit holder must submit to the Environment Permit Authority an application with a plan on the aftercare measures required because of the discontinuation, at least six months before the discontinuation. The plan must cover aftercare for open pits, disposal areas and settling ponds, and the processing of the sludge accumulating at the bottom of the ponds. The plan must further detail water treatment and conveyance at the mine site once aftercare has been implemented, and a monitoring plan.

Table 3. Natural stone quarries as per the mining act

	Tulikivi Oyj **Soapstone extraction in Koskela mining district** **Permit 3 May 2002, Eastern Finland Environment Permit Authority**
Party responsible for aftercare and monitoring	The permit holder must manage aftercare for the waste rock disposal areas for as long as they are found to have a harmful impact on the environment, though for not more than 30 years after operations are discontinued. If, after 30 years, the disposal areas are still found to have a harmful impact on the environment, the environment permit authority can rule that the aftercare responsibility will continue beyond that limit.
Guarantee to organize/ensure waste management	EUR 80,000 As approved by the Regional Environment Centre (bank guarantee or deposit certificate). The purpose of the guarantee is to ensure fulfillment of the obligations regarding the soil and rock disposal areas and the carrying out of measures required by the discontinuation of operations and aftercare.
Waste classification	The waste rock and the stripped soil are classified as waste, and the waste rock disposal area is considered a landfill. Non-hazardous soil and rock waste (stripping soil and waste rock) should primarily be reused. The provisions of the environmental permit also call for more investigations into the composition, solubility and other properties of the waste rock and the powdered soapstone.
Landscaping and covering of waste rock piles and tailings ponds	Aftercare for the disposal area must progress in stages while the area reaches its final height. The disposal area must be landscaped using clean soils and a sufficient growth layer, and the surface must be shaped so that no water-collecting depressions remain. The parts of the disposal area that have reached their final height must be landscaped so as to merge with the landscape and terrain.
Discontinuing operations, and aftercare	Once the mine operations have been discontinued, aftercare must be provided so that within three years the site no longer poses a danger or harm to the environment or to human health. If operations will be discontinued before the permit decision is revised, the permit holder must submit to the Environment Permit Authority an application with a plan on the aftercare measures required because of the discontinuation. The plan must cover aftercare for quarries, disposal areas and settling pools, and the processing of the sludge accumulating at the bottom of the pools. The plan must further detail water treatment and conveyance at the mine site once aftercare has been implemented, and a monitoring plan.
Validity of environmental permit	The permit is valid indefinitely. An application to review the permit provisions must be submitted by 1 April 2009.

APPENDIX 6. PERMITS GOVERNING MINE OPERATIONS

Tables 1-3 list the principal permits and notifications governing mine operations. These are divided as follows:
- Permits and notifications before the decision to establish a mine is taken
- Permits and notifications related to operations after the decision to establish a mine is taken
- Permits and notifications related to discontinuation of operations

Both mining legislation and environmental protection legislation require a permit procedure. There are also permits and notifications stipulated in the legislation on land use, construction and chemicals. In addition to the legislation cited here, the Antiquities Act may require notification to be made to the Archaeological Commission, running a canteen requires a notification to the municipal health inspector, etc. Existing and pending legislation governing mining is described in chapter 3.

Table 1. Permits to be obtained and notifications to be made before taking the decision to establish a mine.

Permit or notification	Legal reference	Application processed by	Application time	Principal content	Further information
Exploring: Notification of sampling	Mining Act (503/1965) as amended (1625/1992)	Landowner or local land registry office	Exploring stage, before sampling	Freeform notification	
Claim	Mining Act (503/1965) as amended (1625/1992)	Ministry of Trade and Industry (MTI)	Before more extensive exploration is launched	Contact information for claimant, data on area, assumed minerals to be exploited, and estimate of exploration required	
EIA	Act on Environmental Impact Assessment (468/1994) as amended (267/1999)	Regional Environment Centre or Ministry of the Environment	Before the mining district application is submitted if the proposed volume of material to be extracted is equal to or greater than 550,000 tonnes per are, or if the surface area of the quarry is greater than 25 hectares.[2]	Two stages: assessment programme and assessment report (see the EIA guide)[1]	EIA report must be appended to permit applications; this also includes the environmental safety of mine closure and by-products.
Planning, decision on municipal planning needs	Land Use and Building Act (132/1999) Land Use and Building Decree (895/1999)	Planning is managed by the local authority	Component master plan drawn up in parallel with EIA procedure		Planning needs must be investigated
Mining district application	Mining Act (503/1965) as amended (1625/1992)	Ministry of Trade and Industry (MTI)	At the same time as the claim is submitted, or during the claim period; EIA report must be appended.	Includes a description of the exploration and its findings, a plan of use for the mining district and its area, a cadastral register extract, parties involved, statement from the local authority	The application launches a mining district process which results in the setting up of a mining district and the granting of a concession; MTI can decide at its discretion whether the EIA report needs to be appended to the general mine plan.
Notification of mine operations	Mining Act (503/1965) as amended (1625/1992)	Ministry of Trade and Industry (MTI)	Annually for the duration of the concession	Has mining been carried out in the mining district, and if so, a report on the extent, nature and results of the operations	
Mine map	Mining Act (503/1965) as amended (1625/1992) MTI Decision on mine maps (1218/1995)	Safety Technology Authority (TUKES)		Topographic and geological surface map, with horizontal and vertical sections	

[1] Salminen R., Heikkinen P., Nikkarinen M., Parkkinen J., Sipilä P., Suomela P., Wennerström M. (1999) Ympäristövaikutusten arviointimenettelyn opas kaivoshankkeisiin. Kauppa- ja teollisuusministeriön tutkimuksia ja raportteja 20/1999, Teknologiaosasto. 80 s. [Ministry of Trade and Industry]

[2] Can be applied to other projects, too, on a case-by-case basis if the anticipated environmental impact is significant.

Table 2. Permits to be obtained and notifications to be made after the decision is taken to establish a mine

Permit or notification	Legal reference	Application processed by	Application time	Principal content	Further information
General plan for mine operations	Ministry of Trade and Industry Decision on mine safety instructions (921/1975) as amended (1187/1995)	Safety Technology Authority (TUKES)	Before mining is started. Must be updated at any time when substantial changes are made to the mine.	Limits of soil extraction, surface water and groundwater arrangements, excavation execution, access shafts and exit routes, dewatering and ventilation, location of industrial and waste dumping areas, mine building schedule.	It is recommended that the application includes a preliminary closure plan. Mine inspection (TUKES) at least once a year.
Environmental permit (including matters related to waste management, groundwater, soil and air protection)	Environmental Protection Act (86/2000), Environmental Protection Decree (169/2000)	Environmental Permit Authority	Before mining is started and whenever substantial changes are made that will increase emissions or risks	Identification data, location data, operations, environmental load, BAT report, impacts, monitoring, damage prevention	Application instructions can be found on the environmental administration website. Mining may not be started before the permit has entered into force. The EIA report and a statement from the contact authority must be appended. The permit application must include a closure plan and a report on the environmental safety of by-products.
Water Act permit (water conducting, water extraction, waterway changes)	Water Act (264/1961)	Environmental Permit Authority	Part of the environmental permit application		
Building permits **- concentrators, offices, storage and other buildings** **- other construction**	Land Use and Building Act (132/1999)	Local building authority	Before construction, or before substantially changing a building or its purpose	Report on possession of the building site, principal drawings of the building	
Permits for the handling and storage of dangerous chemicals	Act on the Safe Handling of Dangerous Chemicals and Explosives (390/2005) Decree on the Industrial Handling and Storage of Dangerous Chemicals (59/1999)	Safety Technology Authority (TUKES)	For large-scale handling and storage of chemicals, before storage is started	Permit application content described in Appendix II to Decree 59/1999	
Permits for the handling and storage of dangerous chemicals		Local civil protection authority	For small-scale handling and storage of chemicals, before storage is started		
Site rescue plan	Act on the Safe Handling of Dangerous Chemicals and Explosives (390/2005)	New production facilities: TUKES Others: Local civil protection authority	In cases of large-scale industrial handling and storage of chemicals	Responsible persons, measures for foreseeable dangers, notification to the authorities, personnel training (Appendix VI of Decree 59/1999).	
Safety report or operating principles document	Act on the Safe Handling of Dangerous Chemicals and Explosives (390/2005) Decree on the Industrial Handling and Storage of Dangerous Chemicals (59/1999)	Safety Technology Authority (TUKES)	Determined on the basis of the volume of chemicals and how dangerous they are	The content of the operating principles document is described in Appendix III of Decree 59/1999, and the content of the safety report is described in Appendix IV.	
Dam safety monitoring programme and risk report	Mining Act (503/1965) as amended (1625/1992) Dam Safety Act (413/1984) Dam safety instructions (Ministry of Agriculture and Forestry 1997)	Safety Technology Authority (TUKES)	In good time before the dam is completed. Must be approved before the dam is taken into use. Date of submission to the authorities depends on the dam classification.	Monitoring of structures and water level, measurements, inspections, etc.	

Permit or notification	Legal reference	Application processed by	Application time	Principal content	Further information
Notification on lifting equipment	Ministry of Trade and Industry Decision on lifting equipment in mines (372/1969) as amended (1188/1995)	Safety Technology Authority (TUKES)	Before new lifting equipment is taken into use		Initial inspection, annual inspection by TUKES
Notification on withdrawal of lifting equipment	Ministry of Trade and Industry Decision on lifting equipment in mines (372/1969) as amended (1188/1995)	Safety Technology Authority (TUKES)	When lifting equipment is permanently withdrawn from use		
Permits for storing explosives, other permits regarding explosives	Ministry of Trade and Industry Decision on mine safety instructions (921/1975) as amended (1187/1995)	Safety Technology Authority (TUKES)	In good time before storage is begun	Type and amount of explosive to be stored, location map and plans of storage facility	
Notification of mine operations	Mining Act (503/1965) as amended (1625/1992)	Ministry of Trade and Industry	Annually for the duration of the concession	Has mining been carried out in the mining district, and the extent, nature and results of the operations	
Mine map	Mining Act (503/1965) as amended (1625/1992) Ministry of Trade and Industry Decision on mine maps (1218/1995)	Safety Technology Authority (TUKES)		Topographic and geological surface map, with horizontal and vertical sections	

Table 3. Permits to be obtained and notifications to be made in relation to mine closure

Permit or notification	Legal reference	Application processed by	Application time	Principal content	Further information
Aftercare plan	Required for the environmental permit for mines as per the Environment Protection Act	Environmental Permit Authority	6 to 8 months before closure at the latest	Detailed plan concerning the discontinuation of mine operations	
Environmental permit for rehabilitation of contaminated areas or notification of cleaning	Environmental Protection Act (86/2000) Environmental Protection Decree (169/2000)	Regional Environment Centre	When planning the rehabilitation action. Notification no later than 30 days before the cleaning action.	Contact information, data on the contaminated area and the contamination, cleaning objective and methods, environmental impacts of the cleaning; permit application must include BAT study, monitoring, etc.	Permit application and notification forms are available on the environmental administration website. It takes more time to process a permit application than a notification.
Notification on withdrawal of lifting equipment	Ministry of Trade and Industry Decision on lifting equipment in mines	Safety Technology Authority (TUKES)	When lifting equipment is permanently withdrawn from use	Freeform notification	
Notification of relinquishing concession	Mining Act (503/1965)	Ministry of Trade and Industry	After mine operations have been discontinued	Written notification to the Ministry of Trade and Industry	The concession expires when the notification is received by the Ministry.
Mine map	Mining Act (503/1965) as amended (1625/1992) Ministry of Trade and Industry Decision on mine maps (1218/1995)	Safety Technology Authority (TUKES)	By May 1 in the year following the discontinuation of mine operations	Topographical and geological surface map with horizontal and vertical sections	

Environmental administration instructions and forms can be found at http://www.ymparisto.fi/

APPENDIX 7. CONTAMINATED SOIL LEGISLATION AND AMENDMENTS

Before 1 April 1979 (before the Waste Management Act entered into force)

- who is responsible
  - holder of the area > obligation to present a waste management plan as per the Environment Protection Act
  - party guilty of littering, but this provision cannot be applied to an operation which ceased completely before the Waste Management Act entered into force (Supreme Administrative Court, 12 June 2001 (1414))
- contemporary legislation (Water Act, Mining Act, etc.)

1 April 1979 to 31 December 1993, Waste Management Act (673/1978)

- obligation to present a waste management plan (section 21)
  - who is responsible
    - holder of the area
- prohibition on littering (sections 32 and 33)
  - 'substance' added in amendment in 1987 (203/1987)
  - who is responsible
    - polluter
    - holder of the area
    - local authority, but only if the polluting party cannot be established and the incident has not occurred in a densely populated area and is not covered by the obligations of the public road keeper (the road itself, shoulders and adjacent areas)

1 January 1994 to 28 February 2000, Waste Act (1072/1993)

- the Waste Decree used to have (1997-2000) a provision whereby the provisions on approval procedure in the Waste Act do not apply to inert soil and waste rock produced in mine operations and used or processed in those operations or mine operations elsewhere, provided that the waste is used or processed according to a plan approved as per the Mining Act
- who is responsible
  - polluter
  - holder of the area
  - local authority

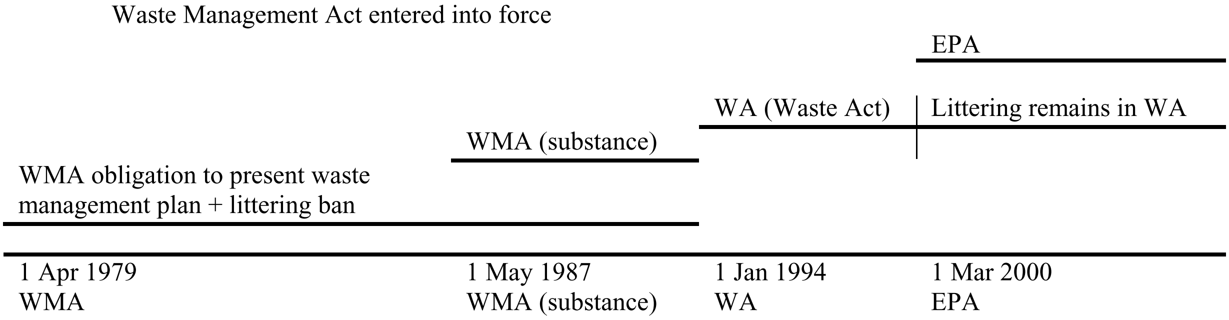
From 1 March 2000, Environmental Protection Act (86/2000)

- exception to permit procedure (institutional or professional treatment of waste)
  - section 28(2) paragraph 4 of the Environmental Protection Act > section 4(1) paragraph 2 of the Environmental Protection Decree
  - the use or processing of clean soil and waste rock according to an approved plan which fulfils the requirements of the Waste Act does not require an environmental permit
  - the specific exception in the Waste Decree pertaining to mine operations has been repealed
- who is responsible
  - primarily the polluter
  - holder of the area
  - local authority

Time dimension of waste legislation

Obligation to present a waste management plan and ban on littering as per the Waste Management Act (WMA) -retroactivity

- obligation to present a waste management plan is retroactive, Environmental Protection Act (EPA) procedure is applied
- prohibition on littering, on the other hand, cannot apply to operations which ceased completely before the Waste Management Act entered into force



APPENDIX 8. EXAMPLE OF HOW TO COMBINE A PARTIAL DISPOSITION PLAN AND A MINE PROJECT

The partial disposition plan for the Suhanko mine area

Suhanko is an area covering the north-western part of the municipality of Ranua and the eastern part of the municipality of Tervola. The exploitation of platinum deposits was planned for there. The local authorities of Ranua and Tervola jointly commissioned a partial disposition plan for the mine area, drawn up by JP-Transplan Oy / Jaakko Pöyry Infra in Oulu.

The plan area covers the deposits as well as the proposed locations of the concentrator, offices, maintenance and upkeep facilities, and waste rock and tailings areas. There are also areas reserved for roads and waterway arrangements. The partial disposition plan covers an area of about 52 sq.km.

The partial disposition plan was prepared in parallel with the EIA procedure. The reports and scenario impacts produced in the EIA procedure were used in the planning process. The partial disposition plan process included these stages:

1) Decision by municipal boards on drawing up a partial disposition plan
2) Initial meeting and briefing
3) Presenting the draft stage
4) Draft partial disposition plan on public display
5) Hearings of landowners and other parties
6) Request for statements from the Regional Council, the Regional Environment Centre and bordering municipalities
7) Proposed partial disposition plan on public display
8) Approval by municipal boards

There were also several negotiations and talks between authorities during the work, which was started in autumn 2001 and finished with the municipalities approving the plan in autumn 2003.

The purpose of the planning was to reserve an area for mine operations and to find the best land-use solution for placement of functions. There was no existing civil engineering infrastructure in the area. The anticipated lively traffic, heavy transport and large quantities of energy and water required for the mine operations needed arrangements of their own. The planning process was governed by the Land Use and Building Act as relevant for the objectives of land use planning (section 5) and by national land use objectives. The area covered by the plan was designated as agricultural and forestry land (MT) in the regional plan in Ranua, whereas Tervola is covered by the Lapland sub-regional plan, where the area was designated as principally a timber-producing area (MT1). The proposed Lapland regional plan highlights the rich deposits of valuable metals in northern Finland and how important their exploitation is for the region; it also highlights the importance of restoring mine areas to a harmless and natural state following the discontinuation of mine operations.

The plan description of the component master plan details the purpose of the planning, its objectives and options, and also describes the natural conditions, land use and community structure, traffic and business in the area and how the proposed project would affect them, including social impacts. The description also links the plan to other planning and to national land use plans and it contains a participation and assessment plan.

The partial disposition plans were mainly determined by the land use requirements of mine operations, which in turn were determined by the functional and economic requirements of mine operations and by nature and landscape conservation aspects. For example, options for the placement of the tailings pond and transport access routes were weighed in the EIA procedure.

The general description of the partial disposition plan notes that the nature of the operations is such that damage will be caused to the area and its vicinity, both to the natural environment and to the landscape. The placement of functions is largely indicative. The area is marked on the plan as EK (mine area). Special markings denote the locations of intensive soil extraction, waste rock areas, tailings areas, the quarry, buildings and dam basin and possible expansion of the mine.

The plan description of the partial disposition plan refers to statutory provisions as regards aftercare measures but notes that mine closure and aftercare actions should be planned at the project planning stage.

At the moment, the expectation is that the Suhanko area will be turned over to timber production after the mine is closed.

APPENDIX 9. SULPHIDE OXIDATION PROCESSES

The oxidation of sulphide minerals is a critical process with respect to the environmental management and potential use of waste rock and tailings. Sulphide minerals present in waste rock and tailings will tend to oxidize when exposed to oxygen and water. Mechanisms for oxygen transport into tailings or water rock piles include diffusion of oxygen, driven by partial pressure differences between the atmosphere and air trapped within porous material, transport of dissolved oxygen via percolation of rainwater, or infiltration through thermally driven convection and wind-generated turbulence. The diffusion coefficient of oxygen in air is approximately four orders of magnitude greater than in water (Robertson *et al.* 1997).

Oxidation of sulphides generates sulphate anions and free hydrogen radicals that will tend to promote acidity. Typical sulphide minerals include pyrite (FeS_2) and pyrrhotite (FeS_{1-x}). A series of simple balanced oxidation reactions for pyrite (Mitchell 2000) are presented below (Equations 1-4).

$$2\ FeS_{2(s)} + 7\ O_{2(aq)} + H_2O_{(l)} \rightarrow 2\ Fe^{2+}_{(aq)} + 4\ SO_4{}^{2-}_{(aq)} + 4\ H^+_{(aq)} \quad (1)$$

$$2\ Fe^{2+}_{(aq)} + ½\ O_{2(aq)} + 2\ H^+_{(aq)} \rightarrow 2\ Fe^{3+}_{(aq)} + H_2O_{(l)} \quad (2)$$

$$FeS_{2(s)} + 14\ Fe^{3+}_{(aq)} + 8\ H_2O_{(l)} \rightarrow 15\ Fe^{2+}_{(aq)} + 2\ SO_4{}^{2-}_{(aq)} + 16\ H^+_{(aq)} \quad (3)$$

$$Fe^{3+}_{(aq)} + 3\ H_2O_{(l)} \leftrightarrow Fe(OH)_{3(s)} + 3\ H^+_{(aq)} \quad (4)$$

The oxidation of pyrite in the absence of the ferric iron (equation 1) is a slow process in nature. Reaction 2 is also slow in an acid environment unless mediated by a biological catalyst, in which case reaction progress and oxidation of Fe^{2+} to Fe^{3+} may be enhanced by up to six orders of magnitude. Ferric iron is a highly efficient oxidant, which reacts with pyrite (equation 3), other sulphides and with water (equation 4) resulting in the formation of e.g suphates and production of acidity.

The pH of mine waters discharging from waste rock and tailings facilities is largely determined by a dynamic equilibrium between acid-producing and buffering reactions. All materials containing sulphide minerals, such as pyrite, have the propensity to generate free protons, and thus acidity. Nevertheless, acidic mine waters (Acid Rock Drainage = ARD; Acid Mine Drainage = AMD) will only form where the neutralizing effect of alkaline reactions is insufficient.

References

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The following sections provide a general summary of numerical hydrogeological and geochemical modelling, a review of available modelling codes and background information on the appropriate input parameters and boundary conditions required for modelling, with particular emphasis on applications in mine closure.

Hydrogeological modelling

Simulation of flow and transport methods used in hydrogeological modelling may be based on either analytical or numerical solutions, or some combination of both approaches. However, in every case, the underlying mathematical calculations rely on the principle of mass balance within groundwater or, if appropriate, within both the saturated and unsaturated zones. A dynamic mass balance represents the interaction between groundwater (and vadose water) flow, infiltration and recharge, and discharge into surface waters. The overall mass balance is also influenced by human activities such as groundwater extraction, or infiltration.

Groundwater flow and particle transport are governed primarily by hydraulic parameters of aquifers (and aquitards), but for the purpose of modelling, mathematical equations also need to be specified for the boundary conditions to the model. Flow within the model, or solution domain, is generally based on Darcy's law. The mathematical derivation of mass balance equations and background theory is considered in numerous textbooks, such as Bear (1979), Bear and Verruijt (1994) and de Marsily (1986). In most cases, the equations describing groundwater are based on differential solutions. Broadly speaking, the analytical approach to modelling produces robust and quantitative mathematical solutions for flow and transport in precisely quantified, though extremely simplified systems, for which boundary conditions and physical parameters are well-constrained. Conversely, numerical models can simulate processes with more complex model geometry and distribution of parameters, but the flow and transport is calculated using relatively simplified (so called discrete) mass balance equations. Depending on properties of flow medium, numerical flow and transport models can be subdivided into three broad groups comprising equivalent porous media, dual porosity media or discretely fractured media models. The various differences between these methods are described in detail in standard texts and references (see Bear and Verruijt 1994, de Marsily 1986).

The analytical modelling approach is typically used for estimation of the hydraulic properties of geological units and can provide constraints on, for example, hydraulic conductivity and groundwater recharge and discharge rates and volumes, or areas affected by downdraw related to pumping. Such results can then be used as input parameters and boundary conditions for more complex numerical simulations. Analytical solutions for groundwater flow into open pits and underground workings have been calculated in connection with mine closure studies (Hanna *et al.* 1994, Marinelli and Niccoli 2000), as has estimations of the rate of filling of decommissioned open pits (Fontaine *et al.* 2003). In addition to these applications, analytical models can be use to evaluate particulate transport and changes in concentration in flowing groundwater (e.g Ogata 1970). One of the main advantages of analytical modelling is the precision with which the underlying equations allow quantitative results, for example extent of downdraw, or species concentration, to be obtained. General summaries of analytical methodology and their application in determining hydraulic parameters are provided by Lohman (1972) and Kruseman & DeRidder (1991). Analytical modelling solutions may also be used in so-called semi-analytical process modelling to substitute for computationally demanding numerical sub-processes. Semi-analytical models have been developed for estimating risk of groundwater contamination and for metal migration in groundwater. Examples of semi-analytical models include the so-called analytical element-based codes TWODAN and MODAEM (Strack 1989, Haitjema 1995), and FRACTRANS, which was developed for bedrock fracture analysis (Sudicky & McLaren 1992).

Numerical flow and transport model calculations may be based on finite-difference, finite-element or finite-volume methods, relying on diverse computer packages that solve according to various combinations of differential equations and matrix algebra. Commercially available finite-difference applications include various graphical interfaces based on the MODFLOW code of McDonald and Harbaugh (1988), such as PMWIN, GMS, and Visual Modflow, and related reactive transport codes (including MT3D, MODPATH; RT3D); a further code SWIFT is designed for simulating transport of heat, saline fluids, and radionuclides as well as groundwater flow, while the TOUGH package (Pruess 1991) is capable of modelling computational intensive processes, including more specialized applications (TOUGHAMD and TOUGHREACT), for mine-related environmental problems. Examples of modelling packages based on the finite-element approach include FEMWATER, FEFLOW, FLONET and FRAC3DVS (Lin *et al.* 2002, Therrien *et al.* 1999). The finite-volume method of calculation is rather less common, but is used for example in the PCGEOFIM-code (Müller *et al.* 2003), which has in fact become widely accepted in Germany in particular, as a standard tool for rock mechanics and evaluation of groundwater flow in abandoned quarries and in mine environments during closure. All these programs are flexible in terms of modifying system set up and have additional modules permitting simulation of two-phase porous flow. In addition, the FRAC3DVS and SWIFT codes are able to solve for discrete fracture-related flow.

Numerical modelling techniques are also capable of simulating advection and transport of gas groundwater flow, heat transfer and radionuclide migration. Numerical simulations of processes relevant to mine closure include evaluations of the rate of filling of open pits (Toran and Bradbury 1988) and transport within tailings impoundments (Johnson 1993).

The choice of hydraulic parameters for use in numerical modelling depends largely on the whether flow is saturated, within the phreatic zone, or above the water table in the vadose zone, or whether or not particulate material is being transported by water. In general, some constraints on hydraulic properties are required, notably parameters relating to the permeability and storage capacity of groundwater aquifers and formations, (hydraulic conductivity or permeability, storage coefficient and specific yield etc.), and also to the water table (hydraulic head or potential). Hydraulic parameters are themselves influenced by the medium, through which fluid flows, so that information will be required concerning geological properties such as grain size distribution, thickness and composition of stratigraphical and lithological units, depth to bedrock and fracture density and patterning in underlying bedrock. In addition to the above information, transport simulations require knowledge of the concentration of contaminants within the fluid and other attributes affecting their behaviour, such as dispersion and adsorption. Depending on the nature of the investigations, field or laboratory measurements are usually required for defining relevant and realistic values for model input parameters and boundary conditions, for example characterization of surficial sedimentary materials, depth to the water table and flow rates at natural discharge sites, geophysical surveys, pumping and other hydraulic tests, groundwater analysis and tracer experiments. In addition generalization and assessment of field and laboratory based hydraulic results is usually performed with geostatistical analysis and interpolation methods.

As noted above, modelling of groundwater flow requires specification of boundary conditions as well as flow-related parameters. Boundary conditions are defined according to mathematically prescribed interactions between the model and the external environment. For example, in groundwater flow models, boundary condition values are commonly based on measured hydraulic head or groundwater flow rate, but can also be defined from groundwater seepage, topology of the phreatic surface, or lakes, wells, drainage channels, natural streams or any other features that influence groundwater discharge or infiltration. Models need to be calibrated against a reference state to ensure stability and that the resolution of the model simulation is consistent with the precision of the input data. For calibration purposes the calculated results of a simulation (for example depth to water table) are compared with actual measured values (such as water levels in observation wells) and relevant variables (for example hydraulic conductivity) may then be modified accordingly, to yield more realistic approximations. Calibration is routinely performed with programs that offer automated mathematical optimization (such as MODFLOW 2000, PEST, UCODE). Optimization procedures can also be used during inverse modelling to better define the relevant parameter space for poorly or inadequately constrained variables. Automated calibration optimization also provides a statistical analysis of input and background variables and their influence on model results, which can then be used in evaluating inherent uncertainties or deficiencies in the modelling process.

Geochemical modelling

Geochemical models are intended to simulate natural chemical processes within a geological context and as in the case of hydrogeological modelling, the same principles of mass and energy conservation and balance apply. Geochemical models are typically thermodynamically and kinetically based and may be used for both forward and inverse simulations. Conceptually, inverse and forward modelling approaches differ in that forward models are used to attempt to predict the future behaviour and final state of a system, by specifying premises and conditions for the initial state, and then simulating the effect of a given process. Examples of the forward modelling approach would include the effect of dissolution of a particular mineral species on water chemistry over time. In contrast, the inverse modelling approach is used primarily to deduce the nature of system processes and pathways, with reference to the observed final state and an inferred initial state. A typical example of inverse modelling would be to determine the weathering or precipitation mechanisms for a mineral species, based on analyses of water chemistry from two or more points along the same flow path.

Geochemical models can be further categorized on the basis of their properties and underlying principles into speciation-solubility models, reaction mechanism models, mass balance models or coupled reactive transport models. Thermodynamic speciation-solubility models can be used to ascertain ionic and molecular concentrations and activities in solution, as well as degree of saturation of solutions and progress and direction of equilibrium reactions. In addition, this approach allows estimation of partitioning of stable species or components between grain surfaces in equilibrium with solution (= chemically bonded ions and complexes) or ion exchangers (= physically bound ions and complexes). Results of speciation-solubility models can be used to indicate which reactions are thermodynamically favorable. However, because they do not take reaction rate into account, they may derive an equilibrium state for a system, which is for kinetic reasons, impossible to attain. While geochemical models based on thermodynamics alone require interpretation by an expert user familiar with relevant chemical processes, calculated results, for example of molality, can be used as input data for more complex models (Zhu & Anderson 2002). As an illustration of geochemical modelling applications relevant to mine closure investigations, it is possible for example, to determine with speciation-solubility models as the basis for mass balance modelling, which mineral species are susceptible to dissolution or precipitation, or ascertain whether contaminants present in surface or ground waters are bioavailable or in toxic form.

Reaction mechanism modelling can be used to define an evolving sequence of successive equilibrium states for a given geochemical system, representing either continuous or episodic mass transfer between various phases, or continuous addition or removal of a given reactive component from the system. Such models are therefore ideally suited to investigating dissolution and precipitation of mineral phases, the characterization of water chemistry resulting from mixing from different sources, or for determining effect of retention of substances and ion exchange reactions. Each of these modelling strategies can also treat geochemical systems as either closed or open system. In the former case, it is assumed that the products formed during reactions will be involved in subsequent processes, whereas for open systems, reaction products are removed from the system and no longer participate in subsequent reactive processes. Reaction mechanism modelling may be used in mine environment studies, in particular in relation to planning and discriminating between alternative site remediation options. For example, model simulations may indicate how the availability of oxygen might influence oxidation of sulphide minerals. Thus, using a range of alternative scenarios, it may be possible to evaluate the effectiveness of tailings covers on inhibiting oxidation and acid production, or to determine appropriate neutralization methods for mitigating the effects of acidic mine waters in open pits, or acidic discharge into the surrounding watershed (Zhu & Anderson 2002).

Inverse mass balance models are typically used for establishing which geochemical reactions are likely to be responsible for specific changes observed in surface- or groundwater geochemistry. Even though mass balance modelling is not strictly based on either thermodynamics or reaction kinetics, it should be verified that all simulated reactions are thermodynamically and kinetically feasible, for example by using speciation modelling (see above). Inverse mass balance models can be used in mine environment investigations for determining amongst other things, rates of dissolution of critical mineral species and processes related to contamination of surface- and groundwater.

Coupled reactive transport modelling is used for tracking and evaluating the dispersion of contaminant in solution, or changes in species concentration in the surrounding environment, or for studying migration of vapor phases through the system and consequent effects on for example, weathering processes. Reactive transport models can simulate both physical phenomena (such as advection, diffusion and dispersion) and geochemical processes (including degradation or (radioactive) decay of components, ion exchange, adsorption, redox reactions and mineral dissolution and precipitation). One of the fundamental issues in relation to the quality of the mining environment (particularly with respect to sulphide mines) is the potential for oxidation of sulphide minerals in tailings and waste rock facilities, and the consequent risk of acid mine drainage. Reactive transport models can be used to predict the composition of waters discharged from tailings and waste rock facilities, by simulating oxygen diffusion through tailings, and the effect of diffusion on sulphide oxidation and weathering (for example Wunderly *et al.* 1996, Lin and Qvarfort 1996). Transport models are also discussed further in relation to groundwater flow modelling, in the preceding section.

Criteria for choosing the appropriate modelling approach depend on the nature of the problem and background data, and the specific objectives and issues to be addressed. In practice this may mean that several diverse geochemical models are used either simultaneously or successively for testing different aspects of the problem. Within the context of mine closure investigations, in particular characterization of tailings and waste rock facilities, coupled reactive transport models are the most widely used, albeit in conjunction with other modelling techniques, in order to better constrain background parameters and input data. During the TEKES-funded project ”Environmental Techniques for the Extractive Industries”, geochemical modelling was used, for example, to evaluate water quality following filling of a former open pit (Kumpulainen 2005a, 2005b) and the long-term behaviour of waste rock facilities (Kumpulainen 2004, 2005c). These simulations involved the use of speciation- and reaction mechanism models and results have been published in several project reports (Kumpulainen 2004, 2005a, 2005b, 2005c).

As with hydrogeological modelling, some geochemical modelling codes are freely available in the public domain, while others require purchasing a formal commercial license. On the other hand, a collaborative research group or consortium often undertakes development of coupled codes for a specific purpose, and therefore these codes might not be readily accessible to other users. Modelling software usually comprises both the processing code, as well as underlying databases for relevant parameters, including thermodynamic and kinetic variables and constants, and data on surface species. The most widely used geochemical modelling packages are MINTEQA2 (Allison *et al.* 1991) and PHREEQC (Parkhurst &Appelo 1999), both of which are suited to speciation modelling, capable of simulating redox-, ion exchange- and surface complexation reactions. PHREEQC is also capable of performing reaction mechanism models and inverse mass balance modelling, as well as one-dimensional reactive transport models. Additional software in common use for speciation, mass balance or reaction mechanism modelling include EQ3/6 (Wolery 1992), WATEQ4F (Ball and Nordstrom 1991), NETPATH (Plummer *et al.* 1994), SUPCTR92 (Johnson *et al.* 1992) and EQBRM (Anderson and Crerar 1993), with examples of coupled transport codes being MINTOX (Wunderly *et al.* 1996), PHREEQM (Glynn *et al.* 1991) and REACTRAN (Ortoleva *et al.* 1987). Summaries of geochemical software programs routinely used in mine environment studies, including an assessment of their relative strengths and weaknesses, has been given for example by Alpers & Nordstrom (1999) and Salmon (1999).

Input parameters and background values for geochemical modelling vary according to the objectives and approach used. For the simplest types of speciation models, individual analyses of water chemistry and thermodynamic and kinetic data may be sufficient; the latter can usually be obtained directly from databases accompanying the software, although they may need to be supplemented by data published elsewhere or even by laboratory experiments. For studies related to mine closure, the analytical data for water chemistry should be as comprehensive and accurate as possible, including parameters such as pH, temperature, redox potential, alkalinity, electrical conductivity, as well as concentration of dissolved oxygen, dissolved anion and cation abundances, and additional data concerning redox pairs, for example proportions of ferric and ferrous iron. Depending on the purpose, modelling may also require, in addition to water chemistry and relevant thermodynamic and kinetic datasets, mineralogical composition and bulk chemistry data for the minerals in the system, and information on mineral species dissolution rates and specific surface area values. Coupled reactive transport modelling requires the most comprehensive range of input data, including variables affecting hydrogeological behaviour, in addition to the compositional parameters outlined above. Irrespective of which approach is adopted for modelling, the modeler always needs a clear understanding of the nature of the hydrogeochemical system under consideration, in addition to adequate input data and constraints.

The outcome of geochemical modelling is contingent upon several factors, the most critical being the quality and quantity of input variables and the reliability of thermodynamic and kinetic databases. Input data may be deficient with respect to analytical precision, or the number of analyses available may be statistically invalid. The quality of surface water may for example, show significant variations due to seasonal fluctuations in precipitation; samples collected during rainy periods commonly tend to be more dilute than those collected during drier months. Moreover, measurements of water composition are particularly subject to analytical uncertainty. Where such uncertainty exists over data quality, the modelling process will inevitably become more reliant upon various assumptions, which must be taken into consideration when assessing the validity of model results.

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APPENDIX 11. INVESTIGATION OF CONTAMINATED SOIL AND MONITORING REMEDIATION PROGRESS

When mining ceases, it is necessary to assess whether mining activities have had any detrimental effect on soils, surface waters or groundwaters. If contamination has occurred, then remediation measures must be planned and implemented, using the following process as a guideline (see also Alanko and Järvinen 2001, SGY 2002, Öljyalan palvelukeskus 2002):

1) Preliminary investigations

- Evaluation of general conditions and background information
  - State of environment prior to commencement of mining
  - Documentation of all activities during mining operations
  - Documentation of any accidents or environmental incidents during mining
  - Documentation of any previous investigations into contamination and ensuing remediation procedures
  - Preliminary evaluation of contaminants present at the site and their likely properties and behaviour
- Evaluation of available planning data and maps
  - Precise location of activities that may potentially have impact on soils or surficial and ground waters
- Collation of existing geological, geochemical and hydrogeological data
  - Geochemical baselines and properties of surficial materials
  - Groundwater flow paths and surface water drainage systems
  - Results of environmental monitoring studies

2) Site investigation plan for contaminated areas

- Preliminary plan of sampling network, with suggested density of observation points and locations on maps
- Sampling technique(s)
- Recommended depth of sampling sites and proposed sampling depths
- Number and volume of samples required
- Sample selection criteria, numbers and analytical requirements, for both in-situ and laboratory investigations
- Sample preparation techniques
- Timetables and schedules
- Occupational health and safety issues
- Relevant regional environmental authorities to be informed of the sampling and investigations, including submission of a detailed plan of research activities for assessment and comment

3) Sampling procedures

- Sampling is to be carried out in accordance with research plan submitted to the environmental authorities
- Details of sampling are to be carefully documented in a standard approved manner
- A report is prepared based on sampling and results of analyses, and a copy should be sent to the relevant environmental authorities. The report should include an evaluation of the status of contamination

4) Site-specific risk assessment (the scheme illustrates the different phases that are recommended to carry out while site is recognized contaminated)

- If the site investigation has revealed that soil is contaminated, a basic risk assessment should be carried out
- Basic risk assessment includes assessment of ecological and health risks related to land use and environmental conditions in the area. Basic risk assessment should also establish whether soil contamination significantly impairs the quality or amenity of the site or causes comparable violation of public or private good
- Assessment of risks is based on detailed site description: distribution of contaminants at the site (source), dispersion of contaminants (pathway), exposure routes, identifying the exposed elements
- Site description includes assessment of all potentially hazardous materials in the studied area, including concentrations in relation to legally prescribed threshold and guideline values, dispersal pathways i.e. migration (as a reflection of local environmental conditions), implications for current and future land use activities and potential susceptibility to short-term and longer term ecological or health risks
- During the first stages of assessment, the acceptability of detected risks is mainly based on the enacted threshold and guideline values
- More comprehensive risk assessment specifies the general status of the site and identified risks, focusing on assessment of those risk factors which could not be acceptably defined through basic risk assessment
- More comprehensive risk assessment includes description of both identified risks and uncertainty analysis
- Regional environmental authorities make the final decisions concerning the need for site remediation or further investigations based on risk assessment oriented report of investigations

5) General plan for remediation of contaminated soil sites

- Drafted on the basis of results of investigations and site-specific risk assessment
- Assessment of remediation requirements and definition of objectives and determination of optimum remedial methods (best practice procedures using best available technologies (BAT))
- Plan for remediation of contaminated soil site to be submitted to regional environmental authorities

6) Remediation of contaminated soil

- Before site remediation can commence, it is obligatory to either inform the relevant environmental authorities or in some cases obtain a formal environmental permit
- Thorough written documentation of the site remediation program is required, describing each stage of implementation
- When the remediation project is complete, a final report is prepared, with an assessment of the effectiveness of the program against objectives and performance indicators, as well as recommendations relating to possible restrictions on future land use and ongoing site monitoring responsibilities
- The final report is to be submitted to the appropriate regional environmental authorities

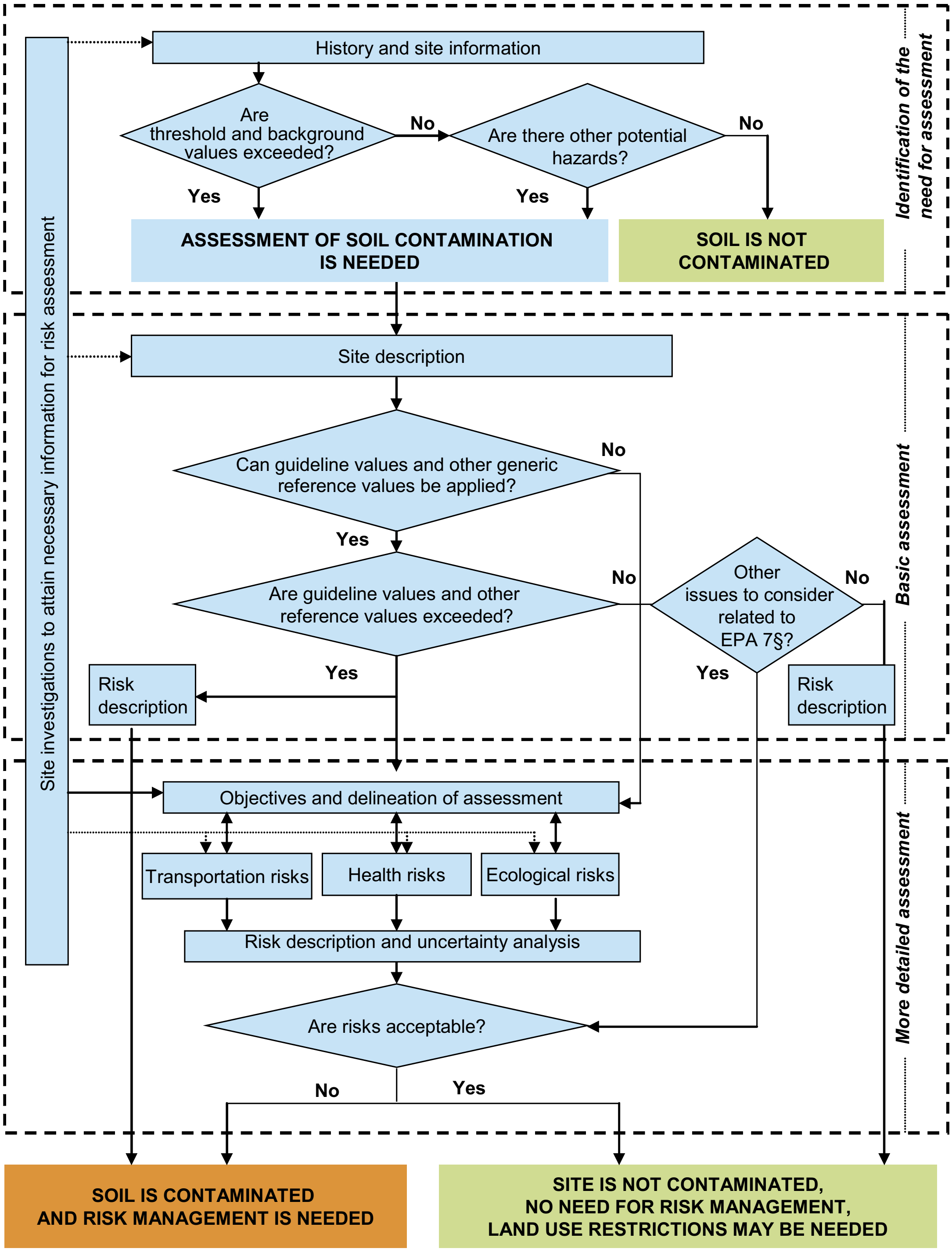

Figure 1. The assessment of soil contamination and the need for remediation (Ympäristöministeriö 2007)

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Detailed descriptions of selected currently available techniques for treating mine waters are given below:

Neutralization of waste waters

Chemical treatment of waste waters at the mine site usually involves addition of alkaline compounds to neutralize the typically acidic compositions of mine-influenced waters (Ledin & Pedersen 1996). The most commonly used compounds are carbonate in the form of calcite ($CaCO_3$), lime (CaO) (Ledin & Pedersen 1996), sodium hydroxide (NaOH), sodium bicarbonate (Na_2CO_3) (Lenter *et al.* 2002) and magnesium oxide (MgO) (Gazea *et al.* 1996). As a result of addition of these alkaline materials, water pH increases and dissolved metals precipitate as hydroxides or carbonates. Under near-neutral pH conditions, the precipitates remain relatively stable and insoluble (MEND 1994).

Neutralization treatment is suitable for all types of acidic mine-influenced waters, irrespective of their total metal concentrations or acidity (MEND 1994). Nevertheless removal of metalliferous sludge precipitated during this treatment process (Ziemkiewicz *et al.* 2003) and appropriate disposal may be problematic, due to the elevated concentrations of potentially toxic metals (MEND 1994). Moreover, operating and monitoring costs of these treatment methods can be very expensive (MEND 1994, Gazea *et al.* 1996).

Anoxic limestone drainage systems (ALD)

Anoxic limestone drains (ALD, contrasting with open limestone drains = OLD) represent a passive remediation technique whereby the acidity of mine waters is reduced by directing the non-aerated effluent stream through calcium-bearing material (PIRAMID Consortium 2003). The limestone drainage system consists of a buried trenches containing single-size crushed limestone, saturated with water such that mine waters directed through the drainage system are excluded from oxygen (MEND 1996). When in contact with acid mine drainage, carbonate in the drain dissolves and hence increases the water pH, promotes bicarbonate-alkalinity and enhances the buffering capacity of the water (PIRAMID Consortium 2003). Conversely, an increase in pH promotes precipitation of metallic compounds (MEND 1994). Where they operate to maximum efficiency, anoxic limestone drains can produce water of good quality (Gazea *et al.* 1995). Moreover, ALD systems can be expected to be effective for considerable lengths of time (MEND 1996). Nevertheless, drainage systems are susceptible to loss of efficiency due to lowering of permeability, caused by formation of iron- and aluminum hydroxides ($Fe(OH)_3$ and $Al(OH)_3$). Ferric hydroxide armor the limestone whereas aluminum hydroxides plug the drain flow paths (Gazea *et al.* 1996, Ziemkiewicz *et al.* 2003). The method is best suited to slightly acidic mine waters (Ziemkiewicz *et al.* 2003), with dissolved oxygen concentrations less than 1 mg/L (MEND 1996), ferric iron and aluminum concentrations less than 2 mg/L (PIRAMID Consortium 2003, Gazea *et al.* 1996) and sulphate concentrations below 2000 mg/L (Hedin *et al.* 1994, MEND 1996).

Reducing and alkalinity producing systems (RAPS) function in effectively the same way as anoxic limestone drains (ALD), but with the additional feature that waters are firstly channeled through a compost bed. A distinct advantage of this approach over the conventional anoxic limestone drain method is that water chemistry is modified such that metal hydroxides are unable to form and flocculate on carbonate particles, which thus allows the limestone drain to remain operational for longer period of time. The RAPS method can therefore be used where acidic mine waters contain elevated concentrations of ferric iron, aluminum and dissolved oxygen (PIRAMID Consortium 2003).

Constructed wetlands

Wetlands represent an ecological treatment method whereby varieties of chemical, physical and biological processes interact resulting in significant changes in the water chemistry (MEND 1996). Wetlands can be divided into two broad categories, namely aerobic and anaerobic. Aerobic wetlands are designed to maximize the opportunities for promoting oxidation reactions (MEND 1996), as a result of which metals precipitate from solution primarily as hydroxides, oxyhydroxides and oxides, accumulating in wetland sediment (Gazea *et al.* 1996, Ziemkiewicz *et al.* 2003). In contrast, anaerobic wetlands rely on the lack of oxygen and maintaining reducing conditions, so that neutralization of acidic effluent is achieved by generating alkalinity through a combined action of bacterial sulphate reduction and limestone dissolution (Gazea *et al.* 1996). To enhance this method of treatment, an organic substrate (such as compost, hay, manure, peat, woodchips or sawdust) is added, to promote bacterial activity and to ensure reducing conditions (Gazea *et al.* 1996, Pinto *et al.* 2001). Aerobic wetland treatment is mainly applicable to the remediation of net alkaline mine waters, particularly those with elevated iron concentrations (PIRAMID Consortium 2003), while anaerobic wetlands are more appropriate for treatment of net acidic mine waters (Gusek *et al.* 1994, Ziemkiewicz *et al.* 2003).

Bioreactors

Mine waters containing sulphate and metallic ions can be effectively treated with conventional bioreactors designed for methanogenic treatment of wastewaters (Hulshoff Pol *et al.* 1998). The effectiveness of bioreactors relies largely on the activity of sulphate-reducing bacteria (Gusek *et al.* 1994, Silva *et al.* 2002, Jong & Parry 2003), which can be further facilitated by the addition of appropriate electron donor, carbon source and nutrients (Hulshoff Pol *et al.* 1998, Zaluski *et al.* 2003). As a result, sulphate is reduced and metals precipitate as sulphides (Christensen *et al.* 1996, de Lima *et al.* 1996, Kaksonen *et al.* 2003). Bioreactors offer advantages in terms of their modest space requirements, and their ease of construction and operation (MEND 1996). However, overall expenses may be greater than for other microbiological remediation techniques because they require constant monitoring and maintenance (Gibert *et al.* 2003).

Flooded open pits and mine shafts can also be used as large bioreactors (Riekkola & Mustikkamäki 1997). Bacterial growth and metabolism are stimulated directly in the contaminated water body and the mine itself is used as a sedimentation basin for metal sulphide sludge formed by precipitation. In order to promote bacterial growth, source of organic substrate and nutrients is added into the open pit or mine shaft (Riekkola-Vanhanen 1999, Riekkola-Vanhanen & Mustikkamäki 1997). This approach makes it possible to control the chemistry of waters discharging from the pits and shafts before their release into surrounding environment. However, the shaft or pit must be deep enough, such that temperature differences between surface and deeper levels do not permit convective overturn and mixing, thereby ensuring that conditions at the bottom of the mine remain anoxic (Mustikkamäki 2000).

Permeable reactive barriers and leach beds

Permeable reactive barriers (PRBs) installed *in situ* in the groundwater flow path can be used to remove contaminants from mine-impacted groundwater. Contaminants are removed by trapping them chemically in a suitable reactive media, or as a result of bacterial sulphate reduction (Waybrant *et al.* 1998). Processes which can be effective in reducing concentrations of contaminants from solution or suspension, or in removing them entirely, include adsorption, precipitation, oxidation, reduction, chemical or microbiological transformations or combination of these processes (Puls *et al.* 1999). Leach beds or filtration beds operate in a similar manner as PRBs, although the beds can also be installed in surface water drainage channels, for instance in the water channels within the mine area (Riekkola-Vanhanen 1999). The most critical aspect affecting functionality of both permeable reactive barriers and filtration beds is the composition of the reactive material (Waybrant *et al.* 1998). In addition to an appropriate substrate and carbon source (Waybrant *et al.* 1998), the PRB or filtration bed requires a source of bacteria for cultivation of an appropriate strain of sulphate reducing bacteria (Christensen *et al.* 1996, Moosa *et al.* 2002, Cocos *et al.* 2002) together with additional chemicals and nutrients (Herbert *et al.* 2000, Cocos *et al.* 2002, Barnes *et al.* 1991, Benner *et al.* 1997, Madigan *et al.* 2000) to further promote bacterial activity and hence efficiency of the treatment process. The reactive material must be sufficiently permeable to ensure that the groundwater flows through the reactive system at the desired flow rate (Benner *et al.* 1997).

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APPENDIX 13. EXAMPLES OF TAILINGS COVER APPLICATIONS IN REMEDIATION OF MINE SITES IN THE NORDIC COUNTRIES

Dry tailings covers have been used in mine site remediation at several locations in Finland, as in other Nordic countries, including the Enonkoski and Keretti mines in Finland and the Viscaria mine in Sweden. Several detailed descriptions of procedures for dry tailings covers and their implementation are presented below:

- The Enonkoski nickel mine, which ceased operations in 1985, is located in the Enonkoski municipality, north of Savonlinna. The tailings at Enonkoski are covered with a layer of till about 50 cm thick. The area was sown with a so-called TVL seed-mix and fertilizer has also been added to the area. Seepage waters are directed into two separate wetland areas for treatment.

- The Keretti Cu-Co-Zn-Ni mine was the most significant ore deposit in the Outokumpu district, until production ceased in 1989. Tailings deposits have been covered with about 20 cm of gravel, overlain by some 10 cm of peat mixed with sand at a ratio of 20:1. Vegetation cover was initially established by sowing a so-called TVL seed mixture, with addition of fertilizer. Seepage waters are channeled through two wetlands for treatment.

- The Viscaria sulphide deposit in northern Sweden primarily produced copper. The tailings area was covered with a 3-5 cm layer of fine sludge obtained from the waste water treatment plant. The area was vegetated using a so-called TVL seed-mix, supplemented by fertilizer. Owing to the relatively high neutralization capacity of the tailings (due to low sulphide content and high calcite abundance), there has been no significant acid production at the site. The incentive for covering the tailings was thus more aesthetic, in terms of landscaping and re-establishing vegetation cover, such that the endemic dwarf birch would progressively recolonize the area. In order to arrest potential erosion caused by extreme rainfall events and flooding, a system of drainage furrows and channels has subsequently been constructed using a combination of till and geotextile lining material (Naturvårdsverket 2002).

- The Kristineberg mine in Sweden has been in continuous operation since 1940. There are five separate tailings impoundments at the site, containing tailings material derived from a total of ten different processing and beneficiation techniques (Naturvårdsverket 2002). The first attempts at rehabilitation of the oldest tailings area (dating from the early 1950's) involved planting grass directly on the tailings. During 1996, impoundments 1 and 2, and parts of impoundments 3 and 4, were treated by a combination of covering the tailings with till, raising the water table and planting vegetation, or submerging tailings beneath water. In areas where the water table is near the ground surface, a protective layer consisting of till, about a meter in thickness, was added. Where depth to the water table was greater, the corresponding layer thickness was 1.5 meters, which was spread over an initial layer of finer-grained clayey till 0.3 meters thick. Prior to this, the tailings were also treated with lime. Of those areas that were submerged by construction of raised dams, the aim was to maintain a water depth of about one meter.

  Site monitoring has revealed that pervasive oxidation penetrates to a depth of about 50 cm beneath the surface of the tailings. Arsenic and copper show some enrichment immediately beneath the based of the oxidized layer. As a result of raising the water table, leaching of metals enriched beneath the oxidized layer has subsequently occurred, thus increasing the concentration of metal species in pore waters.

- Galgbergsmagasinet, Sweden. The tailings area was covered with a composite material one meter in thickness, comprising a mixture of fiber pulp and fly-ash, which was then compacted as two separate layers and covered by a 0.5 meter thick layer of wood processing residue and coarse-grained till. Laboratory testing of the material revealed a permeability of $<0.5 \times 10^{-9}$ m/s.

Wet covers have also been used at some mine sites, such as at Stekenjokk in Sweden:

- At the Stekenjokk Zn-Cu mine, tailings impoundments and settling ponds were dammed in 1991, so as to submerge them beneath water at least 2.2 meters deep. Use was also made of pre-existing embankments when constructing the dams. Some waste rock was also removed in the process, so that the surface of the tailings impoundment was somewhat lowered and leveled. A breakwater barrier was also built to inhibit wave action in the water overlying the tailings. Covering with water was decided upon because suitable till resources were not readily available. Monitoring of the structure and other parameters has shown that the discharge of metals into the surrounding environment has decreased significantly, although this effect was noticeable only after several years had elapsed. The accumulation of layers of organic and manganese- and iron oxyhydroxides was also found to improve the performance of the water cover over the longer term. Because the area is subject to the formation of thick ice cover, up to 2 meters in some winters, it has proven necessary to modify the outflow spillway due to increases in water levels caused by ice-damming. In response to recommendations made during subsequent safety auditing, an additional outflow drain was constructed, which ensures release of water should the main spillway become blocked. A contingency plan has also been prepared in case the water level drops significantly.

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APPENDIX 14. EXAMPLE PROCEDURE FOR MINE SITE RISK IDENTIFICATION AND CLASSIFICATION

The table represents an assessment of the mine site prior to initiation of closure procedures

Location	Risk factor	Probability of risk occurrence	Severity of event	Risk level	Description of consequences	Existing risk abatement and mitigation strategies	Comments
Tailings area	*Discharge into groundwater*				Deterioration of groundwater quality and restrictions on water use, adverse effect on surface water quality, potential deterioration of soil quality. Groundwater already contaminated, unsuitable for domestic use	Groundwater flow through aquifer in (interlobate) esker passing through tailings area is arrested by impervious clay barriers. Effectiveness evident in lowered sulphate abundances. Lining of drainage channels.	Most sulphate in pore waters is derived from sulfuric acid used in processing, while chloride is mainly derived from ore. Nitrogen originates from explosives
	• Infiltration of contaminated water into soil and groundwater						
	◦ Tailings material						
	- Oxidation of sulphides	3	3	Moderate			
	- **Processing chemicals residue**	**5**	**4**	**Severe**			
	◦ Water in tailings drainage systems	3	4	Moderate			
	• Infiltration of contaminated groundwater into pristine aquifers	4	3	Moderate			
	Discharge into surface waters				Deterioration of surface water quality and restrictions on domestic use; potential effect on aquatic biota and other animals (livestock + drinking water), possible effect on soil quality	Recycling of processing waste waters and capture of tailings drainage waters for treatment. Precipitation of metals as hydroxides in tailings drainage system, return water to concentrating plant. Ensure that controlled release of mine waters is diluted with natural water at a ratio of 1:500; regulation of waste water pH if necessary	Adverse impacts on surrounding waters are only likely if exceptional circumstances (intense rainfall, rapid snowmelt) require unscheduled release of waste waters
	• Tailings drainage channels						
	◦ Tailings deposits						
	- Oxidation	3	2	Minimal			
	- Chemical residues	4	2	Moderate			
	◦ **Pumping of contaminated groundwater**	**5**	**4**	**Significant**			
	◦ Controlled discharge of waste waters	4	2	Moderate			
	• Waters channeled from subsidiary tailings drains into main collecting drain	5	2	Moderate			
	• Outflow from tailings drainage channel into surrounding water catchment	5	1	Moderate			
	Emissions to atmosphere				Adverse effect on human and ecosystem health, possibly also on land use (airborne dust and fallout)	Treatment with lime, partial covering with water, sludge removal by pumping as slurry, immediate planting of vegetation whenever tailings embankment is raised	
	• Airborne dust and particulate matter	4	2	Moderate			
	• Gaseous emissions	1	1	Negligible			
	Changes in hydrological balance	3	1	Minimal	Effect of tailings impoundment waters on ambient water table, compared to situation prior to mining		
	Stability issues				Dispersal of tailings materials into surrounding environment, potential for human casualties, (transient) water turbidity, adverse effects on quality of soil, surface waters and groundwaters, and ambient ecosystems. Damage to vegetation and consequent enhanced erosion of tailings covers	Vegetation of embankments. Periodic stability inspections in accordance with legislative requirements of the Dam Safety Act. Factor of Safety >1.5 for all earthen dam and embankment structures.	
	• **Failure or collapse of dams and embankments**	**3**	**5**	**Significant**			
	• Erosion of dams and embankments	4	2	Moderate			

	Other safety risks • Unauthorized access to tailings area	4	3	Moderate	Becoming trapped in mud, sinking or drowning	Locked gates and barriers preventing access by road, and warning signs	
	Noise	1	1	Negligible	Traffic very sporadic		
	Impact on landscape	4	1	Minimal	Modification to original landscape	Vegetation planting programs on embankments, and natural regeneration	
	Waste generation and treatment	1	1	Negligible			
Waste rock storage facilities	*Discharge into groundwaters* • Oxidation • Explosives residues	 3 3	 2 1	 Minimal Minimal	Deterioration of groundwater quality and restrictions on use, possible adverse effect on soil quality.	Siting of waste rock storage facilities on low-permeability substrate, remote from exploited groundwater aquifers	
	Discharge into surface waters • Discharge into drainage channels • Discharge from mine drainage systems and waste facilities into surrounding agricultural drainage network • Further discharge via agricultural drainage network into rivers and streams	 4 3 3	 2 2 1	 Moderate Minimal Minimal	Deterioration of surface water quality and restrictions on use. Impact on biota. Metal transport by water and infiltration into soil.	Buffer zones between waste heaps and open drainage systems (locally); waters directed through settling and clarification ponds	
	Changes in hydrological balance	1	1	Negligible	Unlikely for highly permeable materials		
	Atmospheric emissions • Dust • Gaseous emissions (from sulphide oxidation)	 2 3	 2 1	 Minimal Minimal	Extremely small amounts of dust (generated during crushing) coating rock surfaces in waste rock piles	Establishment and regeneration of native vegetation	
	Stability issues	3	2	Minimal	Rockfalls	Terracing of piles to stabilize slopes, in accordance with geotechnical assessments of maximum angle of repose and load-bearing capacity of substrate	
	Other safety issues • **Unauthorized vehicular or pedestrian entry**	**5**	**3**	**Significant**	Injury from falling, burial by rockfall or scree, illegal dumping of unauthorized waste	Restriction of vehicular access by placement of rock barriers and dismantling drainpipes at culvert crossings	
	Noise	1	1	Negligible			
	Impact on landscape	4	2	Moderate	Modification of original landscape		
	Wastes and treatment • Miscellaneous waste mixed with waste rocks	3	2	Minimal	Waste rock storage facilities also contain waste derived from previous site infrastructure	Waste no longer accumulated at waste rock facility and has been covered with rock and topsoil	
Mine (Underground and open pit operations)	*Discharge into groundwaters (explosives residues, sulphide oxidation, mining activity)*	3	2	Minimal	Water in open pit ultimately drains into underground mine workings. Deterioration of bedrock groundwater quality due to infiltration of waters affected by mining activities (explosives residue and chemicals, vehicular emissions) and sulphide weathering	Accumulation of water in open pit dominantly from meteoric precipitation, which infiltrate into underground workings, where pumping returns water to surface. Pumping operations induce groundwater downdraw and flow towards mine	

	Discharge to surface waters from mine pumping				Deterioration of surface water quality, restrictions on use; effects on biota. Dispersal of metals via water infiltration into surrounding surficial materials, with possible restrictions on subsequent extraction or land use activities	Water channeled through settling and clarification ponds before discharge into surrounding water catchment.Oil containment booms at settling pond outflow sites.	
	• Discharge into waste facility drainage systems	4	2	Moderate			
	• Discharge into surrounding agricultural drainage systems	3	2	Minimal			
	• Discharge into rivers and streams	2	1	Negligible			
	Changes in hydrological balance	**5**	**3**	**Significant**	Drying of wells	Connection to municipal reticulated water supply	
	Atmospheric emissions				Particulate emissions from mining machinery, explosives and loading operations. Metal content and susceptibility to acidification means that dust can adversely affect quality of water pumped out of mine. Exhaust emissions from mining machinery and vehicles, residual gases from blasting operations, impact on health of miners	Periodic monitoring for presence of carbon monoxide and abundance of airborne particulate emissions. Vehicles exceeding emissions limits to be excluded from mine area	Dust release via ventilation system exhaust outlets throughout the mine area. Dust settles extensively throughout the open pit area (over 40 ha); pit walls and floor contain sulphide minerals.
	• Airborne particles	4	2	Moderate			
	• Gaseous emissions	4	2	Moderate			
	Stability issues				Collapse of pit walls. Underground failure and collapse, which also affects stability and subsidence in open pit and surroundings	Prevention of unauthorized entry to open pit and surrounding safety buffer zone. Backfilling of open pit with waste rock. Strengthening of underground tunnels and galleries with rockbolting, meshing and shotcrete	
	• Open pit	4	2	Moderate			
	• Underground workings	4	2	Moderate			
	Other safety issues				Risk of falling and injury. Risk of becoming lost, dangers from mining equipment or explosives	Access to mine area primarily through security staff at mine entrance. Underground access only in company of authorized personnel; vehicular traffic restricted to defined, remotely monitored routes, while blasting, loading and transport of ore is suspended	
	• Access to open pit area by unauthorized persons	3	3	Moderate			
	• Access to underground mine areas by unauthorized persons	1	4	Minimal			
	Noise and vibration	4	2	Moderate	Noise from mine vehicles, blasting operations, and from air ventilation system. Vibration from blasting operations.	Ventilation systems and vehicles equipped with sound dampers. Strict scheduling of blasting activities. Pit walls and waste heaps and embankments act as barriers for noise abatement. Bedrock and overburden tend to dampen noises and vibrations generated during underground mining	Significant issue for mine workers, effects outside mine less significant
	Effect on landscape	2	1	Negligible	Local modification of original landscape	Revegetation around edges of open pit	
Transport and crushing of ore	*Discharge into surface waters and ground waters*				Metal migration into surface waters and ground waters	Clay-rich surficial sediments inhibit infiltration of contaminated waters. Pre-emptive servicing of machinery. Automated monitoring of oil supply	
	• Contaminated soil	4	2	Moderate			
	• Spillage and leakage of oil lubricants and fuel	3	3	Moderate			

	Atmospheric emissions				Contamination of road verges and exposed ground in proximity to the crushing mill. Surface contamination further away from airborne dust. Oxidation of sulphide-bearing dust and transport via melt waters and runoff into adjoining drainage systems. Contamination of soil, air, surface waters and groundwater	Salting and wetting of ore haulage roads and temporary stockpiles. Enclosing of conveyor belts, roofing over stockpiles and confining main dust generation phase to interior of crushing facility. Centralized ventilation and dust removal and siltation. Watering of ore during crushing process in summer months	
	• Dust generated during road transport	4	1	Minimal			
	• Dust generated at crushing facilities	4	3	Moderate			
	• Generation of dust from drying rock surfaces in temporary storage sites and around crushing plant	4	2	Moderate			
	Other safety risks				Human casualties, generation of harmful smoke. Workers and visitors	Fire safety regulations and emergency procedures protocol. Clear traffic signage	
	• Conveyor belt or vehicle fire	3	3	Moderate			
	• Traffic accidents	3	4	Moderate			
	Noise	4	2	Moderate	Noise from mining activities and traffic; Noise from percussion drilling	Soundproofing and enclosing of dust extraction systems. Confinement of activities to within stockpile areas or areas enclosed by sound barriers, use of percussion drills restricted to hours between 08:00-16:00	
	Impact on landscape	4	1	Minimal	Industrial infrastructure		
Concentrator plant	*Atmospheric emissions*				Dust transported by ventilation of exhaust systems and settles on asphalted areas and other nearby locations. Risk of worker respiratory problems and poisoning	Areas prone to dust generation, such as crushing mill feeder, enclosed, dust collected and extracted with hose filters. Automated pH regulation to ensure controlled release of sulfuric acid in concentration process. Dilution of acid with water prior to feeding for processing. Separate storage and addition of xanthates and acids to processing system. Xanthate solutions prepared in separate location away from acid reagents	
	• Particulate emissions	4	2	Moderate			
	• Gaseous emissions						
	◦ Generation of hydrogen sulphide from excess addition of sulfuric acid	2	4	Moderate			
	◦ Formation of carbon disulfide from reaction between xanthates and acids	2	4	Moderate			
	Other safety risks				Structural corrosion and human casualties. Leaks are transient and small. Toxic gases released during combustion of cables, plastic pipes and tubes, rubber, lubricants, and flotation frothing agents. Water and extinguishing agents used for firefighting cause contamination of soil, surface waters and ground waters	Periodic inspection of feeder pipes. Leaked material is collected in drains and piped to waste pumps and tailings impoundment. Fire safety regulations and conduct code; compartments for fire containment and isolation; regular fire safety inspections; emergency response plan. Smoke and gas detectors in offices and buildings with electrical fittings and equipment	
	• Sulfuric acid leaks from feeder pipes	3	2	Minimal			
	• Leakage of other reagents from pipes or (short-term) overflow from storage tanks	3	1	Minimal			
	• **Fire**	**4**	**5**	**Significant**			
Storage and transport of concentrate	• Oxidation of concentrate stored in stockpiles	4	2	Moderate	Migration of metals into soil, and surface and groundwater.	Concentrate stored primarily under cover. Stockpile storage areas paved with asphalt. Main storage area floored by concrete.	
	• Dispersal of wind-borne concentrate dust from loading site	4	3	Moderate	Dispersal outside asphalted areas causes contamination of soils and runoff into surface drainage systems.	Inclined surfaces of storage area to collect rainwater into milling process.	
	• Loss of control of loaded truck	4	1	Minimal	Contamination of soil, surface waters, and groundwater. Mass of full load = 40 t.	Immediate removal of concentrate and any associated surface soil and transport to mine.	
	• Other road accidents	3	3	Moderate	Risk of human injury < 1000 loads per year	Transported loads to be covered.	
	• Noise and dust generation during loading and transport	3	1	Minimal			

Storage and transport of chemicals	*Discharge to surface waters and groundwater*	2-3	1-5	Negligible to significant	Contamination of soil, surface waters, and groundwater	Specifically designed safety procedures according to attributes of chemicals	
	Other risks • Atmospheric emissions • Safety risks (fires, explosions, theft)	 2-3 3	 1-4 1-4	 Negligible to moderate Minimal to moderate	Effect on human health.Risk depends on specific chemical (classify on individual basis)	Specifically designed safety procedures according to attributes of chemicals	
Waste generated during production	*Hazardous waste* (more detailed list elsewhere)	3	2	Moderate	Leakage of oil and oil residue and contamination of soil, surface water and groundwater	Operations in accordance with requirements of Waste Act and company specific waste plan. Hazardous waste regularly delivered to waste station for appropriate treatment and disposal	
	Wastes for waste depot	1	1	Negligible	Collection skips	Transported to waste depot	
	Wastes for recycling	1	1	Negligible	Collection bins and skips	Separated and sorted for distribution to recycling agencies for further use or processing	
Treatment of waste waters	• Biological sewage and domestic effluent treatment plant • Metal precipitation in drains	4 4	1 1	Minimal Minimal	Increase in chemical oxygen demand and release of nutrients Metalliferous hazardous waste generated (200t dry matter/a) is combined with concentrate, treated water recycled back into concentrator processing system, thus improving the overall rate for waste water recycling	Treatment plant meets performance standards Reduction of metal content by >95%. Water is directed to cover tailings and other waste areas where it inhibits dust generation	

RISK CATEGORIES

Probability of occurrence		*Severity of consequences*	
Extremely likely/probable	5	Extremely severe	5
Highly likely/probable	4	Severe	4
Likely/probable	3	Moderate	3
Unlikely/improbable	2	Minimal	2
Extremely unlikely/improbable	1	Negligible	1

Risk classification based on combination of probability of event occurring and severity of consequences

Probability	*Severity of consequences*				
	Negligible (1)	Minimal (2)	Moderate (3)	Severe (4)	Extremely severe (5)
Extremely likely (5)	3	3	4	4	5
Highly likely (4)	2	3	3	4	4
Likely (3)	2	2	3	3	4
Unlikely (2)	1	2	2	3	3
Extremely unlikely (1)	1	1	2	2	3

Unacceptable risk	5
Significant risk	4
Moderate risk	3
Minimal risk	2
Negligible risk	1

APPENDIX 15. WORKING REPORTS AND OTHER PUBLICATIONS PREPARED DURING THE "ENVIRONMENTAL TECHNIQUES FOR THE EXTRACTIVE INDUSTRIES" PROJECT

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Kauppila, T. 2004. Sedimenttitutkimus Hituran kaivoksen vaikutuksista Pidisjärveen. Geologian tutkimuskeskus, julkaisematon raportti 27.10.2004. 17 s.

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APPENDIX 16. EXAMPLE LIST OF CONTENTS FOR A TYPICAL MINE CLOSURE PLAN

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APPENDIX 17. MINE CLOSURE PLANNING CHECKLIST

A. Issues to consider in relation to planning closure of underground mining operations:

1) Preparation of finalized map of mine workings and selection of representative drill cores for archiving

- A current map is to be prepared, detailing mine workings up to the time of closure, and submitted to Safety Technology Authority of Finland (Tukes = Turvatekniikan keskus)
- A representative range of cores and logging reports, relating to drilling during mining, is to be selected and submitted to the Geological Survey of Finland (GTK = Geologian Tutkimuskeskus), for storage at the national drill core archives

2) Measures taken to ensure that underground mine workings comply with requirements for general safety

- Prevention of unauthorized access to mine workings (sealing entrances to declines and shafts, closure of mine access roads)
- Delineation and fencing off areas susceptible to collapse or subsidence
- Warning and prohibition signs affixed to fencing

3) Backfilling of underground workings subject to collapse or failure and stabilization with retaining barriers

- Backfilling with waste rock or tailings, providing that there is no demonstrable risk to surface and groundwaters
- Retention barriers constructed of quarried material or, if necessary, concrete

4) Removal of machinery and equipment and related infrastructure

- Fixtures such as stairways and ladders installed during mining, particularly those relevant to mine safety, may only be removed at the discretion of the Ministry of Trade and Industry (KTM = Kauppa- ja teollisuusministeriö)
- All other machinery and underground installations are to be removed, including pipes and cables, and electrical equipment
- Any fixed equipment or facilities remaining at the mine site should be drained of fuel and lubricants and any other materials that could potentially contaminate surficial or groundwaters
- Servicing and maintenance workshops and accommodation, recreational and catering facilities, whether of concrete or wooden construction, are to remain
- All waste and other materials that may potentially contaminate groundwater should be removed from the site
- Materials destined for removal from the site should be sorted and stored for possible subsequent reuse or recycling

5) Cessation of dewatering of mine workings and assessment of whether water treatment is needed; implementation of treatment program if required

6) Land use strategies after mining has ceased

- Assessment of collapse or subsidence risk in relation to future land-use planning, for example by classifying the area separately in municipal building codes and excluding the relevant area from residential or industrial development or recreational zoning

B. Issues to consider in relation to closure of open-pit mining operations

1) Preparation of finalized map of mine workings and selection of representative drill cores for archiving

- A current map is to be prepared, detailing mine workings up to the time of closure, and submitted to Safety Technology Authority of Finland
- A representative range of cores and logging reports, relating to drilling during mining, is to be selected and submitted to the Geological Survey of Finland, for storage at the national drill core archives

2) Measures taken to ensure that the area surrounding the open pit meets general safety requirements

- Restriction of access to the open pit area (fencing enclosures, closure of access roads)
- Isolating and fencing off areas at risk of subsidence or collapse
- Landscaping and stabilization of pit edges and other areas prone to failure
- Stabilization of rock walls potentially subject to collapse (mechanical strengthening and support, or slope reduction)
- Affixing warning and prohibition signs to fencing

3) Potential infilling of open pits

- Tailings and waste rock may be used as backfill, providing they do not represent a source of contamination for surficial or groundwaters

4) Removal of machinery, equipment and other fixtures from the open pit

- Fixtures such as stairways and ladders installed during mining, particularly those relevant to mine safety, may only be removed at the discretion of the Ministry of Trade and Industry
- All other machinery and equipment is to be removed from the site, including steel fittings and other materials
- All waste and other materials that may potentially contaminate groundwater should be removed from the open pit
- Materials destined for removal from the site should be sorted and stored for possible subsequent reuse or recycling; any further waste material remaining should be disposed of through appropriate treatment processes

5) Cessation of dewatering of the pit and assessment of whether water treatment is needed; implementation of treatment program if required

6) Landscaping in accordance with closure plan and future land use strategies

- Planting of vegetation for stabilizing slopes and embankments
- Ensuring that the area influenced by mining is registered appropriately for municipal land use planning (e.g in building code)

C. Issues to consider in relation to closure of waste rock disposal sites:

1) **Determination of waste rock characteristics (prior to commencement of mining)**
   - Ascertain chemical and mineralogical composition, acid production potential, likely risk of dissolution of potentially hazardous compounds and long-term behaviour of waste materials
   - Determine physical, geotechnical and hydrological properties of waste rocks
   - Estimation of volume of waste rocks generated during mining

2) **Determination of characteristics of surficial materials in substrate beneath planned waste rock storage areas and facilities (prior to commencement of mining)**
   - Determine internal sedimentary and permeability structure of surface materials
   - Define groundwater and surface water flow
   - Design waste rock areas, preferably in locations where substrate has relatively low hydraulic conductivity

3) **Determine options for utilization of waste rock (before and during mining operations**
   - Maximize use of waste rock during mining and after mine closure to ensure minimization of material requiring ultimate placement as separate waste heaps
   - Potential applications include earthworks and road construction within the mining precinct, or elsewhere and backfilling within mined-out areas
   - Use of waste material is contingent upon results of geotechnical studies and compliance with environmental guidelines (refer to point 1 above)
   - Use of waste materials may require approval from relevant permitting authorities (refer to Section 3.1.1)
   - Stockpiling of material separately during mining for potential utilization, on the basis of differences in geotechnical or environmental properties

4) **Ensure that the waste rock storage facilities remaining after mine closure meet the safety and stability requirements over the long-term, with respect to both physical and chemical behaviour**
   - Mitigation of the risk of subsidence, slope failure and erosion by landscaping, designing structurally stable landforms, drainage systems and through stability investigations (refer to point J below)
   - Prevention of unauthorized access to dangerous areas and enclosure by fencing and clearly displayed warning signs
   - Assessment of need for covering the waste rock areas, with respect to long-term behaviour and risk of contamination by airborne dust, and if needed, determination of appropriate covering strategies

5) **Evaluation of the risk of seepage water discharge from waste rock storage areas and appropriate containment and treatment strategies**
   - Assessment of possible need for water treatment, based on environmental characterization of waste rocks, or (in the case of operating mines) on the quality, volume and discharge rates of seepage waters derived from waste storage facilities
   - Evaluation of the likely effects of other closure-related procedures on quality and quantity of seepage water discharge
   - Design of procedures and systems for water collection and drainage systems for passive and active methods of water treatment
   - Maintenance and monitoring plans for water treatment programs

6) **Integration of waste rock storage facilities with surrounding environment and assessment of post-closure land use**
   - Stabilization and landscaping of waste rock areas
   - Promotion of vegetation programs where necessary, by covering with topsoil and mulch, sowing mixed seed, planting of established seedlings, and furrowing and terracing to arrest erosion
   - Assessment and planning of post-closure land use options; clarification of ownership and custodial responsibilities and obligations
   - Determination of any potential restrictions on post-closure land use

7) **Assessment of the need for ongoing monitoring of final waste storage sites and proposed performance guidelines and monitoring plans**
   - Geotechnical monitoring of physical parameters to determine long-term stability of waste storage facilities
   - Facilitation and monitoring of vegetation programs
   - Monitoring seepage water quality and performance of treatment systems

D. Stockpiles of overburden in relation to mine closure planning:

1) **Options for using stockpiled overburden during mining**
   - Geotechnical characterization of different overburden materials to ascertain suitability for subsequent applications
   - Estimation of likely volume of overburden removed
   - Survey of potential applications: earthworks during mining or mine closure; planning of specific applications during mining start-up phase
   - Sorting and separate stockpiling of materials during mining, based on geotechnical or other material properties
   - Use of overburden materials may require approval under the Waste Act (1072/1993, refer to Section 3.1.1)

2) **Ensure that overburden stockpiles comply with general safety requirements**
   - Landscaping to ensure physical stability and aesthetic objectives of landscape restoration
   - Implement vegetation programs as needed

E. Closure planning in relation to mine tailings impoundments:

1) **Physical and chemical characterization of tailings (before commencement of mining)**
   - Chemical and mineralogical composition, acid production potential, likely risk of dissolution of potentially hazardous compounds and long-term behaviour of tailings materials
   - Assessment of seepage water quality during initial processing and enrichment tests
   - Characterization of geotechnical and hydrological properties

2) **Characterization of material properties of substrate to proposed tailings impoundment (prior to commencement of mining)**
    - Internal sedimentary and permeability structure of surficial materials
    - Surficial and groundwater conditions
    - Design location of tailings impoundment, preferably on substrate with relatively low hydraulic conductivity

3) **Determine options for use of tailings (before and during mining operations)**
    - Attempt to minimize final amount of tailings by maximizing opportunities for use, during both active mining and closure
    - Potential applications include earthworks at the mine site or elsewhere in the vicinity, or backfill within the mine workings. In some cases, tailings materials may be suitable for soil improvement or for agricultural purposes (e.g as fertilizer)
    - Use of tailings is subject to determination of relevant geotechnical and environmental properties (refer to point 1 above)
    - Appropriate statutory permits may be required before tailings can be utilized (refer to Section 3.1.1)

4) **Ensure that remaining tailings impoundments comply with general safety requirements and are demonstrably chemically and physically stable with respect to long-term environmental risk**
    - Ensure stability of tailings impoundment dams and embankments; stability investigations, landscaping, drainage systems, vegetation programs (refer to point J)
    - Draining of settling ponds and dismantling of an unnecessary earthworks, including assessment of potential use of material elsewhere; determine final storage options for sludge accumulated on the bottom of the settling ponds
    - Prevention of unauthorized access to potentially dangerous areas and enclosure by fencing with clearly marked warning and prohibition signs
    - Assessment of need for tailings covers, with respect to long-term behaviour and risk of contamination by airborne dust, and if needed, determination of appropriate covering strategies
    - Determine appropriate timing for implementing covering program: usually can be commenced during mining
    - Determine whether tailings discharge into the surrounding groundwater, map discharge sites and contain release of seepage waters; evaluate possible need for groundwater treatment and choose appropriate remedial methods

5) **Determine need for treatment of waters discharging from final tailings impoundment after mine closure, including appropriate operational plan**
    - Evaluate need for water treatment program, based on environmental characterization of tailings, or (in the case of operating mines) on the quality, volume and discharge rates of seepage waters derived from tailings impoundments
    - Estimation of potential effects on amount and quality of seepage water discharge resulting from any other closure-related procedures
    - Design appropriate procedures for water collection and containment, drainage systems and passive or active forms of water treatment
    - Prepare maintenance strategy and monitoring plan for selected treatment program

6) **Ensure integration of tailings impoundments with surrounding environment and assessment of post-closure land use**
    - Stabilization and landscaping of tailings impoundments and embankments
    - Promotion of vegetation programs where necessary, by covering with topsoil and mulch, sowing mixed seed, planting of established seedlings
    - Ensure that the tailings area is assigned separate status in municipal land use zonation and building codes
    - Assessment and planning of post-closure land use options; clarification of ownership and custodial responsibilities and obligations
    - Determination of any potential restrictions on post-closure land use

7) **Assessment of the need for ongoing monitoring of tailings areas and defining monitoring procedures**
    - Geotechnical monitoring
    - Monitoring amount and quality of seepage water production and discharge
    - Monitoring performance of water treatment systems and other related closure procedures

F. Issues to consider with respect to buildings and infrastructure during decommissioning and closure:

1) **Ensure that area is restored to a state complying with general safety requirements**
    - Dismantling of unsafe or unnecessary buildings and structures
    - Removal of tanks, drums and other containers for storage of chemicals
    - General cleaning and landscaping of mine site
    - Environmental audit of potential risk or contamination relating to remaining infrastructure and propose risk abatement or remedial measures

2) **Evaluation of possible options for ongoing use of remaining mine infrastructure**
    - Infrastructure specifically constructed for the purposes of maintenance of mine safety, and structures designed solely for mining activities, such as concrete headframes at the concession, can only be dismantle or removed if permission has been granted by the Ministry of Trade and Industry (KTM = Kauppa ja Teollisuusministeriö)

3) **Inventory of infrastructure and assessment of potential options for reuse**
    - Evaluation of potential need for using roads and buildings and other infrastructure and potential opportunities, for example for industry or other commercial activities
    - Evaluation of potential cultural significance of mining infrastructure, designation of sites for protection and conservation
    - Clarification of ownership issues and liabilities in relation to infrastructure remaining at the mine site

4) **Dismantling buildings and infrastructure**
    - Assessment of potential reuse options for dismantled structures (recycling, energy value)
    - Sorting of materials
    - Safety precautions if hazardous materials are present (asbestos)
    - Disposal of materials in appropriate manner

G. Decommissioning and removal of plant and machinery in relation to mine closure:

1) Removal of mining plant, machinery and equipment from the mine site

- Plant or equipment whose purpose is specifically related to maintenance of mine safety can only be removed after approval has been granted by the Ministry of Trade and Industry. All other machinery and equipment is to be removed from the site
- Assessment of potential for deploying or reusing equipment and plant elsewhere, including resale value, recycling of components or possible use in energy production
- Evaluate options for selling concentrating plant
- Appropriate disposal of equipment that is unsuitable for reuse or recycling
- Environmental risk assessment in relation to mining plant and equipment

H. Issues to consider in relation to mine site vegetation programs:

1) Future land use activities and aesthetic considerations

2) Requirements for effective and sustainable vegetation cover:

- Assessment of nutrient state/requirement for fertilizer
- Determine humus content, pH and potential contaminants that might inhibit growth
- Determine moisture content
- Determine whether substrate has sufficient depth for establishment of large plants and establish whether addition of topsoil or mulch is needed
- Determine susceptibility to erosion and need for terracing or furrowing

3) Characterize endemic plant taxa and assess their suitability for planting and revegetation programs

4) Identify other plant taxa for planting, and assess their suitability

- Determine climate tolerance, growth rate
- Optimum substrate requirements
- Effectiveness as ground cover and stabilization capacity of root systems; assessment of potential damage of the root penetration on the performance of cover structures

5) Requirements for maintaining and promoting growth, plan for on-going monitoring of revegetation program

I. Checklist of monitoring procedures for surficial and ground waters

- Perform thorough study of surficial and groundwater conditions at the site (refer to Section 4.1.1)
- Document all drainage methods and systems in relation to mine closure, including tailings and waste rock storage facilities; conduct research on water chemistry and associated processes
- Identify locations of domestic wells in proximity to the mine
- Determine appropriate density and locations for sampling network required for post-closure monitoring of surficial and groundwater quality
- Document all known observation stations relating to groundwater, including observation well characteristics (location, general condition, depth, diameter and composition of tube materials and lining), which should normally be found in reports relating to installation of the tubes. Assess suitability of observation wells for post-closure groundwater monitoring
- Evaluate the need for installing a more extensive array of observation wells at the site and determine the most appropriate tube materials and size. Define locations, depths and appropriate well screen length, so as to ensure representative sampling of the groundwater column, taking into account natural variations in depth to the water table
- Based on previously available water chemistry data, define the most significant variables for measuring during post-closure monitoring, as well as analytical requirements
- Prepare a practical implementation plan for water quality monitoring, including assignment of responsibility for sampling, equipment required for sampling, specification of sampling procedures appropriate for local site conditions, analytical techniques and reporting procedures. In addition, frequency of routine sampling, as well as random inspections, should be defined.
- Assessment of need for independent verification of accuracy of water quality measurements
- Define procedure for reporting results of monitoring program
- Estimate likely annual budget for monitoring program
- Provide complete monitoring program plan to relevant authorities

J. Checklist for monitoring stability of embankments and waste rock and tailings facilities

Checklist relating to stability investigations:

1) Compile and collate available background data

- Compile information relating to previous geotechnical ground surveying
- Compile information relating to dimensions and geometry of earthen structures
- Compile data on pore water levels in mine structures, general depth to phreatic surface and water table fluctuations
- Compile database of strength parameters of relevant materials
- Assess whether above data are current and adequate
- Determine what kind of additional investigations, including field studies and laboratory experiments, might be necessary to supplement existing data, and
- Assess the potential effect of mine closure procedures on the stability of structures

2) Performing site stability investigations

- Determine potential failure surfaces with lowest safety factor along specified transects through dams and embankments
- Perform risk and sensitivity analyses

3) Closure procedures

- Planning and implementation of a monitoring program for activities related to mine closure

Post-remediation activities and monitoring

Geotechnical inspections are carried out after completion of the site rehabilitation program, to check structural stability and that structures and systems meet performance criteria, and to make sure that any potential problems or shortcomings can be identified and addressed at an early stage.

A regular site inspection program should include:

- Visual assessment of the overall area and structures
- Inspection of water levels, including pore waters
- Checking the amount of seepage water discharge related to dams and embankments
- Assessment of the need for precise leveling measurements to check for evidence of displacement or creep

Specific features to examine during visual inspection of the mine site and structures are as follows:

1) **General site inspection, paying attention to**
    - Condition of fencing and enclosures
    - Condition and performance of monitoring equipment

2) **Inspection of open pits and waste rock stockpiles:**
    - Possible displacement or deformation and erosion of slope and embankment surfaces
    - Effectiveness of surface drainage and drying schemes

3) **Structural integrity of dams and embankments and related structures are assessed by observing in particular:**
    - Possible deformation and displacement of the outer slope of dams and embankments, particularly at lower levels
    - Evidence of erosion of embankment material by surface water runoff or seepage water infiltration
    - Evidence of fissuring or fracturing within embankment material or terraces and berms.
    - Effectiveness of drying and drainage schemes and systems
    - Establishment of vegetation on dams and embankments (colonization and growth, extent of groundcover, presence of large trees)
    - Evidence of deformation, fissuring or subsidence in tailings and waste rock cover materials
    - Effectiveness of drying strategies in cover materials
    - Establishment and condition of vegetation on covering material

All dams and embankments should be inspected immediately after intense rainfall events.

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Abstract

The Mine Closure Handbook has been compiled within the Tekes-financed project “Environmental techniques for the extractive industries” and it has been directed to mining companies, authorities and consultants. The planning and implementation of mine closure are constrained by legislative requirements that define criteria and objectives for closure, as well as dictate responsibilities and sanctions. In addition to legislation, principles of sustainability, best practice and environmental management systems provide guidelines for closure. The wide variety of raw materials mined and the differences in operations are reflected in mine closure planning and implementation. The selection of methods employed is dependent on e.g the nature of the deposit and the production process, the type and properties of the by-products and the environmental conditions at the site. The selection of methods must be based on site-specific considerations.

The introductory section of the Handbook describes the special features of mining projects, e.g the life-cycle and environmental impacts of mines. The structure and importance of mining industry in Finland are also reviewed. The next section discusses the general principles and aims of mine closure, while the subsequent section on legislation reviews current legislatory requirements for mine closure and presents case law and permit decisions. The following sections describe procedures of environmental impact assessment and risk assessment related to mine closure and present examples of studies that can be used to support planning. After the planning section, the Handbook focuses on the implementation of mine closure and presents technical solutions and risk control measures of relevance to closure. The final sections deal with aspects of after closure monitoring and cost accounting.

The appendices of the Handbook provide in-depth views of the most important topics raised in the main text.

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