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ENVIRONMENTAL PROTECTION

Best Environmental Practices in Metal Ore Mining

Päivi Kauppila, Marja Liisa Räisänen and Sari Myllyoja (eds)

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FOREWORD

The aim of the present publication Best Environmental Practices in Metal Ore Mining is to create a joint knowledge base presenting the best environmental practices in metal ore mining as well as how the relevant legislation and administrative procedures may best be taken into account in environmental matters throughout the life-cycle of a mine. The publication is primarily designed for use by mine operators, authorities, consultants in the sector and others who are interested in mining.

The publication has been compiled in cooperation with the Association of the Finnish Extractive Resources Industry (FinnMin), the Geological Survey of Finland (GTK), the environmental administrative authorities (Centres for economic development, transport and the environment of Kainuu [KAIELY] and Lapland [LAPELY], the Regional State Administrative Agency of Northern Finland (PSAVI) and the Finnish Environment Institute [SYKE]). In addition to financing from the participating organisations, the work has received financial support from the K.H. Renlund Foundation and the Ministry of Employment and the Economy of Finland (MEE).

Compilation of the publication was supervised by a steering group consisting of: Alec Estlander (K.H. Renlund Foundation), Kari Pääkkönen (KAIELY), Hannu Idman (GTK),

Heikki Kovalainen (FinnMin until 1 March 2011), Olavi Paatsola (FinnMin), Juhani Itkonen(LAPELY/PSAVI since 1 January 2011), Riikka Aaltonen (MEE), Sami Koivula (PSAVI), Timo Jouttijärvi (SYKE), Kimmo Silvo (SYKE) and Irina Hakala (SYKE).

Publication of the volume was prepared by a working group whose chair was Sari Myllyoja (KAIELY) and secretary Timo Jouttijärvi (SYKE). The members of the working group included Päivi Kauppila (GTK), Marja Liisa Räisänen (GTK/KAIELY 1.10.2010–31.12.2012), Sami Koivula (PSAVI), Juhani Itkonen (LAPELY/PSAVI), Erkki Kuronen (FinnMin / Mondo Minerals B. V. Branch Finland), and Päivi Mannila (Kemira Oyj). The publication was edited by Päivi Kauppila, Marja Liisa Räisänen and Sari Myllyoja.

The authors of the component chapters are as follows: Chapter 1, Päivi Kauppila, Timo Jouttijärvi, Sami Koivula and Olavi Paatsola; Chapter 2, Matti Himmi (FinnMin), Päivi Kauppila, Maria Nikkarinen (GTK), Anna Tornivaara (GTK) and Sami Koivula; Chapter 3, Sami Koivula, Juhani Itkonen, Timo Jokelainen (LAPELY), Taina Kojola (LAPELY), Liinu Törvi (LAPELY), Johanna Juvonen (MEE), Päivi Kauppila, Eriikka Melkas (MEE), Sari Myllyoja, Heidi Karjalainen (Pyhäsalmi Mine Oy) and Tuomas Vanhanen (Talvivaara Mining Company Plc); Chapter 4, Matti Himmi, Päivi Kauppila, Kalle Reinikainen (Pöyry Finland Oy), Maria Nikkarinen and Anna Tornivaara; Chapter 5, Päivi Kauppila, Marja Liisa Räisänen, Timo Regina (KAIELY), Maria Nikkarinen ja Sami Koivula; Chapter 6, Matti Himmi, Marja Liisa Räisänen, Päivi Kauppila and Sami Koivula; Chapter 7, Sari Myllyoja, Matti Himmi and Marja Liisa Räisänen; Chapter 8, Marja Liisa Räisänen, Päivi Kauppila, Juhani Itkonen, Sami Koivula, Maria Nikkarinen, Erkki Kuronen, Timo Regina and Ilkka Haataja (KAIELY). The descriptions of the mine sites in Appendix 1 have been prepared by Anna-Leena Pitsinki (Agnico-Eagle Ltd / presently LAPELY), Veikko Neijonen (Outokumpu Oyj), Heikki Kovalainen (Talvivaara Sotkamo Oy), Heimo Pöyry (Polar Mining), Vesa-Pekka Takalo (Polar Mining), Petteri Tanner (Polar Mining) and Päivi Kauppila (GTK). Appendix 2 was written by Päivi Mannila, Appendices 3, 4 and 5 by Päivi Kauppila, and Appendix 6 by Marja Liisa Räisänen.

ABBREVIATIONS

AUTOG	Autogenous grinding mill
BAT	Best Available Techniques
BEP	Best Environmental Practices
BOD_7	Biochemical oxygen demand, method based on addition of allylthiourea
CLP	Classification, Labelling and Packaging of substances and mixtures (CLP Regulation)
CMC	Carboxymethyl cellulose
CODCr	Chemical oxygen demand, based on dichromate oxidation
CODMn	Chemical oxygen demand, based on potassium permanganate
CPE	Chlorinated polythylene
DePont™ HYPALON®	Chlorosulphonated polyethylene
EFF	Electronic Frontier Foundation
E-PRTR	European Pollutant Release and Transfer Register
GCLs	Geosynthetic clay liner (contains Na bentonite capable of cation exchange)
HDPE	High-density polyethylene
IP	Induced Polarisation
IRR	International Rate of Return
JORC code	Joint Ore Reserves Committee Code
KHO	Finnish Supreme Administrative Court
LLDPE	Linear low-density polyethylene
LSL	Nature Conservation Act (Finland)
MIBC	Methyl Isobutyl Carbinol
MMI	Mobile Metal Ion
NI	National Instrument
NPV	Net Present Value
PE	Polyethylene
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SAG	Semiautogenous grinding mill (diameter 12 m, 12 MW motor)
SCI	Site of Community Importance
SPA	Special Protection Area
SP	Self Potential
UCVB	Substance of Unknown or Variable composition, Complex reaction products or Biological materials
VaHO	Vaasa Court of Appeal
VNA	Government Decree
VNp	Government Decision
VSD	Variable-speed drives
YEL → NEA	Nuclear Energy Act (Finland)
YSA → EPD	Environmental Protection Decree (Finland)
YSL → EPA	Environmental Protection Act (Finland)
YVA → EIA	Environmental Impact Assessment

CONTENTS

1 Introduction

Mining has long traditions in Finland. The first iron mines began operating in the southern part of the country as far back as the 1560s. Since that time, over one thousand mines have been opened that have extracted metal ores and industrial minerals (Puustinen 2003). Today, mining is an expanding sector that produces essential raw materials for the metal, chemical and paper industries, for agriculture and for many other sectors of the economy. At present, there are some forty mines operating in Finland, of which ten or so produce precious or base metals (e.g. gold, chrome, nickel, copper and zinc), with the other facilities extracting industrial minerals (e.g. apatite, talc and limestone) (See Appendix 1). These mines stand to be complemented by a number of metal ore and industrial mineral mines currently being planned in southern, eastern and northern Finland. These facilities include new gold mines in various locations throughout the country, as well as an apatite mine in eastern Lapland. In addition to an increasing global need for base metals, there is a growing dependence on a supply of what are known as high-tech metals (including rare earth metals), a trend which has sparked intensified prospecting for and exploration of high-tech metals in Finland (MEE 2010). In European perspective, the mineral wealth in Finland is significant, as the country's reserves will improve Europe's self-sufficiency in mineral and metal production. In fact, Finland is the continent's largest producer of industrial minerals.

The production of the metal mining sector in Finland has increased robustly since 2009, following what had been a long-term recession. According to forecasts, the quantity of commercially viable extractable ore and minerals in metal mines will increase from the earlier level of 4 million metric tons to as much as 70 million tons over the next decade. At present, the mining sector employs 6,000 to 10,000 people directly, with the mining industry as a whole indirectly giving work to over 30,000 persons (Hernesniemi *et al.* 2011). Judging from the cases to date, the increase in extraction will have a significant impact on the development of the technology and metal-refining industries and on the economy of Finland overall through the boost in indirect employment they provide. For example, older mines have spurred the creation of almost ten significant concentrations of industry and metal refining, in particular along the coast. In the interior of the country, there are numerous concentrations that have grown up to serve the mining industry, built around industrial minerals and engineering. Many of these are known today as technology parks; the activities for which they were established are still a significant factor regionally but operations serving their original function and new industrial sectors have also come to play a key role.

Yet, mining inevitably has an impact on its environment. Prevention of negative impacts requires sound management of environmental matters, beginning with exploration and planning of a mine, through the life-cycle of its operation, to decommissioning and rehabilitation of the site. Environmental and mining legislation on environmental impacts has been enacted in order to prevent pollution of the environment and to reduce emissions. Of the legal instruments in force, the Environmental Protection Act (EPA) and Environmental Protection Decree (EPD) in particular require the application of Best Available Techniques (BAT) and Best Environmental Practices (BEP) in activities that entail a risk pollution.

The European IPPC (Integrated Pollution Prevention and Control) Bureau has drawn up a separate BAT reference document for the management of tailings and waste rock in mining activities (EC 2009). In addition, international guidance on best environmental practices in mining is available from various countries (e.g. Environment Canada 2009, INAP 2009, PDAC 2011). The present volume represents a Finnish national report bringing together the best environmental practices and best available techniques in the mining sector, with a focus on the mining of metal ore. The practices and techniques described here comply with Finnish and EU legislation and draw on lessons learned in the field and international practices, but have been chosen with an eye to their applicability under the conditions prevailing in Finland.

As a basis for this work, the Finnish Environment Institute compiled a preliminary BAT report for the mining industry (Niinivaara 2009), the purpose of which was to provide a foundation on which operators, experts and authorities could discuss the need for a BAT document for the Finnish mining industry. The Institute's report dealt with mining activities and their impact on the environment in different phases of operation. It provided information on the legislation, environmental protection techniques and technical solutions pertaining to mining activities as well as on issues of consumption and emissions levels. Discussions following publication of the report confirmed the need to continue the work. Given the unique characteristics of metal ore mining, however, it was considered more worthwhile to produce a national report on BEP in metal ore mining than a BAT report setting out limit values for such activities or consumption and emission levels complying with the best available techniques. The section to follow describes the aims of the present publication and the choice of topics and scope.

1.1 Aims and scope of the publication

The aim of the present publication, *Best Environmental Practices in Metal Ore Mining*, is to provide a joint knowledge base that presents the best environmental practices in metal ore mining that are applicable under the conditions prevailing in Finland as well as the legislation and administrative procedures to be taken into account in environmental affairs. Best environmental practices refer to the combination of actions which make it possible to purposefully and cost-effectively prevent pollution of the environment. The volume examines environmental considerations in metal ore mines at all phases in the mine life-cycle from exploration and the beginning of operations to decommissioning of the mine and rehabilitation of the site. The topics covered encompass legislation, emissions and environmental impacts related to the operation of mines, the environmental reports required, as well as the applicable methods and techniques for reducing emissions and environmental impacts.

As the nature and extent of emissions and environmental impacts in mining depend heavily on the mineralogical and chemical properties of the ore being extracted, the report places an emphasis on the environmental geology of metal ores. In describing the techniques for reducing emissions and presenting the best environmental practices, the focus is on issues relating to the management of metal ore mining wastes, for these pose the central and most challenging aspects when trying to reduce the environmental footprint of metal ore mining. The report has been compiled for operators, permit and supervisory authorities, and consultants in the sector as an aid in successfully planning, implementing and terminating operations.

In mining, the operation of every mine is unique. For example, the quantities of ore produced, the technical solutions and duration of production vary considerably depending on the ore deposit and the conditions at the site. Similarly, the emissions and environmental impacts vary markedly from case to case and, on the whole, mining differs substantially in nature from other, conventional industrial activity. One of the principal aims of the publication has been to create a basis for harmonising practices with due consideration for the special features of the activities described.

The scope of the report is confined to metal ore mining. Metallic ores are defined as ores containing minerals formed by valuable metals, which are separated from the ores using concentration techniques or metallurgical methods. The valuable metals found in metal ores are customarily divided into iron and iron alloy metals (Fe, Mn, V, Cr, Ni, Mo, W, Co), base metals (Cu, Pb, Zn, Sn), light metals (e.g. Li, Mg, Be, Ti, Al, Na), rare metals (e.g. Li, Be, Sn, Ga, Zr, Nb), precious metals (Au, Ag, Pt, Pd) and radioactive metals (U, Th). The report focuses on the metal ores extracted in Finland, that is, on mining that produces base and precious metals. It excludes panning for gold.

2 Metal ore mining: the mine life-cycle and processes

The life-cycle of a mine encompasses roughly four principal phases: ore exploration, construction of the mine, production, and rehabilitation of the site (Figure 1). The life-cycle of a mine is closely linked to economic cycles. The ore exploration phase, geared to locating a commercially viable deposit before mining proper begins, may last years or even decades. Similarly, the duration of the production phase may vary markedly depending on, among other factors, the size and quality of the deposit, the excavation techniques used, and the market prices of the valuable substances being extracted. When a commercially viable deposit is exhausted, the site is decommissioned and restored, through rehabilitation, to a state in which it poses no risk to the environment and public health. The closure phase of a mine can then continue for years or decades in the form of monitoring of the site following the cessation of mining operations.

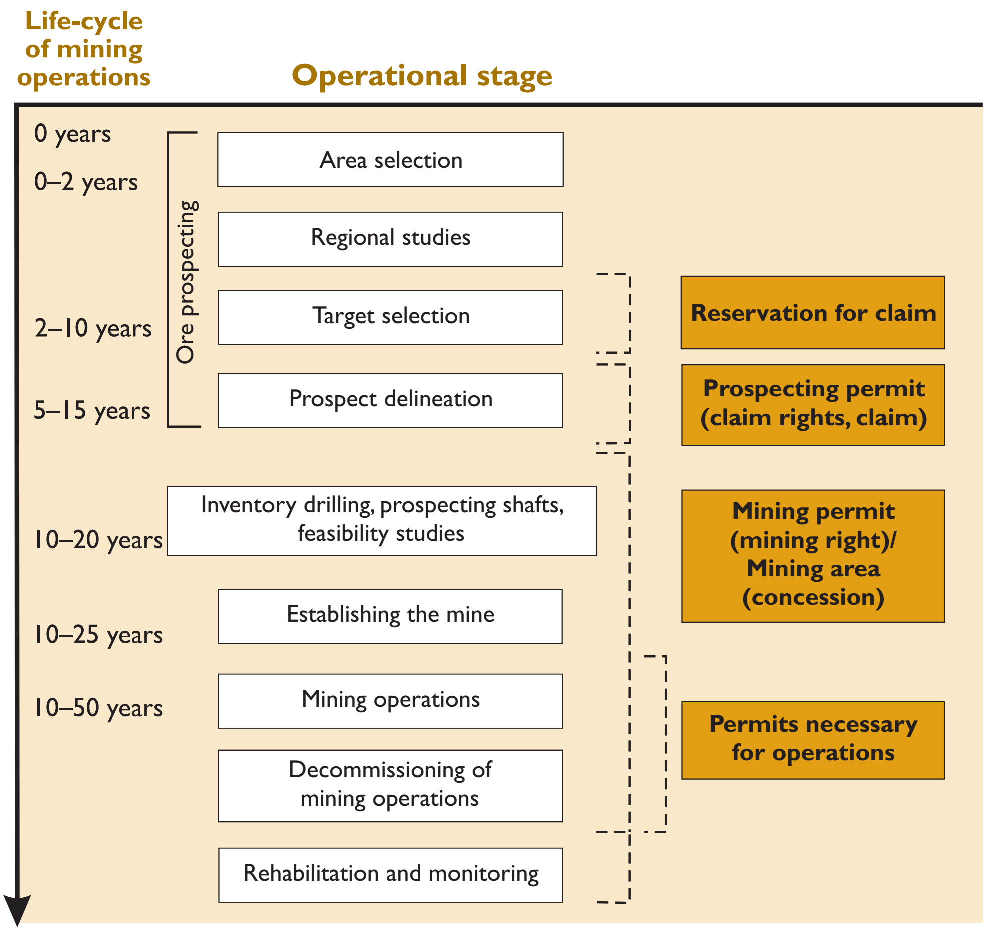

Figure 1. Life-cycle of mining activities (adapted from Heikkinen *et al.* 2005).

The sections to follow describe the key processes in the different phases in the life-cycle of a mine. Descriptions of mines in Finland currently producing metal ore and the production processes used at those mines are presented in Appendix 1.

2.1

Exploration

The objective of exploration is to discover and locate a mineral deposit in the ground which can be shown to be commercially viable in order to initiate mining activities. Exploration is a long-term effort which proceeds in phases from regional studies to site-specific investigations. In the phase of areal exploration, interpretation of potentially ore-bearing zones draws on data for the entire country that has been produced by geological surveys and studies carried out by the Geological Survey of Finland (GTK). Bedrock mapping has produced data on the rock types and the bedrock structure in Finland. Soil mapping describes the distribution of soil types and soil formation. Interpretation of potentially ore-bearing zones also makes extensive use of the results of geophysical and geochemical studies. Data on different regions are kept in the databases of the Geological Survey, where they are made available for further studies (http://en.gtk.fi/informationservices/geological/). Today, potentially ore-bearing areas and rock types are known to the extent that they provide some indication of where to explore, allowing targeted and site-specific exploration to be directed to these areas.

2.1.1

Exploration methods

Targeted exploration is based on geological field studies, that is, direct observations and measurements of outcrops, boulder prospecting, as well as samples taken from outcrops and till and their analysis (GTK 2006).The vast majority of exploration activities are terminated if the indications of ore reserves prove insufficient in site-specific studies. Very rarely does exploration lead as far as exploratory excavation or applications for a mining permit. On the other hand, investigation of the same sites may be reactivated as a result of new research findings, changes in world market prices for the metals or developments in metal extraction techniques. Exploration activities do not hinge exclusively on the resources in the bedrock; they must take into account economic, environmental and social factors as well.

Outcrop mapping and sampling from the bedrock surface

Geological exploration is based primarily on field observations of outcrops (e.g. rock type, structure and indications of ore formation). In practice, an area of topsoil some one square metre in size is peeled back off the rock surface for observations and measurement; this is then replaced after observations have been conducted. The most interesting outcrops are cleaned using water and a brush and are kept bare for the duration of investigations in the area.

Bedrock samples are collected for the purpose of mineralogical studies and other analyses by chipping a piece from the surface of the bedrock with a hammer, by a small hand-operated drill (using 10–20 cm long rock drilling bits), by cutting the rock with a diamond disc (a 5 cm wide and a 5–7 cm deep groove sample) or by taking powder samples using a drill. The bedrock is left with a mark in it that is the size of the sample, along with any rock dust created during sampling.

Boulder prospecting
Most – over 90% – of the bedrock in Finland is covered with loose soil grades. For this reason, site-specific exploration requires other methods in addition to outcrop mapping; one is boulder prospecting, which involves using glacial erratics transported by the continental ice sheet to locate potentially ore-bearing bedrock for more detailed study. Samples are taken from boulders of interest using a hammer or a small drill.

Geophysical fieldwork
Geophysical methods measure the physical characteristics of the ground, with these providing the basis for interpretations that serve geological purposes as well as ore exploration. The results of the measurements make it possible to determine the quality of bedrock deep beneath the overburden, for example, variations in rock types and mineral composition, and to locate fault and shear zones, rock type structures and zones exhibiting discontinuities in rock type. In exploration, geophysical measurements and models are used to assess the depth dimensions and below-surface structure of ore-critical rock masses. Magnetic and electrical methods are ordinarily used and occasionally gravimetric methods are employed as well. The most common electrical methods are the slingram method and measurements using the induced polarisation (IP) and self-potential (SP) methods. Exploration can also employ seismic and radioactive methods.

Geophysical measurements for exploration are carried out in summer on foot and in winter using snowmobiles. Sampling lines are spaced appropriately to the task at hand, generally every 50 to 100 m. Measurements are also carried out by aircraft, which fly over the site (airborne geophysical surveying). Geophysical measurements may also be conducted from boreholes (e.g. susceptibility, density, electrical conductivity). With the developments in 3D modelling and exploration for non-outcropping (i.e. subsurface) ore deposits, work has begun on developing special depth-dimension measurements and the interpretive skills these require.

Geochemical exploration
Geochemical exploration searches for anomalies in the concentrations of chemical substances in a region. The most common sample material is till, which contains ground bedrock material and thus indirectly reflects the composition of bedrock. In site-specific investigations, geochemistry is a routine procedure and the sampling density varies from a couple of metres to several hundred. Fieldwork in winter is done using snowmobiles. Samples are usually taken using a core drill (or spiral drill) attached to a percussion drill mounted on a light tracked vehicle. In addition to the sampling of till, a percussion drill may be used to collect samples of drilling mud and crushed rock from the bedrock surface.

Other geochemical survey methods commonly used in Finland are humus and bedrock geochemistry (lithogeochemistry) and heavy mineral and isotope studies. Bedrock geochemistry is based on the analysis of the chemical composition of bedrock samples. Humus geochemistry is best suited for areas in which the vegetation and moisture conditions do not vary much and the overburden is sufficiently thin. In studies of heavy minerals, the heavy mineral material is concentrated from the soil sample and then either studied using a microscope or analysed chemically.

The chemical composition of soil and bedrock samples is analysed using multielement methods with the results then interpreted in geological terms. The variations in concentrations of different metals are depicted on maps. General information is available on the geochemistry of till in Finland, for example, based on sparse-point data (1 sample/4 km^2) (Salminen 1995).

Other geochemical applications include determination of ore potential on the basis of the chemical composition of the minerals in rock samples, studies using the Mobile

Figure 2. Left: Sampling for MMI in Lapland. Right: Survey trench dug by excavator for bedrock and soil survey and heavy mineral sampling. Studies of the area were continued using *in situ* sampling of weathered rock and till and drilling. (Photos: Janne Hokka)

Metal Ion (MMI) technique, and statistical and graphical methods for examining the analyses of samples collected in surveys. MMI studies are based on the analysis of the concentrations of mobile metal ions and other elements bound weakly to the surface of mineral and humus particles in the overburden. A representative sample is taken using a pit some 0.25 m deep, dug using a shovel (cf. Mann *et al.* 1998, Figure 2).

Exploration trenches

In areas covered with thicker layers of overburden, the surface of the bedrock is studied using the above-mentioned techniques in exploration trenches dug by an excavator (Figure 2; see foregoing paragraphs). In soil and till studies, exploratory trenches dug using a shovel or excavator provide a location for determining the structure and composition of the soil, its stratigraphy, the transportation distance, as well as the heavy minerals in till and the occurrence of ore boulders in till. The sides of the cleaned trenches are mapped and photographed. Calculations of the orientation of rock and elongated rocks are made from the sides of the trenches, and samples are taken for grain size and geochemical analyses as well as studies of the heavy minerals.

Bedrock drilling

The most important phase in *in situ* exploration is bedrock drilling, which yields reliable uniform and continuous series of samples of the rock types and the structure of the bedrock at the site. Exploration then proceeds to deep boreholes when the geological, geophysical and/or geochemical studies have made it possible to delineate an interesting area that shows a potential ore deposit. Drilling is an important exploration method, particularly in areas where the overburden is thick and there are few outcrops.

Drilling equipment comparable in size to agricultural tractors and, at its largest, to forestry harvesters, is transported on trailers or built as part of a truck. When moving the equipment in the field, existing equipment tracks are used as much as possible. In deep-borehole drilling a cylindrical sample of the bedrock is taken using a diamond drill head. Drilling is carried out through a steel or aluminium protective tube extending down through the soil, with water or air, or both, used as a drilling fluid. Drill core samples are removed from the tube in as intact a condition as possible, broken into sections, placed in sample boxes and sent on for additional analyses. Often a protective tube extending to the surface and a cap are left in the borehole in order to enable additional geophysical studies from the same borehole. The cooling water used in drilling is taken from streams in the area and when drilling is finished the water is channelled through a settling pond into the soil.

The depth of holes drilled varies in the main from 50 to 200 metres. The drilling operation is divided into different phases as the purpose requires. In reconnaissance drilling boreholes are scattered throughout the area being explored on the basis of the results of previous investigations and indicators. In exploration drilling the profile of the area is studied by locating the boreholes one after the other across the area being studied. The drill lines are typically located 50 to 200 metres apart and the distance between the boreholes is correspondingly 50 to 100 metres. In inventory drilling, the distance between holes and drill lines is further decreased and fan drilling may be carried out in the area.

Pilot mining

Pilot mining and concentrating trials are required in order to determine the feasibility or profitability of an ore deposit and to test and develop a concentrating method as part of ore exploration and the planning of a mining project. Pilot mining uses methods corresponding to those used in full-scale mining and takes place when the planning of mining activities has begun on the basis of exploration results (see section 2.3.1).

The amount of ore excavation required for concentrating trials at laboratory scale is smaller than that for trials at plant scale. A typical quantity of samples required for a trial run of grinding-flotation is 100 to 300 tons. By contrast, developing an appropriate concentrating method in mineral technology facilities generally requires 200 to 1000 tons of ore. Larger quantities – 20,000–60,000 tons – are used if the concentrating trial is carried out in a mill near the deposit or a new concentrating process is being developed near the deposit within the planned mining concession. In pilot mining the amount of overburden and waste rock, if any, removed from on top of the deposit ordinarily varies from several hundred to several hundred thousand cubic metres.

2.2

Opening a mine and the construction phase

Opening a mine requires that extraction and processing of the ore deposit will be economical. The discovery of an ore deposit does not always lead to the start-up of a mine. Assessments of the feasibility of the deposit will take into account, among other factors, the location of the deposit, its size, mineralogical composition, concentrations of valuable minerals, bedrock mechanics, concentrating and further processing, as well as opportunities to market the concentrate, the costs of constructing the mine, and the environmental and other permits that apply to the project. The assessment and other reports required may take a number of years to complete.

The commercial viability of a deposit is generally determined in keeping with strictly defined standards or the mining group's internal procedures, as mine operators are generally listed on the stock exchange. Examples of guidelines used for this purpose are:

- National Instrument 43-101
- The JORC Code

Ascertaining the feasibility of a deposit requires that the information gathered in the exploration phase be complemented with more precise data obtained through, among other procedures, geophysical measurements and drilling and soil and rock analyses (cf. section 2.1.1). In order to determine how best to process the ore, concentrating tests are carried out on the core samples at laboratory scale. At the same time, environmental characterisation tests can be performed on the samples, with these providing a tentative idea of the environmental suitability of any waste rock and waste material and of its chemical behaviour in the short and long term (see section 5.4.2 and Appendix 6). Before a final decision is taken on constructing a mine, additional pilot mining and concentrating is carried out to ensure the soundness of excavation techniques and to work out the details of the concentrating process.

Construction of a mine is generally begun promptly after the decision is taken to establish the mine. Constructing a mine normally takes some two years if a concentrating plant is built along with the mine. When construction is started, the first facilities built are normally roads and, in consideration of the work in the start-up phase, the provision of a sufficient electrical supply is ensured. In the initial phase, work, break and storage facilities are usually arranged using temporary buildings. The construction of permanent structures (concentrating plant, maintenance, storage, office and others) and of other infrastructure (including tailings ponds, water treatment systems, lining of waste rock areas) is begun in order of urgency.

As a rule, before production is begun, storage areas are built for the mining wastes resulting from excavation and the concentrating process, in particular waste rock from open pit mining and tailings from the concentration plant. These facilities ensure the secure storage of the waste in terms of both health and the environment. In planning the location and construction of the waste rock facilities, attention should be directed to the physical and chemical behaviour of the materials and their potential impacts on the environment (cf. section 5.4.3).

Storage of tailings is usually handled through extensive dammed ponds equipped with structures for draining wastewater and facilities for water treatment. In order to prevent pollution of the overburden (glacial and postglacial sediments) and groundwater (and subsurface water), the impermeability of the base structures of the tailings ponds is ensured, where necessary, using compacting materials or liners. The structure of waste rock storage areas is generally simpler, as they typically do not require dams. In these areas, as in others, the compactness and strength (bearing capacity) of the soil is determined beforehand. Management of drainage water is also planned before storage of waste materials is begun. Technical considerations relating to the storage of mining waste are taken up in more detail in sections 5.4 and 6.2.3.

The construction phase is also the time when the necessary preparatory work is done for production mining of ore. Efforts are made to begin the production of ore before the on-site concentrating plant is completed. In open pit mining, the surface of the deposit is uncovered over the area where excavation will begin. In addition, overburden and waste rock are removed from around the deposit. This often requires massive earth-moving operations. Starting up an underground mine generally begins with the excavation of a decline and the construction of a hoist shaft if needed. These structures are typically dug into waste rock. Underground maintenance and storage facilities are also built before the beginning of production mining.

Table 1. Examples of measures taken when opening metal ore mines operating in Finland.

Mine / valuable metal	Production begun	Measures taken related to opening of mine
Kemi mine Cr	1969	Company-specific procedure in assessing the ore deposit in the 1960s, pilot mining and concentrating studies in pilot plant, soil investigations on the base of the tailings pond dams
Kittilä mine Au	2008	Company-specific procedure in assessing the ore deposit in the initial phase, improvement and construction of roads and construction of electrical power line, pilot mining and concentrating, construction of base structures for tailings area (impermeable bitumen geomembrane layer + till), today uses NI 43-101 system in reporting ore reserves
Pyhäsalmi mine Cu, Zn, S	1962	Company-specific procedure in assessing the ore deposit in the late 1950s and early 1960s, pilot mining and concentrating studies at a pilot concentrating plant, soil investigations on base of tailings pond dams, today uses NI 43-101 system in reporting ore reserves
Talvivaara mine Ni, Zn	2009	First phase of pilot mining in the 1980s and pilot plant scale process studies and extensive laboratory tests; in the 2000s new pilot excavations and heap leaching experiments, reports on mineral reserves use the JORC Code and NI 43-101 system. Leaching heaps and piles of waste rock, as well as the bottoms of the waste ponds, lined with HDPE liner, construction of infrastructure included roads, a rail link and electrical power line, production facilities encompass some 700,000 m^3.
Orivesi mine Au	1995	Laboratory tests of core samples, pilot mining, plant-scale process studies and extensive laboratory tests and pilot runs
Jokisivu mine Au	2009	Pilot mining, plant-scale pilot runs, economic assessment based on feasibility study based on cash flow and parent company's price and currency exchange rate predictions, NPV and IRR calculations. Construction included building of road connections, base of waste rock storage area lined with layer of till, facility built for processing mine drainage water consisting of two preclarification basins and two sequential postclarification basins.
Lahnaslampi mine Talc, Ni	1970	Pilot mining and concentrating in the 1960s, choice of concentrating method based on laboratory and pilot tests, open pit mining based on nature of ore deposit.

Plans generally call for the rock (excavated rock and crushed rock made from it) needed in building roads, dams and other structures in the mining area to be obtained from the open pit in the area outside of the ore deposit and/or from the excavation of the decline shafts and other spaces in the underground mine. The quality of rock material used in building such facilities must fulfil the requirements for environmental and technical compatibility (see section 5.4.2 and Appendix 6).

The overburden removed from the open pit area and other construction sites is ordinarily stored in the mining area in anticipation of earthworks and landscaping. During the construction phase, rock material excavated from the open pit or the underground mine that cannot be used for any purpose or that is in excess of what is needed is stored in the waste rock area.

Table 1 puts together cases of measures related to the opening of metal ore mines in Finland.

2.3

Mining and milling processes in the production phase of a mine

In the production phase of a mine, ore is removed from the bedrock through excavation. After this has been done, the ore is crushed and ground to a size appropriate to the concentration process. In concentrating, the valuable substances and minerals in the ore are removed chemically or mechanically from gangue, the resulting material becoming what is known as concentrate (Figure 3). The following sections describe the different phases of the mining process.

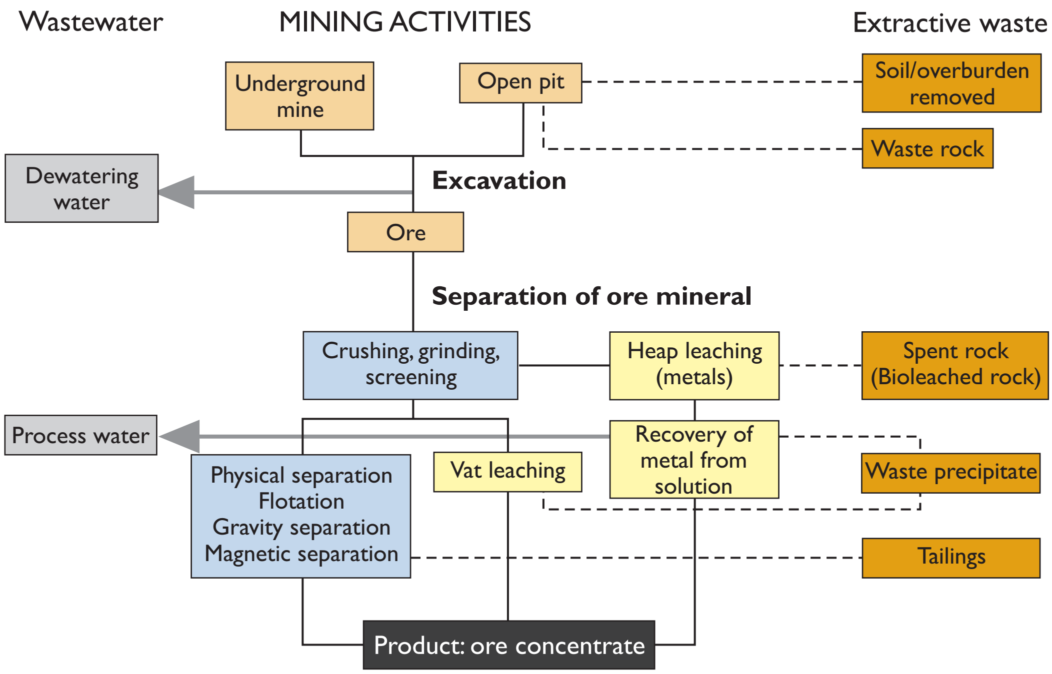

Figure 3. Diagram of the general processes in mining operations.

2.3.1

Excavation and ore transportation

Ore containing valuable minerals is removed from bedrock such that the concentration of valuable substances in the ore is economically sufficient. Depending on the excavation technique, removal of the ore will also require excavation of waste rock, which has no value. The amount of waste rock is limited to the extent possible in the material sent on for further processing in order to ensure that the capacity of the concentration process will be as efficient and economical as possible. It is not considered acceptable in mining to waste natural resources by, for example, exploiting only the richest part of the ore deposit and leaving poorer and less profitable parts untouched or removing them along with waste rock. Adhering to this principle requires constant optimisation of excavation on the basis of the prices of metals and the costs of mining, concentrating and extraction wastes.

If the ore deposit extends to the surface or is located near it, the excavation technique used is open pit mining (Figure 4). Ore deeper in the ground is generally mined using underground techniques. Often production is begun in the form of open pit

Figure 4. Open pit at the Kittilä mine. (Photo: Agnico-Eagle Mines Ltd)

mining and changes over to underground mining as operations proceed deeper into the deposit (Figure 5). If the ore deposit in its entirety is located deep under ground, open pit mining is not at all possible.

In open pit mining, the technique used generally results in large quantities of waste rock being excavated, as ensuring safe walls in the pit requires that the pit be widened as it becomes deeper. The ore-to-waste rock ratio (strip ratio) in Finnish metal ore mines varies from 1:1 to 1:14.5. In the early years of operation, the amount of waste rock is typically smaller than in later stages. The challenge to address in separating ore and waste rock is to ensure that the feed entering the concentrating process does not become too dilute. If the ore deposit extends deep into the ground, an assessment is made as to whether it is economically feasible to extend the pit or is it preferable to switch over to underground mining.

Open pit mining may use a number of techniques: bench excavation, buffer blasting, excavation by crane, and excavation by hammer drill. Of these, bench excavation is the most common in Finnish mines. The phases of bench excavation are loosening, breaking, and loading and transport of ore. In loosening, rock is detached from the bedrock by drilling and blasting. In breaking, oversized rocks are broken to a size suitable for transportation and crushing. Bench excavation proceeds in benches of equal width from above to below and the benches are linked to one another by haulage roads along which the ore and waste rock are transported to the crushing plant. (Hakapää and Lappalainen 2009).

Buffer blasting is a variation on bench excavation in which the ore is not loaded before the following explosion. It is applicable, for example, in the following cases: gently dipping ore bodies in which there is a layer of gangue between the layers of ore; narrow veins of ore; and the large-scale excavation of massive ore bodies. The advantage of the technique is the selective nature of loading, which ensures maximal recovery of ore and minimal dilution by gangue. Buffer blasting is used at the Kittilä mine, for example (Paalumäki 2009).

The maximum depth of open pits at metal ore mines in Finland varies as a rule between 150 and 200 m, with the bench height typically 14–15 m (Paalumäki 2009). The planned depth for the open pit at the Talvivaara nickel mine is 300 m.

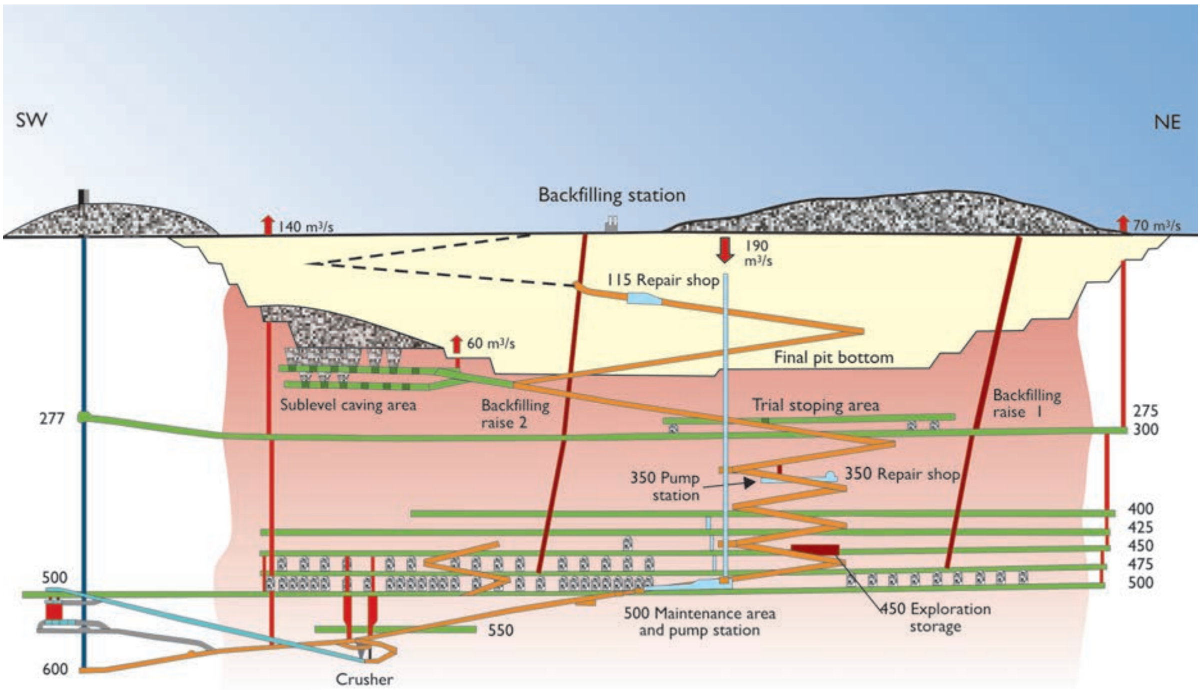

Figure 5. Diagram of the underground mine at Kemi, where operations were begun as an open pit mine. (Diagram: Outokumpu Oyj)

In underground mines, as little waste rock as possible is excavated (for example the strip ratio at the Kemi mine is 1:0.5–0.4 and at Pyhäsalmi 1:0.05–0.04.) Shafts and access ramps are generally dug into waste rock. Waste rock is generally not transported to the surface but rather is used in the underground mine to backfill and support excavated spaces. In an underground mine the methods and techniques for mining ore depend on the form and location of the deposit and the mechanics of the bedrock. In addition, the value of the ore, the excavation costs and environmental considerations have a bearing on which excavation method is chosen.

The methods typically used in underground mining are divided into three categories (Lappalainen 2009):

1. Open methods (supported by pillars)
   - Room and pillar mining
   - Sublevel stoping
   - Bench stoping
2. Cut and fill methods
   - Short hole mining
   - Uphole bench and fill mining
   - Shrinkage stoping
3. Caving methods
   - Sublevel caving
   - Block caving

In underground mining, mined out spaces and tunnels are supported to prevent collapse. These measures generally consist of backfilling stopes with waste rock and a “mine fill” made from tailings to which hardening agents such as cement, limestone, fly ash and blast furnace slag have been added. Tunnels are shored up using rock bolts, concrete and/or plaster.

Drilling today uses extensively automated, efficient equipment that is powered by electricity or compressed air. Drilled and charged fields are generally blasted in accordance with an established timetable, without causing any hazards to the person-

Table 2. Mining and haulage methods, as well as explosives used in mining, at the metal ore mines operating in Finland.

Mine	Mining method and technique	Explosive	Amount	Ore haulage
Kemi	Open pit (ended in 2005)	Kemite 510 emulsion	0.2 kg/t	Dump truck Hoist
	Underground mine Bench stoping		0.14 kg/t	
Kittilä	Open pit and underground mine	Riogel emulsion	Gangue fields 0.225 kg/t Ore body 0.18 kg/t	Transport by dump truck to crushing plant
Pyhäsalmi	Underground mine, Sublevel stoping, bench stoping	Kemite 810	0.33 kg/t	Hoist, conveyor belts
Talvivaara	Open pit	Kemite 510 emulsion	0.25–0.28 kg/t	Dump truck transportation to primary crushing plant
Orivesi	Underground mine	Kemite 510 emulsion	0.3–0.6 kg/m^3	Dump truck transportation to Vammala production centre, 85 km
Jokisivu	Open pit, bench stoping	Dynamite Anfo Kemix-A	0.3–0.6 kg/m^3	Dump truck transportation to Vammala production centre, 40 km
Lahnaslampi	Open pit	Kemite 510 emulsion	0.25 kg/m^3	Dump truck transportation to primary crushing plant

al safety of workers. In open pit mining in particular, the blasting schedule is often limited in the permit conditions to prevent disturbances due to noise and vibration. The explosives used in mining are described in section 4.2.3.2 and presented in Table 2.

In both underground and open pit operations, mining extends below the water table. Excavated spaces are kept dry by pumping the water that collects in the mine to the surface.

Ventilation of underground mines is effected by blowing fresh air from a primary fan through the ventilation shaft into underground spaces. The mine heads are ventilated using fans and ventilation pipes located underground. In older mines with extensive networks of tunnels the ventilation system may be very complex and its smooth operation requires automated control and careful monitoring. In winter the incoming air is heated in order to prevent icing up of the ventilation shaft. Deep mines use air conditioning in summer to prevent the air coming in through the ventilation system becoming too warm.

Ore is moved from open pits for processing by trucks, dumpers or rock trucks and sometimes by conveyor belts (cf. Table 2). If open pit and underground mining are under way at the same time, ore excavated from the open pit may also be dropped through an ore pass into the mine, from where it is hoisted along with the ore extracted from underground. From the underground mine, the ore is moved by hoist, trucks or a conveyor belt or some combination of these means.

In some cases a mine may be located as many as tens of kilometres from the concentrating plant. The ore may then be transported from the mine to the plant by road or railway if the distances involved are very long or if the quantities of material to be transported are large. At the Enonkoski mine, where the mine and processing plant were appropriately located by waterways, the ore was transported at the time by ship.

2.3.2
Crushing and screening

The extracted ore is crushed to reduce the size of the pieces for further processing. In underground mining the ore undergoes primary crushing to make it of suitable size for the hoist before it is transported to the surface. If the ore is transported from the mine to the concentrating plant by truck, oversized pieces of ore are broken up before transport and the first phase of actual crushing is carried out in a crushing plant on the surface. The first phase of crushing is called pre- or rough crushing and it is typically done using jaw crushers or gyratory crushers (Figure 6).

Figure 6. Underground jaw crusher at the Pyhäsalmi mine. (Photo: Pyhäsalmi Mine Oy)

Table 3. Crushing and screening methods used at the metal ore mines operating in Finland.

Mine/Production facility	Crushing and screening
Kemi mine	Three-phase crushing Phase 1: underground (gyratory crusher) Phase 2: open circuit (STD cone crusher) Phase 3: open circuit (SH cone crusher)
Kittilä mine	Single-phase crushing on the surface (jaw crusher)
Pyhäsalmi mine	Single-phase crushing underground (jaw crusher), screening into three grain sizes on the surface, additional crushing of grains if necessary in connection with screening /grinding (cone crushing)
Talvivaara mine	Primary crushing by gyratory crusher, transportation to intermediate storage facility, three-phase fine crushing with cone crushers, of which the last two phases in a closed circuit with screeners; grain size of 80% of crushed product less than 8 mm
Vammala concentrating mill	Three-phase crushing Phase 1: jaw crusher Phase 2: gyratory crusher and Phase 3: cone crusher All operate in an open circuit, which includes a vibrating screener that separates material that has been crushed finely enough for grinding
Lahnaslampi mine	Two-phase crushing, primary crushing with jaw crusher, second phase with impact crusher

After this, the crushing process depends on the grinding and other processing to follow (Table 3). Normally, the crushing circuit consists of crushers and screeners which are connected in a closed circuit that produces material with a grain size in the desired range. Sometimes the material can be graded into different grain sizes following primary crushing by screening alone. Most often ore is crushed in one or two stages to achieve a finer grain size before further processing.

Fine crushing is usually done using cone crushers and screening makes use of vibrating screeners consisting of one or more decks. The crushing and screening circuits are sometimes built outdoors without protective buildings. This approach poses challenges for environmental protection and operations under extreme weather conditions.

2.3.3
Grinding

In grinding, the ore is fractured to a grain size where the valuable minerals contained in the ore occur as sufficiently pure, discrete particles that can be separated from the particles of waste rock in the concentrating process.

In metal ore mines, ore is typically ground in horizontal rotating mills in a slurry using either metal grinding balls or larger pieces separated from the ore (in what are known as autogenous grinding methods). The ore is ground in one or more stages (Table 4). The mills in the grinding circuit (Figure 7) are most often connected to a closed circuit along with classifiers, which return coarse grains to the grinding circuit. This ensures that the material produced by the grinding process falls within the desired grain size range for further processing.

The grinding circuit may also have coarse froth flotation machines, gravity separators or even magnetic separators connected to it. These separate the coarse particles of valuable minerals from the material returned by the classifier, or what is known as the recirculating load. These configurations are quite typical, particularly in the processing of gold.

Figure 7. Grinding mills at the Pyhäsalmi mine. (Photo: Pyhäsalmi Mine Oy)

Grinding usually consumes more energy than any other phase of mineral processing (30–63%). For this reason, optimisation of the grinding circuit is frequently a focus of continuous development in mining works.

Table 4. Grinding methods used at the metal ore mines operating in Finland.

Mine/production plant	Grinding circuit
Kemi mine	Phase 1: rod mill in open circuit
	Phase 2: ball mill in closed circuit with Derrick sieves functioning as classifiers
Kittilä mine	Single-phase grinding using a SAG mill connected to a closed circuit with a cyclone classifier
Pyhäsalmi mine	Phase 1: rock mill (SAG) rocks and balls (100 mm)
	Phase 2: 3 autogenous mills (AUTOG), as well as balls if needed (60 mm)
	Phase 3: ball mill (balls 30 mm)
	Phases 2 and 3 in closed circuit with a cyclone classifier
	Grinding fineness: 65% < 0.074 mm.
Talvivaara mine	No grinding phases as such, ore goes after crushing and screening to heap leaching
Vammala concentrating mill	Phase 1: rod mill
	Phase 2: ball mill (balls 40 mm) in closed circuit with cyclone
	Gravity separation circuit for processing of recirculating load (Reichert cone, spiral classifiers and two vibrator tables)
	Grinding fineness of feed to flotation: 75% < 0.074 mm
Lahnaslampi mine	Single-phase ball mill grinding in closed circuit with a cyclone classifier

2.3.4

Concentrating ore

In concentration, minerals containing valuable substances are separated from minerals with no economic value. The following are the most common concentration methods used in metal ore mining (Table 5):

- Flotation
- Gravity concentration
- Magnetic concentration
- Leaching methods

These methods can be used as stand-alone processing methods but often they are used in combination, for example, such that flotation is linked to some other method for processing concentrate, waste and intermediate products (e.g. Hukki 1962, Lukkarinen 1987).

Table 5. Concentration methods and recovery of valuable metals at metal ore mines operating in Finland.

Mine/production plant	Concentration method	Products	Total recovery %
Kemi mine	Gravity separation	Chrome concentrates (Cr_2O_3) Coarse concentrate (36% Cr_2O_3) Fine concentrate (44.2% Cr_2O_3)	75
Kittilä mine	Flotation, pressurised oxidisation, CN leaching and electrolysis	Doré bars (Au 92–95%)	84–88
Pyhäsalmi mine	Flotation	Cu concentrate (29% Cu)	95–96
		Zn concentrate (54% Zn)	92–93
		S concentrate (52% S)	approx. 50
Talvivaara mine	Bioleaching and chemical precipitation of metals	NiS (precipitate) ZnS (precipitate)	approx. 80
Vammala concentrating mill	Gravity separation and flotation	Au concentrate / flotation (150–200 g/t Au) Au concentrate / vibration table (approx. 80% Au)	80–85
Lahnaslampi mine	Flotation	Ni concentrate (8% Ni)	58

2.3.4.1

Flotation

By far the most common method used in the concentration of sulphide minerals is flotation, a process in which chemicals are added to the ore slurry both to modify the electrochemical conditions of the slurry and to alter the mineral surfaces to make the ore particles cling to air bubbles and rise with them to the surface of the slurry. This takes place in flotation cells in which the slurry is mixed and aerated, with the bubbles kept as small as possible (Figures 8 and 9). Frothing is carried out in several stages in order to ensure sufficient ore recovery and the purity of the final concentrate. For this reason, the flotation circuit must have a number of flotation cells of different sizes.

Flotation circuits and the slurry flows in them are designed and built case by case on the basis of the composition of the ore being processed. The chemicals required

Figure 8. Cu flotation circuit at the Pyhäsalmi mine. (Photo: Pyhäsalmi Mine Oy)

in flotation and the amounts needed also depend on the particular ore type. Occasionally successful flotation may require, in addition to or instead of the regulation of pH, regulation of the redox potential of the process. The composition of the ore also affects the metallurgical results achieved in processing. Table 6 brings together examples of the chemicals used in the flotation of sulphide ores. The use of chemicals in the concentrating process is dealt with in more detail in, among other sources, textbooks on concentration techniques (Hukki 1964, Lukkarinen 1987, Parekh & Miller 1999, Fuerstenan *et al*. 2007).

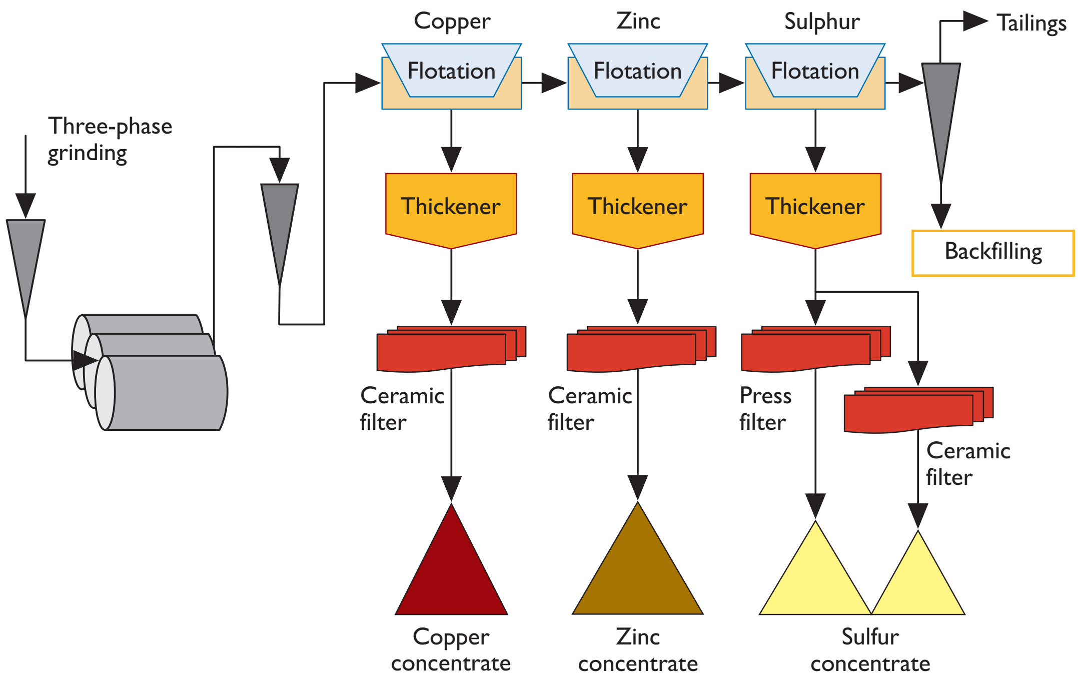

Figure 9. Example of the flotation circuit at the Pyhäsalmi mine.

Table 6. Examples of the most commonly used chemicals in the flotation of sulphide ores.

Chemical group	Example chemicals
Collector chemicals	Xanthates, chemical formula R-O-CS_2-Me, in which the hydrocarbon group is usually an ethyl, isopropyl, isobutyl or amyl groups and the metal group is Na or K
	Dithiophosphates, chemical formula $(RO)_2 = P = S_2$-M, e.g. Danafloat
	Dithiophosphinates, chemical formula e.g. Aerophine $(C_4H_9)_2$-P-(S)-S-Na
Foaming agents (surfactants)	Terpene compounds, which are obtained from the wood-processing industry as a by-product of the terpene distillation process (e.g. Sylvapine)
	Long-chain alcohols, e.g. Montanol
	Ethers, e.g. Dowfroth foaming agents such as polypropylene-glycol-methyl ethers $[CH_3\text{-}(OC_3H_6)_n\text{-}OH]$
pH regulators	Sulphuric acid (H_2SO_4)
	Lime either in the form of slaked lime $Ca(OH)_2$ or quicklime CaO
Regulators of redox	Sulphuric acid, which adjusts the potential in a positive direction (oxidation)
	Sodium sulphide, which adjusts the potential in a negative direction (reduction)
Activators	Copper sulphate, which is used to activate sphalerite and iron pyrites
Sinking agents	Zinc sulphate, which is used in particular to make zinc sink in copper flotation
	CMC, or carboxymethylcellulose, which is used to cause silicate minerals to sink in the flotation of sulphides
	Starch, which is used to make silicate minerals sink in the flotation of sulphides
	Na dichromate, which is used to make lead, for example, sink in copper-lead flotation. (Na dichromate is a strong and toxic oxidising chemical).
	Sodium cyanide, which is used for example to make zinc sink in copper flotation. Its use is based on its tendency to form complex compounds easily. In the production of gold concentrate, cyanide is used to leach gold. (Cyanide is an extremely toxic chemical).
Auxiliary agents	Flocculants, which are used as auxiliary agents in condensing and clarification (e.g. polyacrylamides)
	Antifoaming agents [defoamers], which are used to dissipate foam in pumps, for example
	Filtration agents (most common Al sulphate)

2.3.4.2
Gravity separation

Gravity separation exploits the difference in specific gravities between minerals, whereby it is suitable for use in the case of ores in which the specific gravity of the valuable mineral is substantially higher than that of the useless minerals. Examples of such ores are chrome and gold ores. Gravity separation may be used in the production of gold concentrate if metallic gold occurs in the ore in sufficiently large particles. A number of commercially available devices are readily available (e.g. spirals, cones, vibrating screening tables) which separate heavy particles from the slurry (Figure 10).

The traditional form of gravity separation is dense-medium separation in which pieces of ore are "set afloat" in a dense medium. The heavy pieces (valuable minerals) sink to the bottom and the lighter (waste rock minerals) float to the surface, where they are easy to separate. The most commonly used medium is a ferrosilicon suspension, whose specific gravity (slurry density) is regulated appropriately.

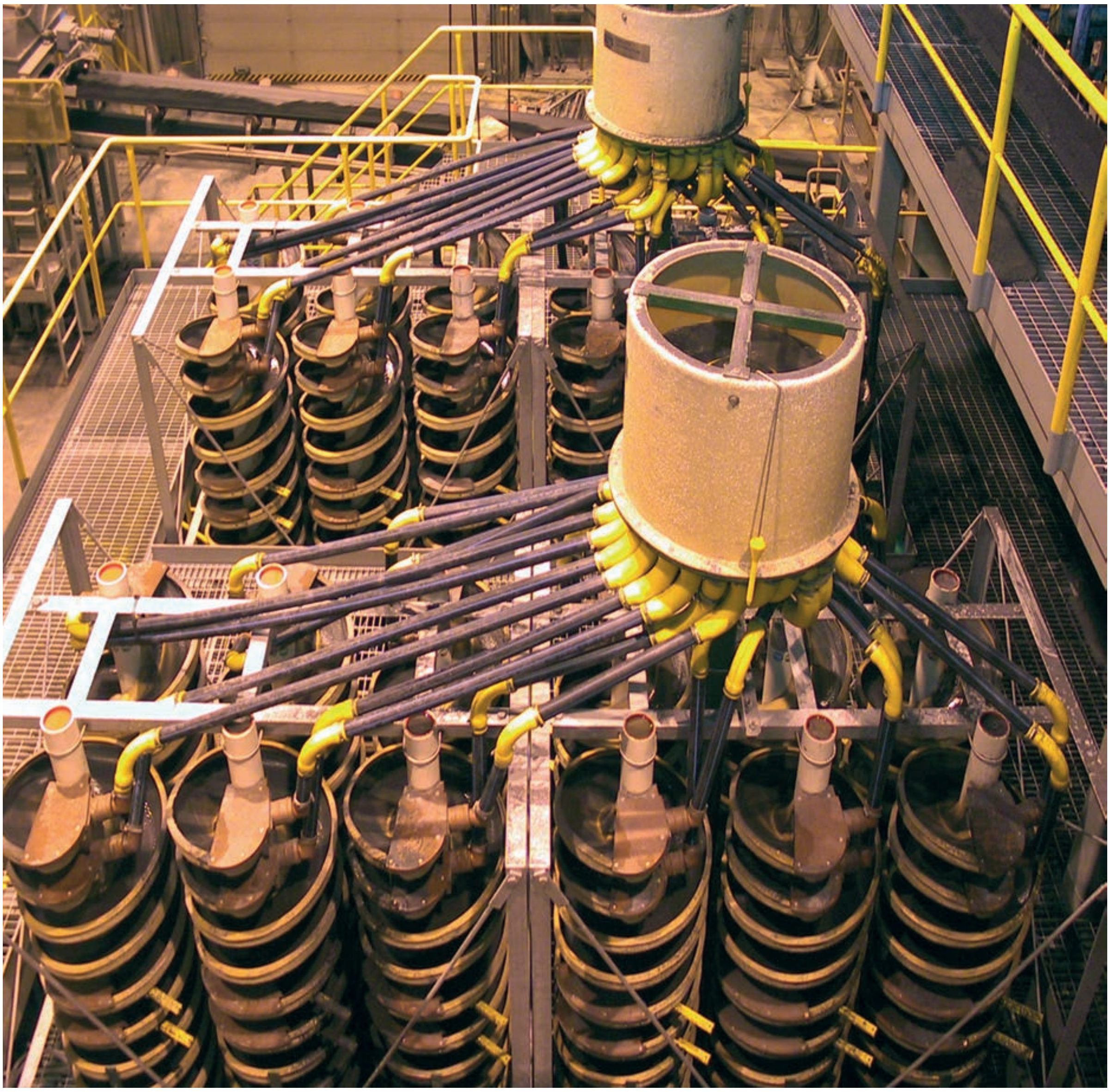

Figure 10. Spiral classifiers used in gravity separation at the Kemi mine. (Photo: Outokumpu Oy)

2.3.4.3
Leaching methods

Leaching is generally used for the processing of readily soluble ores or for ores to be concentrated that are mineralogically more difficult to process in other ways, for example, by flotation. In leaching, the valuable minerals are separated from the ore using various solvents, for example acids or cyanide. Cyanide is used to improve the recovery of valuable metals, for example in processing gold-bearing ores, as the cyanide solution is able to separate most of the gold that cannot be separated using gravity separation or flotation. (see Figure 11).

Leaching can, where appropriate, be enhanced using bacteria or leaching can be based solely on the action of bacteria (e.g. the bioleaching at Talvivaara). Following leaching, the valuable metals are precipitated from the solution chemically (e.g. by reducing it using H_2S) or electrochemically (electrolysis / electrowinning). Prior to the precipitation process, the solution is enriched by recirculating the leaching solution, by extraction/stripping or by extraction/absorption.

The leaching of metal ores is carried out in either vat or heap leaching. Vat leaching uses leaching reactors and/or autoclaves. Leaching reactors are tanks equipped with a mixer in which the ore is dissolved using chemicals and/or gases in a water slurry. Sometimes dissolution is enhanced by heating the reactor, for example, with steam. In autoclave leaching the reaction rate is raised by increasing the temperature of the solution to above its boiling point (positive pressure). Oxygen is added to the autoclave to oxidise the sulphide minerals. Before dissolution, the ore can be processed if necessary using other concentration methods, such as flotation (e.g. in the processing of gold concentrate the dissolution of sulphides before cyanide leaching, when the gold is bound to the sulphide minerals, Figure 11).

In heap leaching, a heap of ore is irrigated with a leaching chemical, which dissolves the valuable metals in the heap. The solution containing valuable metals is then collected in a collection system at the base of the heap. In Finland, heap leaching is used at the Talvivaara mine, where the metals are dissolved from the ore using bioleaching (heap leaching based on the catalysing action of bacteria). An impermeable base has been built under the heaps at Talvivaara using a bentonite mat, on top of which is a 2-mm thick HDPE geomembrane. The acidic liquid (dilute sulphuric acid) that percolates through the heap drains along the impermeable layer to a drainage layer, which channels the liquid into an array of pipes located underneath the heap and further on to collection ponds. From these the liquid is pumped on, either for recovery of metals or back into the leaching flow. Heap leaching is usually used for what are known as low-grade ores, that is, those with low precious metal concentrations.

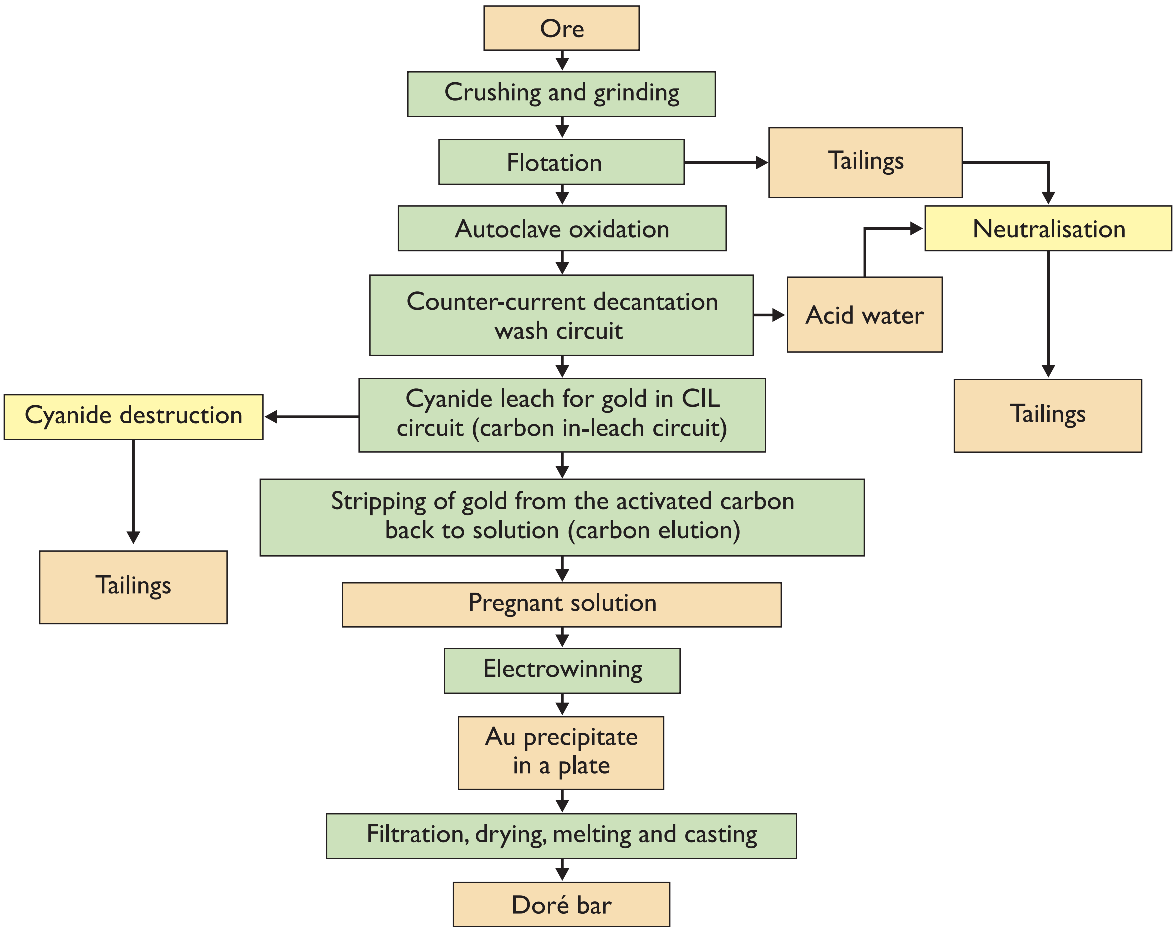

Figure 11. Leaching of gold-bearing ore at the Kittilä mine.

Figure 12. The Kittilä mine produces gold bars.
(Photo: Agnico-Eagle Mines Ltd.)

2.3.4.4
Magnetic separation

Magnetic separation is based on the different magnetic properties of minerals. Separation is performed either as wet separation from slurry or as dry separation. Magnetic separation is used most often in the processing of iron and chrome ores but where necessary it is applied as one component of the concentration process. In addition to concentration, magnetic separators can be used to remove scrap iron or iron slivers that hamper the process from conveyor belts, for example.

2.3.5
Drying, storage and transportation of concentrate

The concentrates that form the end-product of the concentration process at metal ore mines generally consist of dry, finely ground mineral material that contains precious metals. Gold mines may also produce doré bars. (Figure 12)

Before being stored, concentrates are dried using drum, disc or compressed air filters. Filtration makes it possible to reduce the moisture content to some 10%, which is sufficient for storage and transportation. Thermal drying is also an option.

The concentrates produced in the process are stored at the mine site until they can be transported to clients for further processing. The concentrates are stored in heaps either in covered storage buildings, outdoors, or in locked indoor locations (e.g. doré bars and uranium concentrate, which is packed in barrels and stored in locked transportation containers) (Table 7) Storage in heaps indoors reduces loss of concentrate through the formation of dust, sludge or leaching. Concentrates stored outdoors without a protective shelter are usually ones having comparatively little value.

The size of the storage facility depends on how the concentrate is to be transported and the timing of the transportation, which are also affected by the client's needs and receiving system of the concentrate. Concentrate is most often transported by rail if the distance is long or the quantities are large (Figure 13). Smaller quantities are transported by truck.

In the international shipping of concentrate, constraints of the loading schedules of ships require that concentrate be stored temporarily at the harbour, particularly where bulk shipments are involved. In the case of container shipments, storage at harbours is generally not essential.

Table 7. Storage of concentrate and transportation methods at the metal ore mines operating in Finland.

Mine/production plant	Product	Storage	Mode of transportation
Kemi mine	Cr concentrate	Storage halls and outside where necessary	Truck to the FeCr plant
Pyhäsalmi mine	Cu concentrate	Storage hall	Train in covered cars
	Zn concentrate	Storage hall	Train in open cars, dust binding using lignobond
	Pyrite concentrate	Open field, concentrates for export in harbour storage buildings	Train in open cars, dust binding using lignobond; concentrates for export transported further by ship
Talvivaara mine	Ni precipitate	Concentrates packed in tanks	Train to client's premises
	Zn precipitate		
Vammala concentrating mill	Au concentrate	Storage hall	Truck, covered
			Concentrates for export transported by ship in containers packed in IBCs
Lahnaslampi mine	Talc concentrate	Storage hall	Train, covered

Figure 13. Loading concentrate onto a train at the Pyhäsalmi mine. (Photo Pyhäsalmi Mine Oy)

2.3.6

Energy consumption and energy efficiency

Mining operations generally require large quantities of electricity and fuels. The energy consumption per ton of ore at a mine varies from 12 to 25 kWh and at a concentrating plant from 30 to 50 kWh (Hakapää and Lappalainen 2009). Other electricity needs consume an additional 2 to 4 kWh per ton of ore.

The electrical equipment used in production can be divided into the following categories (for additional information, see Hakapää and Lappalainen 2009)

- equipment for the transmission and distribution of electricity: power lines, transformers and cables
- equipment operating by electricity: electric motors, lighting, hand tools
- control, monitoring, communication and automation equipment.

The amount of energy consumed in concentrating ore depends primarily on the quantity of ore being processed and the processes and equipment used in concentrating. As a rule, the grinding of ore requires the highest-capacity motors, particularly when the ore is concentrated using flotation. For example, the motors powering the grinding mills at the Kevitsa Mine have a rating of some 7 MW. The crushing, screening and flotation phases in the processing of ore also consume a great deal of energy, but the capacity of the individual electrical motors or pumps used is an order of magnitude smaller. Flotation can consume a great deal of energy if the flotation circuit is complex and incorporates numerous machines and pieces of equipment. Table 8 brings together examples of the energy consumption at metal ore mines in Finland.

Table 8. Examples of total energy consumption at the metal ore mines in Finland, as well as the consumption per ton of ore, for 2009.

Mine/production plant	Total energy consumption MWh/a	Energy consumption / ton of ore kWh/t
Kemi mine[1)] (includes fuels)	57,629	43.5
Kittilä mine (electricity only)	104,640	
Pyhäsalmi mine (includes fuels)	88,814	63.6
Talvivaara mine	Electricity: 111,000	
	Heating: 37,200	
Vammala concentrating mill (not including energy used in excavation or fuels)	6,000	30

[1)] data from 2008, because the mine experienced a long break in production in 2009

The choice of electrical motors used is made after weighing the costs of the capital required and durability and efficiency of the motors. In mining, where motors tend to be powerful and large and the hours of use per year high, it is crucial to choose motors with the highest possible level of energy efficiency. The higher price of such motors will normally be fully offset by lower energy costs over the space of one to two years. IEC 60034-40 defines the new energy efficiency classification for three-phase 50 Hz cage induction motors. The new classification replaces the older EFF1, EFF2 and EFF3 classes. Table 9 describes the efficiency classes of electrical motors.

Pumps used in the concentration process also consume significant amounts of energy. In order to achieve a high level of efficiency, pumps are sized and chosen to fall on the most applicable and most efficient point on the performance curve. Energy efficiency can be improved by using equipment with constant speed and a frequency converter.

Frequency converters are used to regulate the speed of pumps and to start conveyors. They adjust the speed at which the equipment operates and improve energy efficiency if compared to the use of oversized motors operating at full speed with

Table 9. Efficiency classes of electrical motors.

Efficiency classes	Description	Corresponding classes	Notes
IE1	Standard efficiency	EFF2	As of the beginning of 2011 all industrial electrical motors must be in at least class IE2
IE2	High efficiency	EFF1	Beginning in 2015, EFF2 class motors may be installed only if they are controlled by an appropriate frequency converter.
IE3	Premium efficiency	NEMA Premium	Beginning in 2015 and 2017, only IE3 or motors in the super premium efficiency class can be sold in Europe for motors rated in the range 7.5–375kW
IE4	Super Premium Efficiency		Not produced commercially

inferior mechanical efficiency. Frequency converters ensure the efficient use of pumps, mills and other equipment.

In excavation and in the movement of ore, electricity is needed for the following purposes (for additional information, see Hakapää and Lappalainen 2009):

- electro-hydraulic tools (e.g. drilling, bolting and concrete-spraying machines)
- conveyor belts
- ore hoists
- producing compressed air, and
- ventilation.

In addition, loading, transportation vehicles and, where necessary, the heating of parts of the mine require fuels.

By way of comparison, the energy needed in mining at the Pyhäsalmi mine, for example, corresponds to the electricity consumption of a community of 10,000 people. In comparisons of energy consumption between mining works and cities and towns, however, it should be pointed out that the latter also use energy for heating that is produced using means other than electricity.

2.3.7
Water consumption

Mining operations require large quantities of water, for example, for the following purposes:

- drilling water
- process water (grinding and concentration in water slurry)
- sealing water (pumps, suction devices, etc.)
- manufacturing of chemicals
- rinse water (e.g. for rinsing equipment and floors)
- cleaning water (e.g. cleaning filter cloth), and
- tap water (drinking water, etc.).

Most of the need for water can be addressed by recycling water from the different phases of the process, but operations often also require sufficient amounts of fresh water. The potential for recycling is process-specific and depends on, among other things, the chemicals used (Table10). Recycling increases the concentrations of substances in the water, which can result in their rising to levels that are detrimental to the concentration process and prevent the use of the water.

Fresh water is typically drawn from a nearby lake or river (Table 10). In some cases, the mine dewatering water can be used as fresh water, either as is or after processing (e.g. settling of solid matter, precipitation of metals). In most concentrating plants, the water needed can be supplied almost wholly through recycling of water or the use of dewatering water. Sometimes the large-scale extraction of fresh water from outside of the mine workings is not possible in practice. The tap water needed at a mine is generally bought separately from an external supplier. In some processes (e.g. the washing of filtration fabrics and the cooling of compressors) water can be used that has been purified using the mining works' own purification equipment (e.g. sand filters). Figure 14 presents a general diagram of the traditional circulation of water at a mining works.

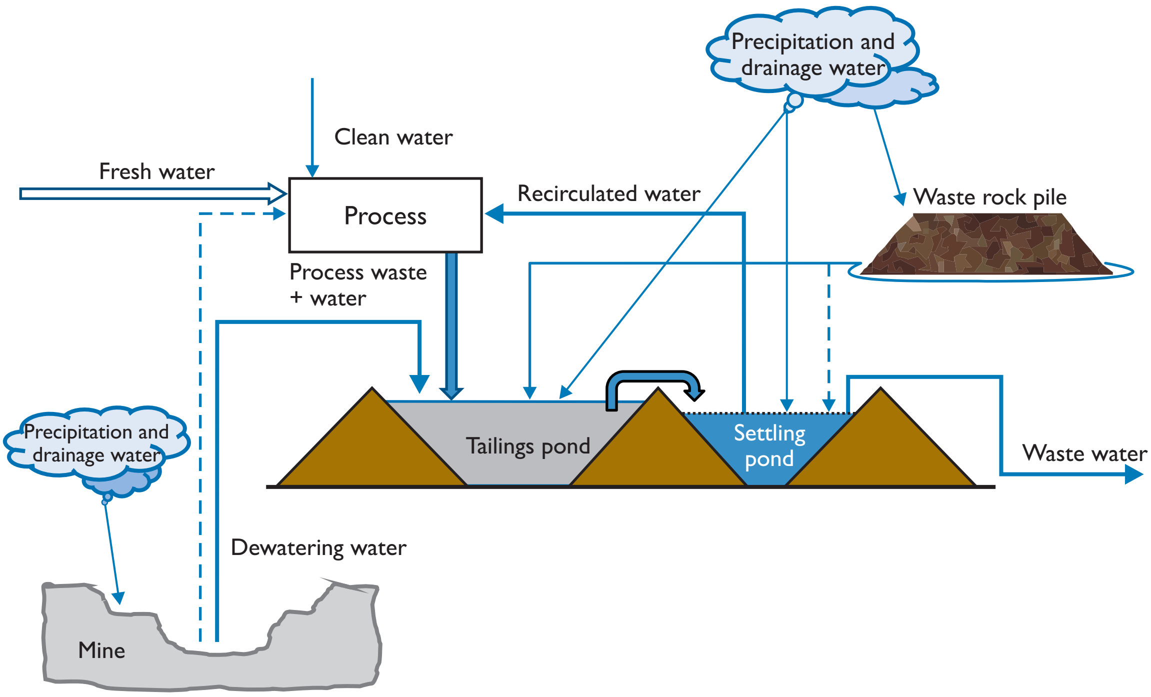

Figure 14. Example of the traditional pattern of water use at a mine (fresh water = surface water taken from a nearby natural source. Clean water = tap water).

Table 10. Use and recycling of water: examples of metal ore mines in Finland in 2009.

Mine/production plant	Water intake m^3/a	Source of fresh water	Sources of recycled water	Recycling %
Kemi mine[1)]	2,546,900	Settling pond	Settling pond	98
Kittilä mine	approx. 1,000,000	Seurujoki River	Tailings pond	65–70
Pyhäsalmi mine	4,970,000	Lake Pyhäjärvi	Overflow from the process thickener	18
Talvivaara mine	1,360,000	Lake Kolmisoppijärvi (located within the mining concession)	Dewatering water from the mine, water from gypsum precipitate ponds	10–20
Vammala concentrating mill	1,200,000	Recirculated water	Tailings pond, old Ni mine	100
Lahnaslampi mine	800,000	Dewatering water from the mine	Dewatering water from the mine, tailings pond	over 90

[1)] data from 2008, because the mine experienced a long break in production in 2009

2.3.8
Consumption of supplies

Production at mines requires not only energy and water but a range of other materials and supplies as well, such as chemicals, grinding elements, filtration fabrics, and the like. The consumption of supplies depends on the particular process being used (cf. Tables 5 and 11).

Table 11. Examples of the most important supplies at metal ore mines in Finland.

Mine/production plant	Supplies/chemicals
Kemi mine	Ferrosilicon, grinding balls, grinding rods, flocculants
Kittilä mine	Cu sulphate, sodium cyanide, K amyl xanthate, nitric acid, MIBC (foaming agent), lye (NaOH, 50%), Aerophine 3418, Na metabisulphate, active charcoal, lime, grinding balls 125 mm, grinding balls 100 mm
Pyhäsalmi mine	Na isobutyl xanthates, slaked lime, Zn sulphate, Cu sulphate, sulphuric acid, Sylvapine (foaming agent), Na cyanide, nitric acid (washing of filters), acetic acid (washing of filters), grinding balls
Talvivaara mine	Sulphuric acid, sulphur, Caustic soda (lye), liquid nitrogen, lime (quicklime and limestone), chalk, propane, flocculants
Vammala concentrating mill	Na isobutyl xanthates, Aerophine 3418A, Danafloat 245, Flopam AN 905 SH (flocculants), Dowfroth (foaming agent), grinding balls, grinding rods
Lahnaslampi mine	Na ethyl xanthate, Montanol (foaming agent), copper sulphate, aluminium sulphate, CMC

2.4
Mine closure and rehabilitation

Decommissioning of a mining works and rehabilitation of the site become topical when the commercially exploitable ore runs out or when mining operations at the site are terminated permanently. Under the current mining legislation, operations are deemed to have ceased when the mining permit expires or is revoked (Mining Act 621/2011). However, according to the Environmental Protection Act (EPA), the operator of the mine has the responsibility even after the cessation of operations to implement the measures required, in the manner prescribed by the permit conditions, to prevent contamination of the environment, to ascertain the environmental impact of the operations and to monitor the site for the period prescribed in the permit (EPA §90). If parts of the mining works or its auxiliary area are relinquished prior to closure, closure and rehabilitation measures are carried out for these areas at the time.

The principal aim in mine closure is to restore the mining works to a condition where they pose no detriment to human health or the environment. The closure plans must also take into account the need to use the area again. Normally, when operations cease, all unnecessary infrastructure at the mine site is removed and steps are taken to ensure that the remaining structures will not pose risks or cause harm to the natural environment and human health or form an obstacle to future use of the site. Depending on the particular case, what remain in the area of a closed mine are rehabilitated storage areas for tailings and waste rock and the mined out spaces. If the buildings in the area are sound and possibilities for their continued use are found, then the infrastructure associated with them may be preserved as well. On the other hand, when a mine is closed, attention should be paid to ensuring opportunities for the future exploitation of any valuable materials remaining in the ore deposit and/or the continued use of buildings and waste areas with a view to the needs of future mining activities. To this end, prior to closing a mine, a map of the mine (decision of the Ministry of Trade and Industry, KTMp 1218/1995) is created that reflects the area at closure and also shows the support structures built as part of the closure process (Heikkinen *et al.* 2005).

The planning of closure is begun at an early stage in the life-cycle of a mine. The first plans for closure and for the related rehabilitation measures are to be made already during planning of the mining activities and feasibility study or, at the latest, when the permit application is submitted. At that point, preliminary plans already exist for the scope of the activities, technical solutions and location of operations, and tentative plans for closure can be drawn up. This way the closure costs can be taken into account in determining the overall costs of the mine. Early planning also helps to reduce potentially detrimental environmental impacts from the activities. This practice promotes the efficient use of materials and cost-effective implementation of closure measures. Legislation requires that an account be provided of the closure and of rehabilitation measures when a mining permit and an environmental permit are sought for mining activities.

During operations, the closure plan is updated regularly to reflect current activities and the conditions of the permits granted. The final closure plan is presented to the authorities for approval in the closing phase of mining activities, some six months to one year before implementation of closure measures.

A closure plan contains measures pertaining to all of the operations at the mine site. The measures are partly mine-specific and depend on factors such as the type of ore and the size of the mine. Often some of the closure measures can be carried out in stages while the mine is still operating. Table 12 brings together examples of the operations to be taken into account in mine closure and the related closure measures. In addition, the measures related to mine closure, the aims of the measures and the studies to be used in planning closure are described in the Mine Closure Handbook (Heikkinen *et al.* 2008). Table 13 presents examples of metal ore mines in Finland that have been closed and the closure measures implemented at them.

After a mine site has been closed, monitoring is used to ensure that the measures carried out, the structures and, for example, water treatment and drainage systems are working as planned and that the aims of closure are being met. Monitoring following closure may include the following:

- geotechnical and visual monitoring of structures remaining in the area and mined out areas,
- filling in of mined out areas and monitoring of the quality of water forming in these,
- monitoring of the quantity and quality of water forming and flowing in the area (in particular the waste storage area),
- monitoring of the functionality of the water treatment systems, and
- monitoring of how successful the revegetation and landscaping of mined out areas, built areas (concentrating plant, loading areas, roads) and the waste storage areas have been.

The obligations to monitor the state of the environment are set out in the environmental permit (EPA §46). The date until which monitoring must be conducted is generally determined by how long the activities on the site will cause impacts.

Table 12. Examples of required mine closure measures.

Location	Closure and rehabilitation measures
Open pit	Shaping, stabilisation and revegetation of embankments
	Measures to reinforce vertical and steep rock faces and modification to gentler slopes where a danger of collapse exists
	Fencing off of the open pit to prevent access by unauthorised persons; restrictions on construction
	Closure of roads leading to the pit
	Termination of dewatering; filling of the pit with water, with collection and treatment of the water if necessary
Underground mine	Removal from the mine of waste and other materials, machinery and equipment, that pose a risk of polluting groundwater
	Supporting and filling of mined out spaces to prevent collapse
	Preservation of structures built to improve safety at the mine
	Closure of declines leading into the mine, ventilation shafts, and roads to prevent entry of unauthorised persons
	Measures to reinforce the soil surface and landscaping
	Delineating and fencing off of areas where a danger of collapse or subsidence exists
	Termination of dewatering and filling of the mine with water; collection and treatment of water in the mine and overflow from it
Waste rock heaps	Possible use in backfilling and stabilising the mine or pit / terminal storage in mined out areas
	Stabilisation and shaping, covering and revegetation of heaps remaining on the surface; possible restrictions on the use of the area
	Collection and treatment of seepage waters and run-off
Tailings area	Possible use in backfilling and stabilising the mine
	Emptying of settling ponds
	Dismantling of structures not needed for terminal storage (e.g. settling pond dams)
	Stabilisation, shaping, covering and revegetation of the remaining area
	Possible restrictions on the use of the area
	Collection and treatment of run-off and seepage waters
Removed top soil and overburden	Usage in landscaping the mine site
Concentration plant and other buildings, maintenance areas and infrastructure	Pulling down of unnecessary and rundown structures and buildings
	Sorting, recycling, sale of materials from demolished buildings and/or transportation of them for terminal storage
	Cleaning and sale of buildings which are serviceable
	Transportation of waste materials for terminal storage
Machinery and equipment	Assessment of opportunities for further productive use
	Sale or recycling of machinery and materials that are still in good condition
Soil at the mine site	Assessment of pollution and need for restoration
	Restoration if necessary
Water at the mine site	Collection of poor-quality water using drainage ditches
	Treatment using active and/or passive methods

Table 13. Examples of closed metal ore mines in Finland. (Sources: Kuusisto 1991, Puustinen 2003)

Mine site	Years of operation	Valuable substances mined	Mined tonnage (Mt)	Rehabilitation measures
Aijala, Metsä-monttu	1949–1958	Cu, Zn;	0.9	Mine shafts fenced off.
	1952–1974	Cu, Zn, Pb, Fe, Ag	1.7	Tailings area in Aijala partially lightly covered with topsoil and vegetation has grown back naturally in the covered areas.
Keretti	1913–1989	Cu, Zn, Co, Ni, Zn, Au	34.9	Some mine buildings have been converted for use as museums or are now listed buildings. Tailings area covered and revegetated.
				Part of the tailings area has been converted into a golf course.
				Wetland is used for tailings seepage water treatment.
Kotalahti	1959–1987	Ni, Cu	13.7	Area partly fenced off with prohibition signs. Buildings at the mine site taken back into use.
				Rehabilitation measures are currently under way in the area.
Luikonlahti[1)]	1968–1983	Cu, Zn, Ni, Co, S	10.0	The mine site has been landscaped.
	1979–2006	Talc, Ni		Waste rock heaps have been shaped, covered with soil, and landscaped.
				The water from the tailings and mine site is being treated by discharging it onto wetlands. (The reuse of the tailings facility started in 2012.)
Otanmäki	1953–1985	Fe, Ti, V	33.0	Some of the mine buildings are being used as a train car manufacturing plant.
				Settling pond is being used as a bird pond. Most of the tailings area is uncovered.
Paroistenjärvi	1943–1966	Cu, W, As	4.2	The mine site is being used by a research facility belonging to the Finnish Defence Forces.
				Part of the second tailings area, as well as the open pit and mined out underground spaces, are covered with water (they are under Lake Paroistenjärvi).
Paukkajan-vaara[2)]	1958–1961	U	0.03	The infrastructure has been dismantled. Prohibition signs have been put up in the area and the area has been partially fenced off. The waste rock and tailings areas have been covered with soil and landscaped.
Vihanti	1951–1991	Zn, Cu, Pb, Ag	30.8	Some of the buildings at the mine site are being used again.
				The tailings area has been covered with a peat layer and landscaped. The water in the tailings area is being treated in wetlands.
				Tailings area now used as a recreational area.

[1)] The concentration plant and tailings area at the Luikonlahti mine site are being used by the new owner of the area.
[2)] Pilot mining and pilot concentrating only.

3 Mining Legislation

Starting and carrying on mining activities require several administrative permit procedures or comparable procedures (Figure 15). Exploitation of mining minerals requires a mining permit and exploration an ore prospecting permit as described in the Mining Act (621/2011). A mine, concentrating plant and mine waste area must also have an environmental permit issued pursuant to the Environmental Protection Act (86/2000). Activities in a mining project that have an impact on waters and groundwater require a permit as described in the Water Act (587/2011). Best practices in metal ore mining play a central role when decisions are made regarding environmental and water permits (Table 14).

Building a mining area often requires the drawing up of plans as described in the Land Use and Building Act (132/1999) and, in practice, always requires the obtaining of building permits (Figure 15). The use and storage of chemicals and explosives in a mine area are regulated by the Chemicals Act (744/1989) and the Act on safety in the handling of hazardous chemicals and explosives. Derogations from the provisions on protected animal and plant species require a permit as described in the Nature Conservation Act (1096/1996) (Table 14).

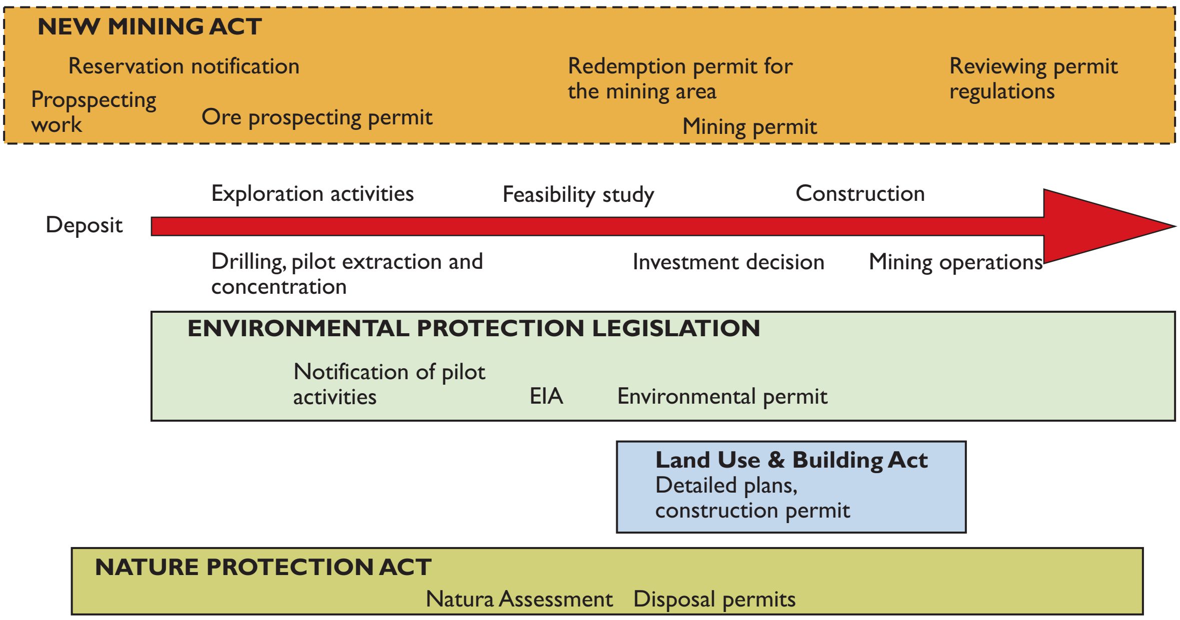

Figure 15. Diagram of the administrative permit and reporting procedures associated with mining activities.

Table 14. Principal acts and decrees relating to environmental protection in mining projects.

Act, decree or decision	Number	Focal mining emissions and operations
Mining Act*	621/2011	provisions on prospecting for and exploitation of mining minerals
Environmental Protection Act	86/2000	general act to prevent pollution
Environmental Protection Decree	169/2000	
Act on Environmental Impact Assessment Procedure	468/1994	EIA Act
Decree on Environmental Impact Assessment Procedure	713/2006	
Nature Conservation Act	1096/1996	conservation provisions on the use of areas
Nature Conservation Decree	160/1997	conservation provisions on the use of areas
Water Act	587/2011	construction on water systems, abstraction of water, impacts of construction on groundwater and water systems
Act on Water Resources Management	1299/2004	impacts of construction on water systems
Dam Safety Act	494/2009	requirements pertaining to watercourse dams and waste dams
Government Decree on Substances Dangerous and Harmful to the Aquatic Environment, 2010 amendment	1022/2006 868/2010	emissions into water systems (includes the environmental standard for nickel)
Government Decree on Urban Waste Water Treatment	888/2006	emissions into water systems (domestic waste water)
Government Decree on environmental protection for quarries, other quarrying and stone crushing plants	800/2010	requirements relating to the key emissions in the activities mentioned
Government Decree on Air Quality	711/2001	emissions into the air
Government Decree on airborne arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons	164/2007	emissions into the air
Government Decree on the environmental protection requirements for production units with a fuel power of less than 50MW	445/2010	energy production units
Government Decree on the sulphur content of heavy fuel oil, light fuel oil, and marine gas oil	689/2006	emissions into the air
Government Decision on the guideline values for air quality and the target values for sulphur deposition	480/1996	emissions into the air
Government Decree on the environmental protection requirements for stations distributing liquid fuels	444/2010	requirements for fuel distribution stations with regard to key emissions
Government Decision on guideline values for noise	993/1992	noise emissions
Government Decree on the Assessment of Soil Contamination and Remediation Needs	214/2007	emissions into the soil, exploitation of rock material and mining wastes
Waste Act	646/2011	wastes
Waste Decree	1390/1993	wastes
Government Decree on Mining Wastes	379/2008	mining wastes
Government Decree on amending the Decree on Mining Wastes	717/2009	mining wastes (annexes)
Government Decision on oil waste management	101/1997	wastes
Government Decision on construction waste	295/1997	wastes
Government Decision on landfills	861/1997	wastes
Council of State Decision on information to be provided on hazardous waste and on the packing and labelling of hazardous waste	659/1996	wastes
Ministry of the Environment Decree on the list of the most common wastes and of hazardous wastes	1129/2001	wastes
Decree on the industrial handling and storage of dangerous chemicals	59/1999	chemicals
Government Decree on safety of blasting and excavation operations	644/2011	explosives
Act on safe handling of dangerous chemicals and explosives	390/2005	chemicals and explosives

* The decrees currently being drafted in association with the Mining Act are the Mining Decree, the Decree on Mine Safety and the Decree on Mining Hoist Stations

3.1
Permits and procedures set out in the Mining Act

The new Mining Act (621/2011) came into force on 1 July 2011, replacing the old Act (503/1965). The new Act lays down provisions on prospecting for and exploiting deposits containing mining minerals, on gold-panning in state-owned areas, on the cessation of these activities and on the procedures for establishing a mining area.

The Mining Act defines the mining minerals which fall within the scope of the Act and whose finder has priority in exploiting them. The scope of mining legislation includes minerals and rock types, deposits of which are rare and random and which accordingly require professional ore prospecting and the assumption of a substantial financial risk. The bases for the list of mining minerals include the technical and economic feasibility of exploiting the deposit and geologically justifiable assumptions regarding the types of mining minerals that might occur in Finland. The holder of a mining permit may also exploit by-products produced in the course of mining activities, as well as other materials lying in the bedrock or soil of the mining area to the extent that their use is necessary for mining activities in the mining area. In other instances, the Land Extraction Act is applied to the extraction of stone, gravel, sand, clay and earth.

3.1.1
Ore prospecting

Every person has the right to make geological measurements and observations to locate mining minerals even on another person's land and to take small samples if these actions cause no damage or any but minor inconvenience or disturbance (prospecting work). The provision of the Mining Act on prospecting work provides somewhat more extensive rights than everyman's right and general rights of use. Everyman's right does not extend to taking materials from the ground, which is possible in the case of prospecting.

The Mining Act specifies the areas in which prospecting on the surface is in principle prohibited. These include cemeteries and private graves, areas used by the Finnish Defence Forces, as well as traffic routes or thoroughfares in public use. Prospecting may also not be carried out closer than 150 metres to a building used as a dwelling, a work site or a private yard. Prospecting is prohibited in an area used for horticulture and less than 50 metres closer to a public building or facility. In locations other than cemeteries or areas with private graves, prospecting may be carried out with a permit from the competent authority or institution or from the holder of the relevant right.

A permit from the mining authority is required for prospecting (prospecting permit) under the following conditions:

- if ore prospecting cannot be carried out as prospecting work or the landowner has not given his or her consent;
- if prospecting might be detrimental to human health, public safety or other commercial activity or detract from landscape or conservation values;
- if prospecting is focused on locating and investigating a deposit containing uranium or thorium;
- one needs/wants priority in exploiting the deposit.

Ore prospecting is subject to the same restrictions regarding location as prospecting work. Additionally, ore prospecting requires a permit from the competent authority or institution, or the consent of the holder of the relevant right when it involves:

- a street area or marketplace as defined in the Land Use and Building Act;
- a highway area as defined in the Highways Act;
- an aerodrome or other site used for aviation as defined in the Aviation Act;

- a railway area as defined in the Railway Act;
- a canal or similar thoroughfare used for public transportation;
- or an area located less than 30 metres from the traffic areas mentioned unless the act cited or other act provides for or is the basis for an order establishing a broader protected zone.

A prospecting permit entitles its holder to explore the structures and composition of geological formations on the holder's own or another person's land within the prospecting area defined in the permit. The holder of the permit may carry out other studies in anticipation of initiating mining activities, as well as other prospecting to locate a deposit and to ascertain its quality, extent and exploitability in accordance with the detailed conditions set out in the permit. The holder of a prospecting permit may build in or bring into the prospecting area temporary structures and equipment necessary for exploration work in accordance with the detailed conditions set out in the permit. A prospecting permit does not entitle the holder to exploit a deposit.

The holder of a prospecting permit is to restrict prospecting and other use of the prospecting area to measures essential for exploration. The measures are to be planned such that they do not cause infringement of public or private interests that can be reasonably avoided. Prospecting and other use of the prospecting area that takes place pursuant to a prospecting permit may not be detrimental to human health, endanger public safety or cause substantial detriment to other commercial activity, significant changes in nature, substantial damage to rare or valuable natural deposits or serious harm to the landscape.

A prospecting permit corresponds essentially to what was known as a claim right under the old Mining Act. The size of the prospecting area is not restricted. According to the old Mining Act a claim could be at most one square kilometre in size.

A prospecting permit is in force for at most four years after the decision granting it has become legally valid. The validity of a permit can be extended for at most three years at a time but its total validity may not exceed fifteen years. According to the old Mining Act, the maximum duration of a claim was eight years. A prospecting permit expires when the period of its validity ends. A mining authority may decide that a permit expires if the activity has been suspended continuously for at least one year for a reason dependent of the permit holder. The permit holder has an obligation to file an application requesting that a permit be voided if the permit holder no longer intends to carry on the activities for which the permit was granted.

The holder of a prospecting permit must pay annual compensation for prospecting to the owners of the properties in the prospecting area. The size of the payment per property is 20 euros per hectare for the first four years during which the permit is valid; 30 euros per hectare for the fifth, sixth and seventh years; 40 euros for the eighth, ninth and tenth years; and 50 euros per hectare for the eleventh and any subsequent years.

The permit holder must post collateral to compensate for any damage or detriment its activities cause and to cover any after-care measures, except where this is considered unnecessary in light of the nature and scope of the activity, the special characteristics of the area, the terms of the permit for the activity or the stable financial situation of the permit holder. The permit-granting authority determines the type and size of collateral to be posted.

3.1.2

Reservation

By way of preparation of the application for a prospecting permit, the applicant may reserve the area for itself by notifying the mining authority accordingly (notice of reservation). The notice may not apply to an area belonging to a prospecting area, a mining area or a gold-panning area, nor may it be located less than one kilometre from such areas where, on the basis of a permit as specified in the Mining Act, they belong to a party other than the applicant. The notice of reservation may also not apply to an area that has previously been the object of a reservation unless a year has elapsed since the expiry or rescission of the decision to grant that reservation.

The reservation decision will be in force for at most two years from when the notification is made (according to the old Mining Act, the validity was at most one year following the reservation notification). In making its decision on the period of validity of a reservation decision, the mining authority must take into account in particular the time required for drawing up an exploration plan and for carrying out the other measures required for the application for a prospecting licence. The reservation decision expires when the specified validity ends. The decision also expires when the priority it accords the recipient has been used to apply for a prospecting permit in the manner prescribed in the Mining Act. In addition, the mining authority must decide that the permit will cease to be valid if the party making a reservation files a written notice with the authority to this effect.

3.1.3
Mining activities

Establishment a mine and carrying on mining activities require a mining permit. The permit entitles the holder to exploit the extractable minerals found in the mine area, the organic and inorganic surface material produced as a by-product of mining activities, excess rock, and tailings, as well as other substances in the bedrock and soil of the mine area to the extent that their use is necessary for mining activities there. A mining permit also entitles the holder to conduct ore prospecting in the mining area.

The holder of a mining permit has an obligation to see to it that mining activities cause no detriment to human health, danger to public safety, substantial detriment to a public or private interest, or a violation of a public or private interest that in light of the overall costs of the mining activities could be reasonably avoided. The permit holder may not excavate and exploit extractable minerals in a manner that would constitute an obvious waste of mining minerals. The permit holder must also see to it that the possible future use of or excavation work at the mine and the deposit will not be jeopardised or hampered.

The mining area must be a coherent area and in size and shape it should be such that it meets the requirements pertaining to safety, the location of mining activities, and mining technology. The area may not be larger than the mining activities requires in light of the quality and extent of the deposit. An area immediately adjacent to the mine and essential to mining activities can be designated as an auxiliary area where this area is necessary for roads, transportation equipment, power and water lines, drainage systems, water treatment or a transportation route to be dug to a sufficient depth below the surface. The location of a mine and the auxiliary area must be planned such that they do not infringe a public or private interest that in light of the overall costs of the mining activities could be reasonably avoided.

The mine operator may acquire ownership or right to use of an area needed for mining activities through a contract or by applying to the government for a permit to redeem the mine area. A redemption permit can be granted if the mine project is required by the public interest. This requirement can be examined with special reference to its impact on the local and regional economy and employment and its necessity in light of the provision of raw materials for society at large. The redemption of rights to use areas and of other special rights takes place in the proceedings to establish the mine area, for which the regional office of the National Land Survey of Finland is the competent authority. According to the old Mining Act, the holder of a mining right had a direct right under the law to use the mining area. The mining permit may grant a limited right to use or other right with respect to the auxiliary area. The right may only be granted insofar as the placement of the functions planned in the area cannot otherwise be arranged satisfactorily and at reasonable cost.

A condition for granting a mining permit is that the deposit is exploitable in size, ore content and technical characteristics. The size of and content of a deposit may be considered sufficient if the revenues to be earned from exploiting it cover the operational costs and ensure the requisite return on the capital invested. The most important technical characteristics to be assessed are those relating to excavation and ore processing.

A mining permit cannot be granted if there are weighty grounds to suspect, for reasons that emerge in the processing of the application, that the applicant does not fulfil the requirements or clearly has no intention to undertake mining activities, or if the applicant has previously substantially neglected obligations based on the Mining Act. The assessment of the seriousness of the neglect must take into account the deliberate nature of the acts of neglect, their duration and recurrence, as well as the amount of damage caused by them. A permit can also not be granted if the mining activities pose a danger to public safety, cause substantial environmental impacts or significantly weaken the living and business conditions of the community or where the danger cited or the impacts cannot be eliminated through permit conditions.

A mining permit is in force until further notice. The conditions of such a permit are reviewed every ten years at the least. A permit may also be granted for a fixed period for a well-justified reason. A fixed-tern mining permit can be in force for at most ten years from the date on which the decision by which it is granted becomes legally valid. The validity of a permit granted for a fixed term may be extended such that it is valid until further notice or for at most ten years at a time.

A mining permit expires when the limit of its validity ends. The permit authority is to decide that a permit expires if the permit-holder has not begun mining activities within the period specified in the permit or undertaken preparatory work showing that it seriously intends to establish mining activities. The permit authority must also decide that the permit has expired if mining activities have been suspended for a reason under the control of the permit holder for a continuous period of at least five years or if mining activities can be considered as having ceased for all intents and purposes. The permit authority can, however, at most twice, postpone expiry of the permit and set a new date for commencement of mining activities or for resumption of activities. Expiry of the permit may be postponed for at most a total of ten years. In addition, the permit authority must decide that the permit has expired if the mining area does not belong to the permit holder, if the permit holder has not acquired possession of it within five years of the permit being granted, or if the permit holder files an application for cancellation. The permit holder has an obligation to file an application if it no longer intends to engage in mining activities.

The permit holder must pay owners of properties belonging to the mine area annual compensation for excavation. The size of this compensation per property is 50 euros per hectare. In addition, in the case of metal ore mines, permit holders are to pay compensation for excavation in the amount of 0.15 per cent of the calculated value of the exploited minerals in the metal ore excavated and exploited. The factors to be taken into account in calculating this value are the average price of the exploited metals in the ore over the course of the year as well as the average value for the year of the other valuable products extracted from the ore.

The holder of a mining permit must post collateral for the measures associated with the closure and after-care of the mine. The collateral must be sufficient in light of the nature and extent of the mining activities, the permit conditions pertaining to the activities and other collateral required by law. The permit authority determines the type and size of the collateral.

3.2

Permits and procedures under the Environmental Impact Assessment, Nature Conservation, Environmental Protection, Water and Land Use and Building Acts

3.2.1

General knowledge requirement of operator

Section 5 of the Environmental Protection Act (EPA) requires that operators have a sufficient knowledge of their activities' environmental impacts and risks and the possibilities to reduce harmful effects. If the activities cause or may directly result in environmental pollution, the operator must take the appropriate action without delay in order to prevent pollution, or, if pollution has already occurred, to reduce it to a minimum. The obligations apply to ore prospecting and mining activities and to those in charge of them.

In the ore prospecting phase, exploration trenches (see chapter 2.1.1) may cause changes in the topography and in the habitats in the area as well as other environmental impacts. In some cases, these can have very harmful effects indeed, for example, the destruction of springs and other valuable habitats and vegetation. On the other hand, these impacts can often be avoided if sufficient studies are made of the target area and if the impacts are also taken into account when planning and carrying out measures. Before beginning to dig exploration trenches or to initiate other actions that change the area, an operator is to conduct at least habitat and vegetation surveys of the area as well as map the nesting sites of birds of prey.

Any planned exploration trenches and other measures which shape or change the environment of the target area should be notified to the regional or local supervisory authority (Centre for Economic Development, Transport and the Environment (ELY Centre) or the municipal environmental protection authority). When this is done, authorities have the opportunity to request additional information if necessary and to provide guidance to the operator so that harmful environmental impacts may be avoided.

3.2.1.1

Pilot mining notification

Making a decision to begin mining activities requires as a rule sufficiently extensive pilot ore concentrating and excavation of the ore fed into that process in the intended mining area (see chapter 2.1.1). Pilot processing is normally carried out elsewhere than in the mine area. Extracting the batch of ore required for concentrating takes place within a short period of time, normally several months. Pilot excavation causes emissions, which may cause pollution of or danger to the environment. Pilot excavation also changes the topography and visual landscape of the area. In addition, it can alter the water balances of nearby areas.

Pilot excavation and processing have long been considered experimental activities in the meaning of the EPA, section 30(2), for which, pursuant to section 61 of the Act, a notification is to be made to the competent environmental permit authority. The notification procedure has proven to function well in practice for all parties. If pilot excavation is long term in nature and results in considerable quantities of mining wastes, an environmental permit may be required for the activity already at this stage (see chapter 3.2.5).

The decision given in response to the notification contains necessary conditions on, among other things, preventing pollution of the environment and after-care of the area. The required notification must present the same matters, as appropriate, as an application for an environmental permit. The activities referred to by the notification may be commenced within 30 days of submitting the notification.

3.2.2 Assessing Environmental Impacts

The objective of the environmental impact assessment procedure set out in the Act (468/1994) and Decree (713/2006) on Environmental Impact Assessment Procedure (EIA) is to promote the identification, assessment and consideration of environmental impacts in the planning and decision making for projects, to increase the information available to citizens and their opportunities for participation and to examine means for reducing harmful effects. It is important to note that section 2 of the EIA Act defines "environmental impact" very broadly. The EIA procedure assesses the direct and indirect impacts of a project, including its effects on human health, living conditions and amenity, the habitats in the area, organisms and biological diversity, the community structure, the landscape and cultural heritage and the utilisation of natural resources. Assessment of impacts on people, that is, social impacts, is a key component of the EIA procedure (see chapter 4.3.2).

The EIA procedure does not involve making decisions on projects but rather produces a rich range of information as a basis for decision making. The procedure generally produces the bulk of the information required in, among other things, processing the project's application for an environmental permit. As the procedure progresses, the residents of the area affected by the project and other interested parties receive information on the project as well as an opportunity to contribute to how it is implemented. Well-planned and well-executed participation for different stakeholders also contributes significantly to the assessment of social impacts.

The EIA procedure proceeds in two phases – the assessment programme (EIA programme) and the assessment report (EIA report) – as well as the related opportunities for parties to be heard and requests for opinions on the project. At the beginning of the procedure, the party responsible for the project (mining company) submits an EIA programme to the coordination authority. This represents the company's plan explaining how it intends to ascertain environmental impacts and carry out the assessment procedure. The programme describes, among other things, the planned project, its implementation alternatives and timetable, the permits and plans it will require, the environment in the area, a plan for arranging participation by citizens and the methods and studies underpinning the assessment of environmental impacts (EIA Decree, section 9). The statement of the coordination authority on the assessment programme examines, among other things, the appropriateness of the programme and, if necessary, provides guidance for the commenced EIA procedure such that it will fulfil the aims set out in the EIA Act.

Based on the EIA programme and on the comments and opinions submitted regarding it, the party responsible for the project (mining company) carries out the necessary studies and assessments of the project's impacts and draws up the EIA report. The report describes the planned project, its implementation alternatives and the environment in the area; presents the results of impact assessments and of examinations of alternatives as well as the materials and methods used in them; presents the possibilities to reduce harmful effects and a tentative plan for monitoring the impacts of the project; and examines possible accidents and environmental risks associated with the project (EIA Decree, section 10). The impacts of the activity are assessed for the different stages of the project and for its alternative implementations (see chapter 5.2). The statement of the coordination authority on the assessment report examines, among other things, the adequacy of the report, the appropriateness of the impact assessments, examinations of alternatives and clarification of possibilities to reduce harmful effects, and the arrangement and implementation of opportunities for citizens to participate.

An assessment in keeping with the EIA Act must be carried out before actions are taken in the project that might be crucial in terms of environmental impacts. The EIA report and the statement of the coordination authority on it are attached to the permit applications required for implementation of the project, with these including the application for an environmental permit, the application for mining rights and for proceedings establishing the mining area. The permit decisions are to indicate how the assessment report and the coordination authority's statement on it have been taken into account.

In the case of mining projects, the EIA procedure is necessary when the total quantities of extracted material involved in the excavation, concentration and processing of metal ores and other mining minerals is at least 550,000 tons per year or the area of the open pit is over 25 hectares. Changes in mining projects on a scale that fulfil these criteria also require that an EIA procedure be conducted. In addition, the assessment procedure is applied in individual cases to projects or substantial changes in them where they are likely to cause significantly harmful environmental impacts comparable to those of projects that fulfil the above criteria (known as a discretionary EIA procedure). The criteria applied in considering individual cases are presented in section 7 of the EIA Decree. The coordination authority in the EIA procedure is the ELY centre of the region in which the project is located and it is the centre which decides on whether a discretionary EIA procedure is applied.

The investigation and assessment of the environmental impacts of a mining project are examined in more detail in Chapter 5 of this volume.

3.2.3 Natura assessment

According to section 65 of the Nature Conservation Act (NCA), the Natura assessment and statement procedure applies to a project which, either individually or in combination with other projects and plans, is likely to have significant adverse impacts on the ecological value for the protection of which the site has been included in, or proposed for inclusion in, the Natura 2000 network. The purpose of the procedure is to ensure that the impacts of the project on the conservation objectives of Natura areas are assessed appropriately and that permit authorities can ascertain prior to a project being approved that the project will not be detrimental to the conservation criteria for the area. The bases for conservation of the Natura area can be the habitat types set out in Annex I of the Habitats Directive (92/43/EEC) or the habitats of the species mentioned in Annex II (SCIs [sites of community importance]) and the habitats of the bird species mentioned in Annex I of the Birds Directive (2009/147/EC) or a habitat of regularly occurring migratory birds (SPAs [special protection areas]). The nature of the area (SCI or SPA) determines the species and habitats that are crucial to the assessment.

Assessment of impacts affecting an area included in the Natura 2000 network, that is, a Natura assessment, is necessary in mining projects if the activities (ore prospecting or mining) takes place in a Natura area or if the impacts of the project might extend into a Natura area. Assessment of the impacts of ore prospecting should be carried out early enough that the assessment report can be attached to the application for a claim. The assessment of the impacts of mining activities should be carried out before applying the permits required for the project (e.g. an environmental permit). Mining projects that require an EIA assessment and are located in the vicinity of Natura areas will generally also require a Natura assessment. Where this is the case, the Natura assessment may be carried out as part of the EIA assessment and it is sensible to do so. They may also be carried out as separate processes.

In practice, it is generally easiest and most straightforward to carry out a Natura assessment and opinion procedure directly in accordance with section 65 of the NCA. One alternative is to ascertain the need for a Natura assessment on the basis of existent information. Such an assessment determines whether the threshold for a Natura assessment proper is reached or not. If the assessment shows that the project is liable to have a significantly harmful impact on the conservation values of the Natura area or the project will have impacts on Natura areas, a Natura assessment and opinion procedure will be initiated. This two-phase procedure has proven to be unnecessarily complex, particularly in the case of mining projects.

In practice, the Natura assessment is generally submitted prior to the actual processing of permits to the ELY centre of the area and to the authority possessing the area (generally Metsähallitus), which issues the opinion referred to in NCA, section 65(2). The party responsible for the project and the consultants it has chosen normally engage in negotiations on the implementation of the Natura assessment with the ELY centre and the area possessor before they begin work on the assessment. Where necessary, discussion of the scope and sufficiency of the assessment is continued while the assessment is being carried out.

The Natura assessment and the opinion issued on it by the ELY centre and the possessor of the area are generally attached to permit applications and submitted to the relevant permit authorities. If the assessment and related opinions are not attached to the application documents, the permit authorities must request them from the applicant. In any event, the permit authorities are to ensure that the assessment has been carried out.

If the Natura assessment is carried out as part of an EIA procedure as described in the EIA Act, the Natura assessment must be a separate component. In Natura assessments carried out in conjunction with the EIA procedure, the impacts on conservation values are generally assessed in relation to each of the alternatives having impacts on Natura areas and that are presented in the EIA procedure. The ELY centre and the possessor of the conservation area will generally submit separate opinions on the Natura assessment component that deal specifically with the Natura assessment. The Natura assessment and the opinions on it are attached to permit application documents, such as the EIA report and the opinion of the coordination authority on the report (chapter 3.2.2).

An authority may not grant a permit for implementation of the project if the Natura assessment and opinion procedure indicates that the project will have a significant adverse impact on the particular ecological value for the protection of which the site has been included in the Natura 2000 network. A permit can be granted, however, if the Government in a plenary session decides that the project must, in the absence of alternative solutions, be carried out for imperative reasons of overriding public interest (EPA, section 66). Where a site hosts a priority natural habitat type referred to in Annex I, or a priority species referred to in Annex II, of the Habitats Directive, a further precondition for granting a permit is that a reason relating to human health or public safety, or to beneficial consequences of primary importance for the environment, or any other imperative reason of overriding public interest so demands. In the latter case, an opinion is to be requested from the European Commission (EPA, section 66). If the decisions result in a protection order on a Natura 2000 site being lifted, or the provisions on its protection weakened, and they lead to deterioration of the overall coherence of the Natura 2000 network or its ecological value, the Ministry of the Environment must take immediate action to compensate for that deterioration (NCA, section 69).

The content of a Natura assessment is described in more detail in chapter 5.2.2

a) b)

Figure 16. Examples of endangered plant species in Finland: (a) lady's-slipper orchid (*Cypripedium Calceolus*) and (b) Alpine catchfly var. *serpentinicola* (*Lychnis Alpina* var *serp.*), the latter of which is also a specially protected species. (Photos: Pekka Helo).

3.2.4
Permits required by the Nature Conservation Act (NCA)

Ore prospecting and mining activities may require numerous permits allowing them to deviate from the protection and conservation provisions of the NCA. The following sections present the central protection provisions, the permits needed to deviate from them and the requirements for those permits.

3.2.4.1
Protection of species

The NCA lists species and habitats for species that are protected in different ways and with different protection statuses.

Taking into account all of the species mentioned in the Nature Conservation Act and Nature Conservation Decree (NCD) in the planning and implementing of a mining project is important for preserving biological diversity. However, only some of the species and habitats of those species mentioned in the Act and Decree are such that measures affecting them require a permit from the regional ELY centre to deviate from the protection provisions of the NCA.

Threatened species
The threatened plants and animals referred to in NCA, section 46 and of the NCD, section 21 are listed in the annex 4 of the NCD (e.g. the lady's-slipper orchid and Alpine catchfly var. *serpentinicola*, Figure 16a-b). The actions affecting these species or their habitats do not require a permit from the regional ELY centre unless they are marked with an asterisk (*) or are mentioned in annexes 2, 3a-c or 5 of the NCD (see the following sections).

Specially protected species
Species marked with an asterisk (*) in Annex 4 of the NCD are, in addition to being threatened, species under strict protection under section 47 of the NCA (examples in Figure 16). Destruction or deterioration of sites where they occur is prohibited if the ELY centre has made a decision in accordance with section 47 to set the boundaries of a site hosting a species. In such cases the destruction or deterioration of the site always requires a permit from the regional ELY centre to deviate from the protection provisions of the NCA. If a claim and/or planned mining area or the vicinity of these areas hosts species under strict protection, the operator is always well advised to discuss with the ELY centre the possible setting of boundaries on the site or the restrictions imposed by the existing boundaries.

Protected species
According to sections 37 and 38 of the NCA, all mammals and birds occurring naturally in Finland are protected, with the exception of the game animals and non-protected animals referred to in section 5 of the Hunting Act. Protected plants and protected animals other than naturally occurring birds and mammals are listed in Annexes 2–3 (a, b, and c) of the NCD.

According to section 39 of the NCA the intentional killing or capturing of protected animals is prohibited. In addition, the appropriation, removal or other deliberate destruction of protected animals' nests, eggs and individuals or specimens at other developmental stages in their life cycles is prohibited. Also prohibited is deliberate disturbance of animals, particularly during breeding, in important resting places during migration, or on any other sites of significance to their life cycles. The above-mentioned section does not restrict normal movement in nature but rather refers to deliberate activity which disturbs protected animals. In addition to what is said above, the nesting tree of a large bird of prey that has an appropriate mark or a sign is always protected. Furthermore, a tree hosting the nest of a golden eagle, white-tailed eagle, greater spotted eagle, lesser spotted eagle, and osprey and in which the nest is clearly visible and in regular use is always protected. In light of these provisions, felling and damaging trees that host the nests of these birds of prey are prohibited.

The picking, collecting, cutting, uprooting and destruction of a protected plant species or part thereof is also prohibited (NCA, section 42).

Deviations from the above-mentioned provisions require a permit from the regional ELY centre. If a site hosting a protected plant species disappears or is in danger of disappearing as a result of ore prospecting or mining activities, the measure cannot be undertaken before a permit for the destruction of the species has been obtained from the ELY centre.

Species in the EU Habitats and Birds Directives
According to section 47 of the NCA it is prohibited to deteriorate or destroy habitats significant for reaching or maintaining the favourable conservation status of sites hosting birds referred to in article 4, paragraph 2, and Annex I of the Council Bird Directive (2009/147/EC) and sites hosting the plant and animal species listed in Annex II of the Council Habitats Directive (1997/62/EC). The prohibition comes into force

Figure 17. Example of animal species in Annex IV of the Habitats Directive, the moor frog (*Rana Arvalis*), whose breeding and resting sites fall under the prohibition against destruction and deterioration of sites. (Photo Pekka Helo)

immediately when the ELY centre has made a decision in accordance with section 47 of the NCA concerning the boundaries of the site. If boundaries have been set for the site in question by a decision of the ELY centre, destruction or deterioration of the site always requires a permit from the centre to deviate from the protection provisions of the NCA (NCA, section 48). In regard to the occurrence of these species, it is well-advised to discuss with the ELY centre the possible setting of boundaries for the site or the boundaries that have already been set.

According to section 49 of the NCA and section 23 of the NCD, the destruction and deterioration of breeding sites and resting places used by specimens of animal species referred to in Annex IV(a) of the Habitats Directive is prohibited without a permit from an ELY centre. The species to which this prohibition pertains are listed in Annex 5 of the NCD. Typical species among these which may be found in connection with mining projects are the flying squirrel and the moor frog (see Figure 17).

According to section 49 of the NCA, it is prohibited to keep, transport, sell, exchange or offer for sale or exchange specimens or any part or derivative thereof of birds referred to in Article 1of the Birds Directive, plants listed in Annex IV(b) of the Habitats Directive and animals listed in Annex IV(a) of the Habitats Directive; the exceptions to this provision are the game birds and non-protected birds referred to in the Hunting Act and the game animals and non-protected animals in section 5 of the Hunting Act. In special cases, the ELY centre is authorised to grant derogations from the prohibition referred to in subsection 1 of this prohibition, and from the prohibitions referred to in section 39, section 42(2), and section 47(2, 5) concerning animal and plant species referred to in subsection 2 of this prohibition, on grounds set forth in Article 16(1) of the Habitats Directive. A derogation can correspondingly be granted for birds referred to in Article 1 of the Birds Directive on grounds set forth in Article 9 of the Directive.

3.2.4.2
Protection of habitats

A publication has been compiled of the endangered habitats in Finland (Raunio *et al*. 2008). It is important to take into account all endangered habitats in planning and construction in order to preserve biological diversity, but only some of these habitats are such that actions affecting them require a permit from the regional ELY Centre to derogate from the protection provisions of the NCA.

Section 29 of the NCA and section 10 of the NCD list the habitats protected by the NCA. These are:

1. wild woods rich in broad-leafed deciduous species;
2. hazel woods;
3. common alder woods;
4. sandy shores in their natural state;
5. coastal meadows;
6. treeless or sparsely wooded sand dunes;
7. juniper meadows;
8. wooded meadows; and
9. prominent single trees or groups of trees in an open landscape.

The habitats referred to in section 29 of the NCA may not be altered such that retention of the distinctive characteristics of the habitat is jeopardised. This prohibition comes into effect when the regional ELY centre has made a decision pursuant to section 30 of the NCA on setting the boundaries of the habitat. If boundaries are set pursuant to section 30, destruction or deterioration of the distinctive characteristics of the habitat always requires a permit from the ELY centre allowing a derogation from the protection provisions of the NCA (NCA, section 31).

In regard to these habitats species, it is well advised to discuss with the ELY centre the possible setting of boundaries for the site or the restrictions entailed by boundaries that have already been set.

3.2.5
Environmental and Water Permit

The Environmental Protection Act (EPA) is applied to activities which cause or may cause pollution. In addition, the Act is applied to activities that produce waste or that make use of or treat waste. In the ECA, environmental pollution refers to an emission or deposit of a substance, energy, noise, vibration, radiation, light, heat or odour caused by an activity in the environment that causes harmful effects.

All activities that cause a danger of pollution are required to have an environmental permit. Among the activities listed in the Environmental Protection Decree (EPD) as always requiring an environmental permit are mining, an ore or mineral concentrating plant and a waste storage facility for mining waste. No threshold is defined in the Decree for the extent of these activities; an environmental permit is required regardless.

An environmental permit is a single permit, the decision on which deals with all emissions-related, pollution-causing matters. The permit decision sets out the necessary conditions on preventing pollution of the environment and the danger of pollution as well as on complying with the Waste Act and provisions based on it regarding waste and waste management. In addition, where necessary, the decision takes into account questions of the efficiency of energy use and preparedness to prevent accidents and limit their impacts. Accordingly, an environmental permit is an emissions permit and does not, for example, determine questions of the use and ownership of the area.

Environmental permit matters are decided, pursuant to an application, by Regional State Administrative Agencies. Detailed instructions on the content of the permit application are given in sections 8–13 of the EPD. A permit application for mining must contain a comprehensive description of the proposed activities, the operating environment, the emissions caused by the operations and the impacts of those emissions on the environment. In the case of large-scale projects, a substantial number of the required reports can be completed as part of the EIA process. It is of the essence that the application documents present and assess the scope and emissions of the proposed project and their impacts with a sufficient level of detail. The applicant and any consultant it may use must have the requisite expertise for compiling a permit application. The Regional State Administrative Agencies, which function as the permit authority, provide detailed guidance on the content and scope of the application where necessary.

A pending permit application is notified through an announcement posted on a notice board in the municipality where the activities are to take place (Figure 18). The posting of the notice is reported in a newspaper with broad circulation in the area. Statements on the permit application are requested from, among other parties, the municipality where the activities will be located, the municipal environmental protection authority and the regional ELY centre. With regard to the emissions for the activities and the impacts of the emissions, the permit authority may also request statements from the expert authorities and agencies referred to in the NCD, examples being the Finnish Meteorological Institute and the Geological Survey of Finland. In addition, the permit authority informs by letter all those parties who, in its estimation, will be particularly affected by the emissions from the activities and the impacts of the emissions. Parties concerned by the project may submit complaints or opinions on the application. The applicant is asked to respond to these statements, complaints and opinions.

Efforts are made to decide on permit matters within one year of the application becoming pending. The processing of an application can be delayed particularly where the application has shortcomings or the application is modified during the consideration process.

The permit decision ascertains that the activity complies with the EPA and the Waste Act and with the decrees and government decisions based on these instruments. In deciding on a permit the provisions of the EPA must also be observed. A condition for receiving an environmental permit is that the activity in question must not result in adverse effects on human health, other significant environmental pollution or risk thereof, pollution of the soil or groundwater, deterioration of special natural conditions or undue disturbance to neighbours. In assessing the significance of pollution, account must be taken of, among other factors, matters relating to the state and use of the water resources in the area affected by the activity as these have been presented in the water management plan required by the Act on Water Resources Management (1299/2004). The environmental permit sets out the necessary conditions to prevent pollution caused by emissions.

In the case of pollution or the risk thereof caused by mining projects, the crucial considerations include emissions into watercourses, noise, vibration, dust and other emissions into the air, as well as the processing and final disposal of mine wastes. For the most part, the harmful effects of emissions may always be limited through technical and other measures to a level where they do not cause impacts that would preclude the granting of a permit. The costs of the measures taken to limit emissions and their impact on the profitability of the mine are a central concern when considering the feasibility of opening a mine. If a mine is located close to residential areas or other sites which may be disturbed by the activities, the environmental permit may impose restrictions on operations that cause noise or vibration, for example.

The permit also sets out the necessary conditions for remediation following the cessation of mining, such as closure and landscaping of the waste areas. It also requires that sufficient collateral be posted to ensure waste management and to carry out the closure and after-care of the mine waste areas.

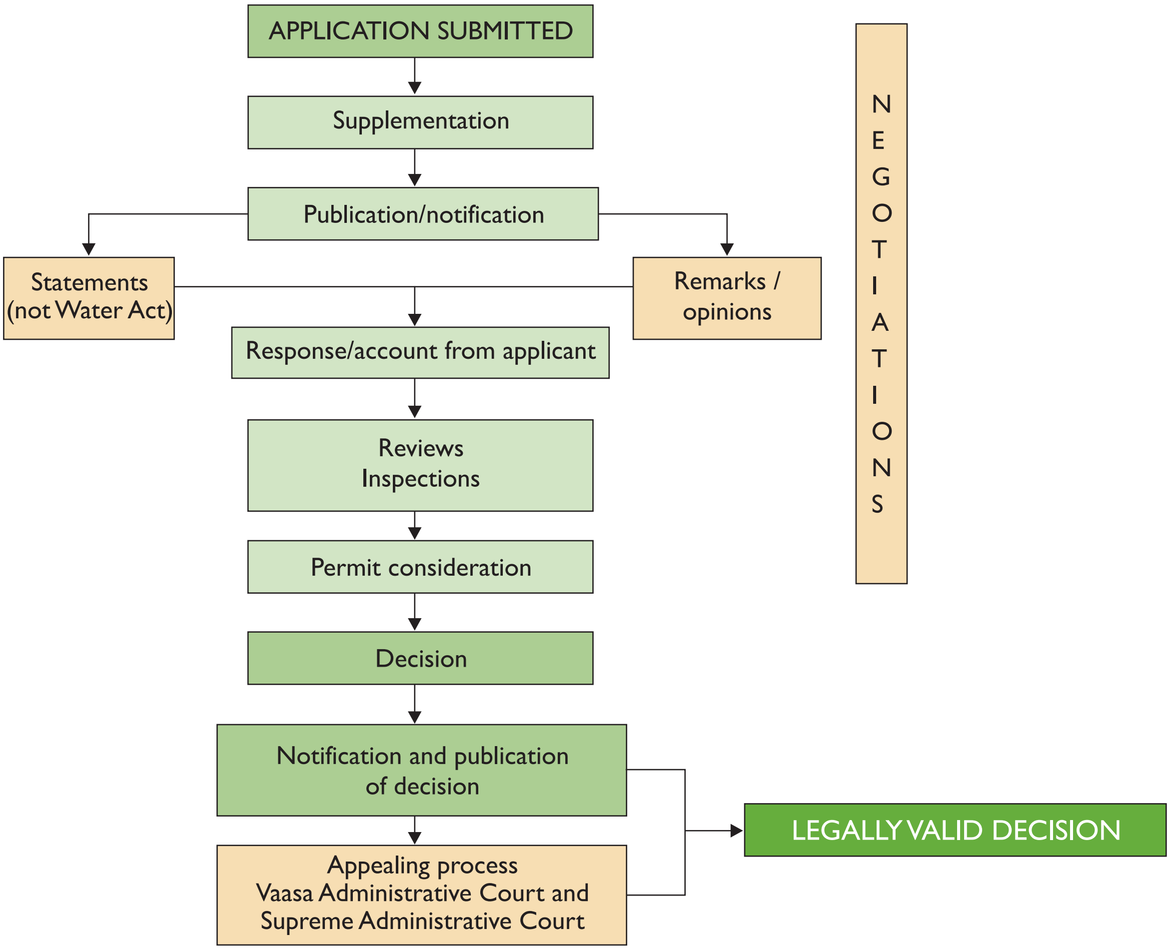

Figure 18. The processing of an environmental permit.

An appeal against a permit decision may be filed at the Vaasa Administrative Court and further at the Supreme Administrative Court (Figure 18). If an appeal proceeds as far as the Supreme Administrative Court, obtaining a legally valid judgment takes 1.5 to 3 years from the date on which the decision of the first instance has been handed down.

3.2.5.1
Mining wastes

The Mine Waste Decree (379/2008) and the amendments to it (717/2009 and 1816/2009) lay down detailed provisions on the management of mining wastes produced in mining activities. The scope of the Decree includes all soil and rock waste produced in mining regardless of whether it undergoes physical or chemical changes as part of excavation or processing. The classification of soil or rock material as waste takes place on the basis of the Waste Act. The scope of the Decree does not include the products produced in the course of operations. Given the typically large amount of waste formed as a part of mining activities, the Decree is one of the key legal instruments pertaining to mining.

For activities in which mining wastes are formed, a waste management plan must be drawn up as described in sections 45a, 103a and 103b of the EPA and in the (amended) Mine Waste Decree (717/2009). The plan must be designed to prevent the formation of mine waste, reduce the harmful impacts of the waste, and promote its beneficial use and safe handling. The plan must contain information on the quantities and characteristics of the waste being created, a description of how the waste will be put to use, a report on the area in which the waste will be disposed of as well as the environment and classification of the area, a report on the state of the soil and the groundwater in the waste storage area and its vicinity, information on the impacts of the waste area, information on measures to reduce impacts, information on supervision and monitoring, and information on the closure and after-care of the waste area.

The mine waste area must be arranged such that it does not cause pollution of the environment or risk thereof even over the course of a long period of time. Seepage and runoff water from the waste area must be collected and treated. The waste area must also not pollute the groundwater or soil. Any easily liquidated and sufficiently large collateral must be posted for the waste area which will cover the obligations with regard to the after-care and monitoring of the site and, if necessary, the costs of remedying soil areas polluted by the waste area.

The annexes of the Mine Waste Decree provide detailed requirements on the application of the Decree. Annex 1 pertains to the classification of mining waste as inert waste and Annex 2 to the classification of the area as one that poses a risk of a major accident; Annex 3 contains determinations of the characteristics of mining waste and Annex 4 operational principles for the prevention of major accidents, the internal rescue plan and notification of it; and Annex 5 estimates the size of the collateral to be posted for the mine waste area. The determination of the characteristics of mining wastes is dealt with in more detail in chapter 5.4.2 and Appendix 6.

An application for an environmental permit has to present the information on the waste area specified in the Mine Waste Decree. The permit provides instructions on the application of the Decree and approves the waste management plan for mining waste.

3.2.5.2
Water resources

Mining activities may involve construction in a watercourse, extraction of process water from a body of water, drainage of water areas, regulation to ensure a supply of process water, as well as dewatering of excavated area and the associated lowering of the water table. A permit as described in the Water Act is required for such activities. If these activities are closely connected with the activities of the mine, the water permit must be applied for as part of the same application as that submitted for an environmental permit. The processing of the permit and the component procedures correspond to those for the environmental permit.

Consideration of a permit according to the Water Act differs markedly from that in the case of an environmental permit. The planned project may not endanger public health, cause significantly harmful changes in the natural conditions or significant deterioration of the living conditions or opportunities to pursue a livelihood in the area. Another condition for receiving a permit is that the benefit of the project must be substantial in comparison to the damage, harm or loss of benefit caused by the project (comparison of interest). Applications for water permits for mining projects must thus present estimates in euros of the profitability of the project and of the harmful effects that it entails.

Being granted a permit as described in the Water Act for building in a watercourse area or altering a watercourse and for implementing the project requires that the applicant have a right to the necessary areas. The permit decision may grant the recipient the right to use an area belonging to another party if the recipient has a right to most of the necessary area. In the case of mining projects, it is essential in the processing of permit matters related to the Water Act that the operator of the mine has acquired the right to use the land in the mining area in conjunction with acquiring the mining right or has purchased the requisite land areas through voluntary transactions.

The Water Act has special provisions governing small water bodies. These apply to ponds less than one hectare in area and natural channels other than in the area of the former province of Lapland, flada and glo-lakes of at most ten hectares, and springs in their natural state. A permit to derogate from these provisions may be granted in individual cases provided that the conservation objectives are not compromised. It is possible to apply for a permit to deviate from these protection provisions in conjunction with the application for an environmental permit. In such cases, the application must examine the number and nature of such small bodies of water in the vicinity of the project and over a wider area if necessary and assess how the project weakens the conservation state of those water bodies.

3.2.5.3
Dam Safety

The objective of the Dam Safety Act (494/2009) is to ensure safety in the construction, maintenance and operation of a dam and reduce the hazard that may be caused by a dam. The construction of a dam requires a permit process in accordance with the Water Act, the EPA or the Land Use and Construction Act. Building dams for mines usually requires a permit as described in the Water Act or the EPA, depending on whether a watercourse or waste dam is involved. Section 9 of the Dam Safety Act prescribes that in a permit application concerning the construction of a dam the owner of the dam must describe sufficiently the dam hazard and its impact on the dam dimensioning and design criteria. The application presents the dam plan on the level of a general plan. This includes an account of the hazard associated with the dam, including a suggested classification of the dam, the major dimensions of the dam and the dammed area as well as the hydrological dimensioning. According to the Dam Safety Act, the permit authority is to request a statement from the dam safety authority and in that statement the authority is to present an assessment of the dimensioning of the dam in the light of dam safety considerations. The Dam Safety Decree sets out the requirements for hydrological dimensions and for the general technical safety requirements. In addition, the Decree includes requirements for the content of the hazard report, safety plan and monitoring programme.

The Dam Safety Act also lays down provisions on the taking into use, use and monitoring of a dam. A dam must be classified before it is taken into use. All classified dams (classes 1–3) must have an approved monitoring programme before they can be taken into use. All class 1 dams must have an approved dam break hazard analysis and dam safety plan. Approval of the classification and of dam safety documents is a matter for the dam safety authority. An information system, in accordance with Dam Safety Act, in which the dam documents (dam safety file) are entered, is under development by the Finnish Environment Institute. The owner of a dam monitors the dam in accordance with the approved monitoring programme. In addition, the condition and safety of class 1 and class 2 dams must be inspected by the owner at least once a year (annual inspection). For class 1 dams, a written report of the inspection must be submitted to the dam safety authority. Dam owners must carry out periodic inspections on dams at least every five years. The dam safety authority and rescue authority have the right to take part in periodic inspections.

A dam is recorded as removed from service to the information system of the dam safety authority when an inspection establishes that the dam structure has been pulled down or the dam has been decommissioned in such a way that it can no longer cause a hazard as referred to in the Dam Safety Act. The inspection is performed in the presence of the dam safety authority after the obligations relating to pulling down a dam structure or dam decommissioning under other laws have been fulfilled. The obligations under the Act cease to be applicable when the dam has been recorded as removed from service.

3.2.6 Permits and procedures under the Land Use and Building Act

The Land Use and Building Act (132/1999) is a law that regulates the planning, building development and use of land. Ore prospecting, mining and gold-panning are subject to the provisions of the Act on the planning and use of areas. Construction that takes place in ore prospecting areas, mining areas and gold-panning areas must comply with the provisions of the Act.

3.2.6.1 The regional plan

The Land Use and Building Act requires that areas where mining occurs must be taken into account in making land-use plans. In drawing up the regional plan and carrying out land-use planning, care must be taken to implement the National Land Use Objectives. Mining areas of national or regional importance must be indicated on the regional plan. In practice, mines are, as a rule, of a size where the threshold for regional significance is met. It has been possible to include mining areas and areas in which mining is possible (areas with ore potential) in regional plans. Plans can guide not only mining activities but also other land use associated with mining, such as traffic arrangements, and reconcile mining and other land use needs, such as reindeer herding. The regional plan is drawn up by the regional council and approved by the Ministry of the Environment. The regional council is responsible for the drawing up of any necessary regional plans and for keeping those plans up to date in a manner required by the development of the region.

3.2.6.2 Local master plans and local detailed plans

Carrying out a mining project generally requires more detailed planning. The need for local master plans and local detailed plans depends closely on the state of the regional plan in an area, the location of the mining project, the conditions at that location and the size and impacts of the project.

The function of a local master plan is to act as general guideline for land use and to coordinate activities. The plan assigns the necessary areas for different activities and designates areas that are to be subject to more detailed planning, other planning and building, and other land uses. A building permit for a mine cannot be granted directly on the basis of a local master plan.

A local detailed plan is drawn up for the detailed organisation, building and development of areas. Such a plan is needed for a mining area if construction in the area will result in structures with significant effects or will cause significantly harmful impacts on the environment. A local detailed plan may also be necessary to coordinate different activities in a mining area or, for example, to give due consideration to the area's cultural and historical values.

If a mining area has no local detailed plan, a decision on whether planning is needed is normally required before a building permit can be issued; this is known as the extended building permit procedure. The construction required by mining projects is often of such a large scale that it is difficult to anticipate whether the requirements for being granted a decision regarding the need for planning can be met such that the decision will survive an appeal. The case-law has few judgements on significant construction and none pertain to mining. Proceeding under a decision to require additional planning is fraught with uncertainty factors where appeals are concerned, among other things, and those factors should be easier to control when making local detailed plans.

The local master and local detailed plans are made by the municipalities. The municipality has an obligation to draw up local master and local detailed plans as needed and to keep these up to date as development of the municipality and guidance of land use require.

If a mining project requires a review of land use plans, the effects of the plans are to be ascertained in the manner required by the Land Use and Building Act. In the initial phase of planning a mining project, it is important to examine how the project relates to existing plans and to assess the need for planning. Required planning procedures are to be coordinated with, among other things, EIA and permit procedures. Large-scale mining projects require an EIA procedure (see chapter 3.2.2). The assessments and assessments of impacts required by the local master and local detailed plans (and consideration of permits under the Land Use and Building Act) can in practice be derived for the most part from the assessments of environmental impacts that are made in accordance with the EIA Act.

3.2.6.3
Building permits under the Land Use and Building Act

The provisions of the Land Use and Building Act are applied to construction in a mining area. A building permit is required for the construction of buildings. Instead of obtaining a building permit for the purpose, an application can be submitted for an action permit which allows the applicant to erect structures and the like; the decision on such permits does not require in all respects the guidance normally required in construction. The provisions of the Act are also applied in the case of tearing down buildings. In the case of old mine structures, provisions of the Act on Preserving the Built Environment may also be applicable.

If the building permit procedure requires extended permit consideration, as is generally the case in mining areas when the area has no local detailed plan in force, the decision on the need for planning described in the Land Use and Building Act is applied. In a mining area, a deviation decision may also be required in some cases before a building permit is considered. The granting of a building permit, an action permit and a demolition permit is decided by the building authority of the municipality. The decisions on the need for planning and on a deviation permit are made by an official appointed by the municipality. For example, the competence to decide on deviation from the building right in the local detailed plan where the deviation is more than slight lies with the ELY centre.

3.3
The Nuclear Energy Act

The Nuclear Energy Act (NEA 990/1987) contains provisions that apply to mining and enrichment aimed at the production of uranium and thorium. The provisions cover the permit requirement for such activities as well as the related permit procedures. The permit procedures described in the NEA in no way supersede the procedures set out in the Mining Act but merely complement them. The view has been taken that due to its connection to nuclear energy and radiation, the production of uranium and thorium involves considerations also requiring supervision such as that prescribed by the NEA.

The permit procedure on mining and concentrating differs to a significant extent from the permit process for nuclear power plants. The procedure for mining and concentrating consists of a single phase, with the government being the authority granting the permit. Accordingly, the permit is one against which an appeal can be filed, using the normal appeal procedure, with the Supreme Administrative Court. The permit is separate from that described in the Mining Act.

The conditions under which a permit may be received are set out in section 21 of the NEA. The section, titled "Other use of nuclear energy", contains the approach and terminology adopted. The supervision of nuclear power plants is, in view of the magnitude of the potential risks, the core of the supervisory system set out in the Act. A nuclear facility refers to facilities necessary for obtaining nuclear energy, including research reactors, facilities performing extensive disposal of nuclear wastes, and facilities used for extensive fabrication, production, use, handling, storage of nuclear materials or nuclear wastes; nuclear facilities, however, do not refer to mines or enrichment plants (see section 3 NEA). The activities falling outside this scope ("other use of nuclear energy") are subject to less stringent control. The content of the term "use of nuclear energy" is perhaps best described with reference to the scope of the Act as defined in section 2 of the NEA. The activities mentioned in that section, which include mining and enrichment operations, are use of nuclear energy in the meaning of the NEA although they do not relate directly to the production of energy.

Section 21 of the NEA lists seven conditions for the receipt of a licence. If these and the general principles of the NEA are met and no conflict exists with the obligations under the Euratom Treaty, a licence can be granted. In other words, the licence involves, among other things, consideration by the government of the appropriateness of the project, and fulfilment of the licence requirements does not mean that a license will be granted automatically. The requirements are that the applicant has taken safety and environmental protection into account, is in possession of the site needed for the use of nuclear energy, has arranged nuclear waste management appropriately and provided for the cost of nuclear waste management, has made sufficient arrangements for control by the Radiation and Nuclear Safety Authority (STUK), has the requisite expertise and organisation, and has fulfilled the economic and other necessary conditions. In addition, the applicant must have secured the authorisations required under the Council Directive on the supervision and control of shipments of radioactive waste and spent fuel from foreign states.

The NEA has no other actual substantive provisions that pertain specifically to mining and enrichment activities. The provisions of the Nuclear Energy Decree are also rather formal in regard to mining and concentrating permits in that they pertain to the matters that must be stated in the application (section 61) and the materials that must be attached to the application (section 62).

The more substantive provisions of the NEA are in chapters 2 and 2A, although a significant proportion of the provisions in the latter are procedural. The provisions in these chapters apply in principle to all use of nuclear energy, not only either mining and enrichment or nuclear facilities. Chapter 2 sets out the general principles of the use of nuclear energy; chapter 2A for its part deals with safety requirements. The principles include the overall interest and security of society as well as safety and preparedness arrangements and other comparable arrangements. The safety requirements concern, among other considerations, maximum values for exposure to radiation, general requirements regarding the personnel of the applicant and the requirements of the responsible manager. It should be pointed out, however, that many of the provisions in chapter 2A, albeit not all, also limit their scope of application to nuclear facilities.

Provisions pertaining to mining and enrichment can be found in the Nuclear Energy Decree, the Government Decree on the Security in the Use of Nuclear Energy and the Government Decree on the Safety of the Disposal of Nuclear Waste.

Amendments were made to the NEA when the new Mining Act was passed. The amendments allow STUK to issue general safety regulations on the safety of mining and concentrating activities aimed at the production of uranium or thorium. In addition, the receipt of a permit requires the approval of the municipality in which the planned mining project and the concentrating plant will be located. This was previously not required for mining and enrichment operations, unlike in the [government] decision-in-principle procedure applied in the case of nuclear power plants. The present laws still require that uranium and thorium production have both a nuclear energy licence and mining permit but the government considers the licence application as described in the NEA in conjunction with the mining permit application for the same operations and decides on the permits in a single decision. Section 23 of the NEA also sets out the procedure to be followed where a mining permit has already been received or where one is not needed.

If the uranium or thorium concentrations in natural resources being extensively exploited as part of mining operations exceed 0.1 kilograms per ton, this must be reported to STUK (ST (Radiation Safety Guide) 12.1.2011). The notification must be made in writing and in good time before operations are commenced. It must contain the following information:

- nature of the operations,
- quantities of material to be processed,
- information on the level of radioactivity of the materials,
- estimate of the number and working hours of the personnel,
- report on the waste to be produced by the operations and on the quantity and nature of emissions.

On the basis of this notification, STUK sets requirements for the operations with regard to radiation safety and requests the necessary reports and measures. The obligation of the operator to ensure that radioactive wastes do not cause harmful effects to people's health or the environment is set out in section 50 of the Radiation Act. The special obligation to notify is set out in section 29 of the Radiation Decree.

Also crucial in terms of Best Environmental Practices in the framework of legislation on nuclear energy is the EIA procedure. Mining and enrichment projects as defined in the NEA are required to carry out an EIA procedure. There is no express provision in the NEA on this matter but the obligation is based on EIA legislation. The list of projects in section 6 of the EIA Decree (Government decree 713/2006) mentions the mining, enrichment and handling of uranium with the exception of pilot excavation, pilot concentration and comparable processing (paragraph 2d). The production of uranium thus normally falls within the scope of the EIA procedure and accordingly there is no discretion in individual cases with respect to the obligation to carry out an EIA procedure.

3.4 REACH

REACH is the Regulation of the European Parliament and of the Council (1907/2006/EC) concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals. The Regulation entered into force on 1 June 2007 and its objective is to improve the European Union's previous system of regulation of chemicals. REACH places more responsibility than before on industry when it comes to the risks that chemicals pose to health and the environment. The REACH procedure is described in more detail in Appendix 2.

In principle REACH is applied to all chemicals. It states that industry bears the main responsibility for the risks posed by chemicals and must provide the users of chemicals appropriate information on safety. At the same time, the Regulation prescribes that the European Union may carry out additional measures in the case of hazardous materials if additional measures are required on the EU level.

Guidance has been developed in recent years for industry and authorities in order that REACH may be implemented smoothly. Guidance documents have been compiled and they have been discussed in projects led by units of the European Commission, in which all stakeholders have participated: industry, the member states, civic organisations and the Commission. The final guidelines will become available at http://guidance.echa.europa.eu/about_reach_fi.htm as they are completed or updated.

3.4.1

REACH from the perspective of the mining industry

The new REACH and the CLP (Classification, Labelling and Packaging) Regulation apply to the mining industry both as a downstream user of chemicals and producers of ores/concentrate. As downstream users, mines should report the use for the chemicals to the supplier so that it can be included in the chemical safety assessment as a recognised use and the supplier will obtain information for drawing up an exposure scenario. If a downstream user does not provide a supplier with information on its use of the material, the user itself is to compile the chemical safety report for that particular use.

REACH also applies to the products of the mining industry, that is, ores and concentrates. Materials that occur in nature, minerals, ores and ore concentrates, have been exempted from the obligation to register under REACH if they have not been altered chemically (REACH Regulation Annex V, point 7). The chemical structure of a substance that is not chemically altered remains unchanged even if it has undergone chemical and physical processes. This category encompasses concentrates produced by gravity, flotation and magnetic separation. On the other hand, leaching, precipitation and sintering are chemical alteration, whereby the bioleaching at Talvivaara, for example, is considered chemical processing of ore. Generally speaking, ore concentrates can be registered as what are known as intermediate substances, allowing for "lighter" registration. According to REACH, ores and ore concentrates are generally classified as belonging to subtype 4 of UVCBs, or Substances of Unknown or Variable composition, Complex reaction products or Biological materials.

Exemption from the obligation to register substances does not, however, exempt an operator from the obligation to classify that is imposed by the CLP Regulation, which was adopted in conjunction with REACH. The properties of hazardous substances which are placed on the market must be appropriately evaluated and classified. An exact characterisation of ores and ore concentrates is complicated and often impossible. In addition to their traditional chemical composition, the properties of minerals are determined by their crystal structure. These make the evaluation and classification of ores and ore concentrates difficult. A notification in keeping with the CLP Regulation needs to be made for an ore/ore concentrate if it is harmful to health or the environment, carcinogenic, acid-generating, flammable or self-heating. Roughly speaking, classification is required in the case of sulphidic ores/ore concentrates and concentrates containing metals that are classified as hazardous (e.g. As, Cd, Pb).

4 Emissions and environmental impacts

The nature and extent of the emissions and environmental impacts in metal ore mining depend on the geology of the deposit, its size and shape, the concentrations of valuable materials, the excavation and concentrating methods used, and the technology and process used in the purification equipment. Also crucial are the commitment of the operator to maintaining and developing operations such that emissions into the environment are kept to a minimum.

The location of the ore deposit is decisive with respect to the impacts it will have on the natural environment and people. For example, the forms of land use, climatic and hydrological factors and topography, which, among other things, affect the migration of harmful substances, are contingent on the location. The sections to follow describe the emissions and environmental impacts typical in metal ore mining.

4.1

Environmental geology of metal ore mines

In metal ore mining, one of the focal environmental concerns is the release of elements and compounds harmful to the environment or human health into surface water or groundwater through emissions into water bodies or into the soil through dust. The harmful elements and compounds in mining may be metals (e.g. Al, Cr, Cu, Fe, Mn, Mo, Pb, Ni, Zn, V), metalloids (As, Sb), salts (e.g. sulphates), nutrients (nitrogen compounds) or organic compounds. They originate in the deposit itself or from the explosives used in excavation (nitrogen compounds), process chemicals (e.g. xanthates, cyanide, sulphur compounds, salts) or the fuels used in machines and equipment (mineral-based oils). The occurrence and concentrations of harmful metals, semimetals, sulphates and nutrients depend primarily on the geology and mineralogy of the ore deposit as well as the efficiency of the concentrating process (Tables 15 and 16). How harmful these are to the environment depends not only on the concentrations involved but, in particular, their toxicological properties and the form in which they occur. These in turn are contingent on the acidity, the oxidation-reduction conditions (pH, Eh/redox) and composition (e.g. nature of suspended solids, other elements and compounds present) of the environment in which they occur. These environmental factors crucially determine the solubility and bioavailability of the harmful substances (cf. e.g. Heikkinen 2000, Reinikainen 2007). The harmfulness of most metals, for example, increases with acidity, when metals occur in a soluble cationic form. The following paragraphs focus on describing the special features of the geology of metal ores.

In metal ore deposits, precious metals typically occur as sulphide minerals (metal and sulphur compounds), oxide minerals (compounds of metal and oxygen) or in elemental form. The metal ores mined in Finland fall mainly into the first two categories, although in some gold deposits the gold may also occur as elemental gold. The principal environmental risks generally derive from sulphide ore deposits, which contain iron sulphide minerals such as pyrrhotite and pyrite and other metal sulphides (e.g. chalcopyrite, arsenopyrite, pentlandite, and sphalerite). These are typically copper, lead, zinc, gold and nickel ores. Chrome, iron, vanadium, titanium and uranium ores are usually oxide metal ores (e.g. Siivola 1986).

The environmental risks of sulphide ores stem from the susceptibility to weathering of sulphide minerals in conditions on the ground surface. Sulphide minerals have formed under reductive conditions in the earth's crust. When they are exposed to the oxygen in the atmosphere and water, they oxidise and acidic waters form containing metals (e.g. heavy metals, Al, Fe), metalloids (As, Sb), and sulphate (e.g. Nordstrom & Alpers 1999). The acidity resulting from the weathering of sulphide minerals further dissolves metals in the minerals in other rock material. Iron sulphide minerals are the most problematic of the sulphide minerals, as they weather the fastest of all when exposed to oxygen and water. Exposure of sulphide minerals to the atmosphere can occur in the walls of stopes, in the concentrating process, in heaps of stored concentrate, in heaps of waste rock, in tailings areas, and in areas into which dust containing sulphide minerals has spread. Control of the oxidation of sulphide minerals during and after mining operations is one of the principal challenges in the effort to reduce the environmental load of metal mines (cf. section 6.2.3).

The acidity of waters formed in the oxidation of sulphide minerals depends on the proportion of acid-producing and neutralising minerals in the rock and mineral material. The distribution and concentrations of the metals and semimetals released depend on the composition and solubility of the minerals, properties which are affected by, among other things, the shape and mode of occurrence of mineral grains, the grain size and the surrounding pH-Eh conditions (e.g. Blowes & Ptacek 1994, Cravotta *et al.* 1999). The pH-Eh conditions further regulate the behaviour of the metals, metalloids and compounds released and affect how they migrate. The solubility of most metals increases with an increase in acidity.

The most significant acid generating minerals in metal ore deposits are the iron sulphide minerals (pyrrhotite [$Fe_{1-x}S$] and pyrite [FeS_2]), and the principal neutralising minerals are the carbonates (calcite [$CaCO_3$], dolomite [$CaMgCO_3$]). If the quantity of acid generating minerals is greater than that of neutralising minerals, the rock material is classified as acid generating and it most likely will produce acid mine drainage (AMD). If the quantity of neutralising minerals is greater than that of acid generating minerals, the material is classified as non-acid generating and drainage and seepage waters will generally be neutral or even alkaline (Price *et al.* 1997). Drainage waters can nevertheless contain significant amounts of environmentally harmful metals (e.g. Heikkinen *et al.* 2009).

The occurrence of heavy metals and metalloids (As) varies by ore type and deposit. The principal source of these in ore deposits are the sulphide minerals and arsenides, from which metals can be released as minerals weather. Often, in addition to the precious metal, sulphide minerals contain small amounts of other heavy metals as impurities. For example, pentlandite ($[Fe,Ni]_9S_8$) may contain cobalt in addition to nickel. Gold, in turn, often occurs in association with arsenopyrite. Secondary sources of heavy metals and metalloids in ore deposits include easily soluble silicate minerals, such as mica minerals and the dark silicate minerals (e.g. pyroxenes, amphiboles), whose mineral crystal lattices may contain heavy metals as impurities (e.g. Cu, Cr, Ni, Zn, V) and whose solubility increases as acidity increases due to sulphide oxidation. For example, chlorite ($[Mg,Fe,Al,Cr]_{12}[(Si,Al)_8O_{20}][OH]_4$) can be a significant source of chrome. Some of the heavy metals in rock material also occur in the mineral lattices of weakly soluble silicates and are therefore unlikely to be released into the environment. The occurrence of metals and the forms in which they occur are investigated using chemical and mineralogical methods. The occurrence and solubility of harmful metals may already be deduced from the mineralogical composition of a deposit (see chapter 5.4.2).

As sulphide minerals oxidise, iron and sulphur are released into the waters in the mine area. Sulphur oxidises to sulphate, and dissolved iron oxidises and precipitates as iron hydroxides, oxides, and hydroxysulphates. The latter further increases the acidity of the waters. The dissolving of silicates and neutralising minerals increases the amounts of aluminium, manganese, silicon, titanium and the alkali and alkaline earth metals (Ca, Na, Mg, K) in mine waters. The distributions of elements being released depend entirely on the mineralogical composition of the weathering materials. The pH-Eh conditions that regulate their migration affect, among other things, the formation of new mineral precipitates and the retention of elements in the soil. For example, iron precipitates retain elements in the waters of a mine site and in the tailings areas, reducing the total load impacting the watercourses in the area.

The amount of sulphide minerals in tailings depends on the concentrating process and its efficiency. Concentrating normally does not extract all of the valuable minerals; rather, some of the sulphide minerals remain in the tailings. The tailings consist mostly of what are known as non-valuable minerals in the ore, that is, mineral grains that did not contain valuable materials and they are stored in the mine area in tailings ponds built for the purpose. Iron sulphide minerals (pyrrhotite and pyrite) generally contain very little precious metals and, accordingly, efforts are made to separate them from the concentrate in processing, with most of these minerals then ending up in the tailings. If pyrite occurs in large quantities in the ore, it can be separated profitably in the concentrating process as a concentrate of its own and be sold, for example, for the manufacture of sulphuric acid, thus lowering the acid generation potential of the mine tailings. Weathering of the sulphide minerals in tailings and the release of metals is faster than, for example, in waste rock due to the smaller grain size of tailings; this is particularly the case if tailings are piled without being saturated with water. In addition, the grain surfaces of minerals in tailings will have been broken in the grinding and concentrating processes, causing the minerals to weather more readily than in intact material.

Waste rock can also contain sulphide minerals. Waste rock refers to the rock in the ore deposit in which concentrations of valuable minerals are so low that it cannot be exploited economically but which must be excavated and removed in order to reach and exploit the ore proper. The shape of metal ore deposits varies from single coherent deposits to smaller, separate veins, which might be pipe-shaped, for example, and in which the valuable minerals may occur as massive, semi-massive and/or disseminated ores. The content of metals and sulphide minerals in waste rock is usually higher closer to the ore. The waste rock farther from the ore, having a lower content of metals and sulphide minerals, is usually environmentally acceptable and can be used, for example, in earthworks at the mine site. Weathering of minerals in waste rock is slowed and reduced by the large size of the rocks compared to tailings.

In surface conditions, oxide minerals are ordinarily more permanent in crystal structure and less susceptible to weathering than sulphide minerals. As a result their chemical impacts on the environment are, as a rule, clearly less significant than those of sulphide ores (Tables 15-16). In exploiting oxide ores, metals can nevertheless migrate from the rock material into the environment due to the formation of dust during excavation and the storing of tailings. Deposits of oxide ore may also contain sulphide minerals, in which case they have environmental impacts corresponding to those of sulphide metal ores (see section 4.3). At this writing, the only location in Finland where oxide ores are being mined is Kemi (chrome ore).

Uranium oxide ores are radioactive and contain the daughter nuclide of the uranium decay chain radium 226. Accordingly, mining of these ores entails the particular risk of radiation and radon. The uranium ore minerals also weather readily in an oxidising environment, meaning that uranium, a heavy metal harmful to health, can be released into the environment (e.g. Lottermoser 2007). The principal environmental risks associated with open pit and underground mining and the processing of uranium ores relate to mine water, tailings, stored waste rock, and dust formation. All of these may contain increased concentrations of uranium and thorium as well as their decay products (Ra-226, Rn-222, Pb-210, etc.), which in decaying releases radioactive radiation (alpha and beta particles or gamma radiation). The decay of radium also leads to the formation and release of radon, which is harmful to health (e.g. OECD 1999, Lottermoser 2007). The risk of radon and radiation is particularly high in the storage of tailings, as most of the radioactive decay products of uranium (e.g. Ra-226 and Th-230) remain in the tailings, whereas uranium is recovered in the processing of the ore (e.g. Lottermoser 2007). In uranium ores that are leached *in situ* (the *in situ* leach technique) pose environmental risks primarily for the groundwater, as the ore is mined by leaching it directly from the deposit; no tailings are produced that need to be stored on the surface nor is there normally any waste rock. Uranium ore deposits may also contain sulphide minerals, meaning that heavy metals and metalloids may pass into the environment, for example in the mine waters, as a result of acidification due to the oxidation of sulphide minerals. Acidity also increases the migration of radionuclides into the environment from waste rock and tailings piles (e.g. Lottermoser 2007). In Finland the natural average concentration of uranium in till is approximately 3.3 mg/kg, and in bedrock approx. 2 mg/kg (Koljonen *et al.* 1992, Rasilainen 2008).

In addition to uranium ores proper, other ore deposits may contain variable quantities of uranium, which can be extracted in conjunction with the processing of the other ore. In Finland uranium occurs, for example, in lead and phosphorus ores in association with carbonatites (Korsnäs, Sokli), in metasedimentary gold-copper ores and gold-copper ores occurring in association with skarn (Juomasuo, Laurinoja), in multimetal ores associated with black schist (Talvivaara) and in association with zinc-copper ores (Pahtavuoma, Vihanti; e.g. Papunen 1986). Depending on the uranium content of a deposit and possible recovery, the mining of such deposits may entail risks that correspond to those related to the mining of uranium deposits proper, although typically on a smaller scale.

As the principal environmental risks of mines are related to their geological characteristics, knowledge of the mineralogical and chemical composition of the rock material is of utmost importance.

Table 15. Examples of the quality (dissolved concentrations of elements) of the seepage and drainage water of tailings areas at Finnish ore deposits at different stages in the operation of the mines. The mineralogical composition of the ore deposit (*) or the tailings (**) is presented for comparison. The formulas for the minerals are provided in Appendix 3.

Ore deposit	**Cu-Zn-Au-sulphide ore**	**Au-Cu-sulphide ore**	**Cu-Zn-Co-Ni-S-sulphide ore**	**Ni-Cu- sulphide ore**	**Cu-W-As-sulphide ore**	**Fe-oxide-Cu-Au-ore**
Ore mineral	Pyrrhotite, chalcopyrite, pyrite, sphalerite*	Pyrrhotite, pyrite, chalcopyrite, magnetite, ilmenite**	Chalcopyrite, sphalerite, Co-pentlandite, pyrrhotite, Co-pyrite*	Pentlandite, pyrrhotite, mackinawite, chalcopyrite, sphalerite**	Pyrrhotite chalcopyrite, arsenopyrite, pyrite*	Magnetite, pyrrhotite, chalcopyrite, pyrite*
Non-valuable minerals	Quartz, chlorite, cericite, calcite, siderite*	Hornblende, plagioclase, quartz, potassium feldspar, chlorite **	Quartz, talc, chlorite, graphite, calcite*	Serpentine, chlorite, talc, carbonates**	Quartz, plagio-clase, potassium feldspar, tourma-line, biotite, chlorite*	Diopside, quartz, hornblende, calcite, plagioclase, potassium feldspar, scapolite, biotite, amphiboles Andradite, chlorite, talc, serpentine, epidote, apatite*
Phase of operations	Closed	Closed	Closed / Processing of talc under way	Operating	Closed	Closed
Water type	Drainage	Drainage	Seepage	Seepage	Seepage	Seepage
Water quality						
pH	2.7–6.9	3.4–6.5	2.7–5.3	5.7–6.8	3.4–6.4	2.8–6.7
SO_4 (mg/L)	25.2–3570	191–1170	760–5690	2800–6900	271–1180	196–4910
Fe (mg/L)	<0.03–978	0.7–8.2	4.7–1730	2.3–163	0.4–58.2	33.4–1260
Al (mg/L)	<1–67.4	0.3–24.3	<0.2–2.7	<0.2–2.7	0.23–25.7	0.004–104
As (mg/L)	–	0.0003–0.0009	<0.0002	–	0.004–3.4	<0.0001–0.03
Co (mg/L)	<0.001–0.9	0.004–0.7	0.06–1.8	0.007–0.07	0.1–1.5	0.0003–23.1
Cr (mg/L)	–	0.0005–0.003	0.0004–0.4[1)]	–	<0.0002–0.002	<0.0002–0.02[1)]
Cu (mg/L)	<0.001–0.8	0.02–1.6	0.006–3.7	<0.001–0.05	0.2–5.5	0.005–3.8
Ni (mg/L)	0.003–0.5	0.01–0.7	0.3–1.9	0.01–2.1	0.004–0.3	0.03–9.9
Zn (mg/L)	0.01–45.1	0.01–0.7	0.1–21.2	0.01–0.3	0.004–1.3	0.01–6.1
Reference	Räisänen *et al.* 2003	Parviainen 2009	Räisänen & Juntunen 2004	Heikkinen *et al.* 2009	Carlson *et al.* 2002	Unpublished material from the Geological Survey of Finland

1) Cr^{III}

Table 16. Examples of the quality (dissolved concentrations of elements) of seepage and drainage waters in the waste rock areas of Finnish metal ore mines at different stages of mine operation. The mineralogical composition of waste rock is presented for comparison. The formulas for the minerals are given in Appendix 3.

Mine	**Talc-Ni mines**		**Cu-Zn-Ni-Co mines**	**Zn-Cu-Au mine**	**Pyrite mine**	**Cr-oxide ore**
Waste rock	Serpentinite, black schist, impure soapstone, chlorite schist, mica schist		Quartz and skarn, carbonate rock, talc schist, serpentinite, black schist, chlorite schist, mica schist, granite	Greywacke, phyllite, black schist, metavulcanite, skarn	Quartz and skarn, black schist, sulphide schist, metavulcanite	Talc-carbonate rock, pyroxenite, peridotite and talc serpentinite, granitic gneiss, albite and dolerite dykes
Mineralogy	Quartz, plagioclase, biotite, serpentine, talc, chlorite, magnesite, dolomite, chromite, apatite, graphite		Quartz, tremolite, diopside, plagioclase, potassium feldspar, biotite, muscovite, dolomite, calcite, serpentine, talc	Quartz, feldspars (plagioclase and potassium feldspars), chlorite, biotite, graphite, tremolite, hornblende	Plagioclase, quartz, phlogopite, cerisite, graphite, calcite, chlorite, tremolite, goethite, limonite	Talc, serpentine, magnesite, dolomite, chlorite, pyroxenes, tremolite, phlogopite, quartz, plagioclase, chromite, (magnetite)
Sulphide minerals	Pyrrhotite, gersdorfite, niccolite, pyrite, alabandite		Pyrrhotite, pyrite, chalcopyrite, sphalerite, pentlandite	Pyrrhotite, pyrite, chalcopyrite, sphalerite, pentlandite	pyrite, pyrrhotite, chalcopyrite, sphalerite, pentlandite, marcasite	pyrite, chalcopyrite, millerite
Phase of operation	Operating		Closed/ talc processing under way	Closed	Closed	Operating
Water type	Seepage	Drainage	Drainage	Drainage	Drainage	Seepage
Water quality						
pH	3.8–6.5	3.6–5.5	4.4–7.0	3.2–5.0	2.0–2.8	6.4–7.1
SO_4[1] (mg/L)	1160–8299	107–1300	360–2028	59–1600	5243–8427	100–250
Fe (mg/L)	0.05–21.2	0.36–14.2	<0.03–24.9	0.28–19.6	1300–2567	<0.03–0.7
Al (mg/L)	0.01–334	0.21–4.39	<0.005–57.6	0.21–6.58	124–307	0.01–0.04
As (mg/L)	0.001–7.3	0.001–0.01	<0.0002–0.001	0.0001–0.0009	0.04–0.14	<0.001–0.002
Co (mg/L)	0.2–7.3	0.01–0.12	0.06–1.71	0.02–0.16	0.60–1.08	<0.0002–0.001
Cr (mg/L)	<0.001–0.1	<0.001–0.001	<0.001–0.007	0.0001–0.005	0.43–0.77	<0.0002–0.003[2]
Cu (mg/L)	<0.0002–0.8	0.001–0.02	<0.0005–5.08	0.003–0.026	1.70–3.10	<0.0001–0.002
Ni (mg/L)	6.1–116	0.23–3.84	0.48–3.54	0.06–0.47	0.83–1.55	0.008–0.05
Zn (mg/L)	0.2–70.4	0.08–0.63	0.41–19.7	0.40–2.16	4.79–9.96	<0.003–0.006
Reference	Unpublished material from the Geological Survey of Finland		Räisänen 2004, Räisänen & Korhonen 2004	Räisänen *et al.* 2003	Räisänen *et al.* 2001, Räisänen 2009	Grönholm 1994, Unpublished material from the Geological Survey of Finland

1) calculated from the sulphur content
2) Cr^{III}

4.2
Emissions caused by mining activities

Mining causes various impacts on and emissions into the environment in the different phases of the life-cycle of a mine. The sections to follow describe the emissions associated with mining phase by phase.

4.2.1
Emissions during prospecting

The emissions in prospecting are generally limited to the exhaust emissions caused in drilling and in moving around in the field. Emissions (e.g. oil from machines) may also affect watercourses, primarily when accidents occur.

Pilot mining in the prospecting phase causes emissions whose extent and significance vary depending on the amount of material excavated and the location of the pilot pit. In the pilot mining, excavation, loading of vehicles and transport can cause noise, dust and exhaust emissions. Pilot mining often requires the pumping out of water that collects in the excavations. With the discharge of dewatering water, water bodies in the vicinity may receive emissions of suspended solids and metals as well as nitrogen emissions originating from explosives.

The possible emissions of a pilot concentration plant are similar to those coming from the plant during production proper. These are dealt with in more detail in later sections.

4.2.2
Emissions during mine construction

When a mine is being built, construction work and increased traffic can cause noise as well as emissions into the air, water and soil.

In the construction phase, dust raised by the roads and earthworks (including tailings dams and reservoir dams, as well as areas where the overburden is removed) causes the emission of fine-grained particle into the air (dust emissions). These emissions may, particularly during dry and windy periods, be considerable and very conspicuous if no attention has been paid to reducing them. Dust emissions are also caused by the excavation and crushing of rock needed in construction. Indeed, preparations geared to reducing dust emissions, such as wetting down roads, encapsulation of the crushing plant, and dust binding at different worksites, should be made from the very outset of the construction phase (see Table 31 in Chapter 6.2.1). If the rock to be excavated and crushed contains significant amount of graphite, there is every reason to prepare to take special measures to prevent the spread of graphite dust; due to its exceptional properties, whereby it remains suspended in air longer and migrates more easily than normal rock dust, graphite can, under appropriate conditions, travel very long distances indeed from the mine area.

The most significant gaseous emissions into the air during construction occur at different sites from the exhaust produced by equipment used in excavation and crushing and the heavy vehicles used to transport rock and earth materials and construction materials (particulate SO_2, CO_x and NO_x emissions). Exhaust emissions are greater, the more overburden is removed and the more dimension stone and waste rock are excavated and transported from the pit to the sites where they will be used and to the storage areas.

As a result of increased erosion, emissions of suspended solids, for the most part, may pass into watercourses near the mine site through drainage waters, particularly during rainy periods and the spring snowmelt. The drainage waters come from dewatering and water channelling systems, dams and other earthworks sites, storage areas, as well as areas where the overburden has already been removed. If appropriate water treatment systems, such as settling ponds and/or overland flow areas, are not built and taken into use before earthworks are begun, the emissions of suspended solids downstream of the mine may at times be considerable indeed and clearly noticeable as turbidity of the water (see chapter 6.2.2).

The dewatering water from the open pit, the access tunnel and other spaces in the underground mine, as well as the soil at the mine site, may produce emissions of, among other things, suspended solids and/or metals in waters downstream of the mine. The dewatering water may also contain nitrogen emissions from explosives used in preparing for mining operations or in excavating dimension stone. If the storage of waste rock is begun on a large scale already during construction, the drainage and seepage waters from the waste rock area may also carry suspended solids, metals, sulphate and nitrogen.

During construction, noise emissions are caused primarily by the blasting required in excavation, by the machinery used in excavating, crushing rock and different types of construction work, and by the heavy vehicles used for transporting overburden, crushed rock and blasted rock at the mine site. The noise carrying from the mine site may become disturbing if the mine is built near permanent habitation, holiday homes or, for example, conservation areas, and if no measures geared to limiting noise are undertaken or implementation of the measures is delayed. These measures include noise abatement barriers, the replacement of the noisiest equipment and vehicles with less noisy ones, locating machinery as far away as possible from sites that may be disturbed and/or behind walls, barriers or the like, and the scheduling of blasting. (See chapter 6.2.4).

In the construction phase, a number of contractors will be operating at the mine site. They use many different kinds of equipment and heavy transport vehicles, which use large quantities of fuel and require regular maintenance. The operations of the contractors and the mining company produce forms of waste (e.g. construction, oil and chemical wastes), as well as domestic waste water. Accordingly, the management of fuels, oils and chemicals, the management of problem and other waste and the treatment of domestic waste water must all be planned carefully in advance and implemented systematically to ensure that no environmentally harmful chemicals will enter the soil, groundwater and/or watercourses and that such waste management and the treatment of domestic wastewater will fulfil the relevant requirements. If these measures are carried out appropriately, the principal factors causing a risk of pollution of the soil and groundwater in the construction phase are occasional oil and fuel spills associated with transport vehicles and equipment and leakage of chemicals needed in construction. Even where such spills occur, the pollution of the soil is generally relatively limited if the mining company and the contractors have prepared themselves appropriately for accidents and controlling chemical spills.

Mining wastes may also be produced during construction, mainly in the form of waste rock. Where this is the case, a waste management plan for mine waste and a plan for the management of rock material must be presented, implementation of which is required at the latest when massive excavation of waste rock is begun (see chapter 5.4).

4.2.3

Emissions in the production phase

During the production of a mine, the concentrating process is normally the largest source of emissions. Quantitatively, the most significant emissions in concentrating are process wastes, that is, tailings and/or mineral precipitate sludge. The emissions from the concentrating process, as all mining operations, are process specific and

Table 17. Comparison of the emissions and environmental impacts of open pit and underground mining. (Adapted from Environment Canada 2009)

Environmental consideration	Open pit mining	Underground mining
Land Disturbance	Relatively large disturbed area	Smaller disturbed area than for open pit mines
Waste Rock Disposal	Can require large area; involves trucking, runoff and leachate management, dusting and aesthetic considerations	Less waste rock than open pit mines, but may involve similar management considerations
Tailings	Tailings volumes generally larger due to large volume of ore processed	Tailings volumes generally smaller
Reclamation	Both mine and waste rock area can represent major concerns due to the extent of the waste rock and pit	Waste rock can be a concern, as can seepage or overflow of water from the mine workings
Land Subsidence	Not a concern	Can be a concern
Truck Noise	Truck traffic between the pit and waste rock dumps and mill can be a serious noise problem	Normally not a concern (underground traffic and milling)
Vent Fan Noise	Not a concern	Requires careful consideration (timing) and mitigation
Blasting Effects	Noise and vibration can be a concern requiring careful management	Noise and vibration could also be a concern at underground mines, particularly when the mine workings are relatively shallow
Dust	Can be a concern due to haulage of ore and waste rock and blasting in open pit	Can be a concern if rock hauled above ground
Mine Water	Mine water volume influenced by precipitation, surface and groundwater ingress. Elevated ammonium levels from blasting can be a concern. High sediment loadings are common. Mine water may contain metals and may have a low pH.	Mine water volume normally quite stable. Elevated ammonium levels from blasting can be a concern. High sediment loadings are common. Mine water may contain metals, and may have a low pH.

depend, among other things, on the composition of the ore being processed and the methods and technologies being used. A level of emissions that can be achieved in the processing of a particular ore may be technically and economically impossible to achieve in the case of another. Table 17 compares the emissions and environmental impacts of open pit and underground mining. The sections to follow describe the emissions associated with the production phase of a mine by type of emission. The emissions relating to the storage of mine wastes (waste rock, tailings, and the like) are dealt with comprehensively in chapter 4.2.3.3.

4.2.3.1
Emissions into the air

Mining causes emissions into the air from blasting, ore crushing, grinding and concentrating, the drying of concentrates, heating, traffic and equipment, and the storage of tailings and waste rock. The most significant air emissions are blasting gases (CO_2, N_2, CO, NO_x), exhaust gases (CO_2, CO, hydrocarbons, NO_x, SO_2, fine particles), process gases (e.g. from bioleaching, the processing of the leachate and the pressure oxidation of concentrate: H_2S, C_2S, SO_2, CO_2, S_0 and drying: SO_2), particulate emissions and mineral dust. Mineral dust emissions (particulate emissions) are produced by a variety of different operations, such as excavation, transport, loading, crushing, grinding and drying, as well as the piling of waste rock and the storage of concentrate and tailings. In composition, mineral dust corresponds to finely ground ore and the associated waste rock and it may thus contain harmful metals. The harmfulness of mineral dust depends on the mineralogy of the ore and the friability of the minerals.

Some minerals, in particular fibrous minerals such as asbestos, may be harmful as such when they occur in dust.

Excavation and transport

The excavation and transport of ore causes mineral dust, exhaust and blasting gas emissions (Table 18). In both open-pit and underground mines, haulage of ore using trucks causes dust and exhaust emissions typical of vehicle traffic, particularly when the ore is brought to the surface to be stored. Mineral dust rises from the ore, road surfaces, tires and truck beds.

In blasting the explosives used in excavation (e.g. emulsion explosives, ANFO) become, as a rule, water vapour, carbon dioxide and nitrogen. In addition, blasting gases contain small quantities of harmful gases, such as carbon monoxide and nitrous oxides. Blasting also creates smoke. The quantity of gases produced in blasting is some 0.7-1 m^3 of gas per kilo of explosive.

The hot gas produced in blasting always raises a certain quantity of rock material into the atmosphere. The amount of dust rising into the air depends on the charge and rock material involved. For the most part, the rock material settles in the immediate vicinity of the mine but the finer matter may travel father from the site. For example, graphite dust spreads over an extensive area and is easily detected even in small quantities due to the staining it causes.

The haulage of ore and waste rock at the mine site takes place on unpaved roads, on which ore and waste rock fall during transport. This rock material is ground into a fine dust under the weight of heavy vehicles, with a muddy sludge often forming on the road surface. The dust and exhaust gases from traffic increase with number of intermediate loadings and unloadings and the distance travelled when the concentrating plant is relatively far from the mine.

In underground mining the allowable emissions into the surrounding air from the ventilation exhaust are restricted by occupational safety regulations, whereby the emissions are generally low. Humidity in the mine also reduces the spread of dust into the outside air from ventilation exhaust. In open pit mining dust and exhaust emissions are often clearly greater than in the case of underground mining due to the vehicle traffic involves. These emissions are also limited through occupational safety regulations.

Screening and grinding

The emissions into the air from crushing and grinding depend crucially on the location of the equipment used (Table 18). The dust emissions of a grinding or screening circuit built indoors or in an underground mine do not generally burden the environment significantly, as such emissions are limited by occupational safety regulations. However, the loads of trucks hauling rock material are usually dumped into the feeder intake of the crusher outdoors in an open space, where it is impossible to collect all the resulting dust emissions for treatment.

The dust emissions of a circuit built wholly or partially outside are normally greater than those in the case of indoor equipment. The quantity and quality of dust emission in the case of an outdoor circuit depend on the weather, the properties of the ore and the technology used.

Grinding, which takes place after crushing and screening, does not usually produce significant emissions into the air, as it is often carried out in closed grinding circuits in a wet slurry (cf. chapter 2.3.3).

Concentrating

The concentrating process can cause gas and dust emissions, for example, in the drying of concentrate, the production and handling of chemicals used in concentrating, and in the concentrating process itself. Processes that require heating cause gas emissions consisting of nitrous oxides, carbon dioxide, sulphur dioxide and particles depending on the fuel and combustion techniques used. The gases formed in the concentrating process may also cause odours, one such gas being hydrogen sulphide (H_2S).

The drying of concentrates using a traditional drying drum heated by fuel constitutes one of the principal sources of air emissions. The gases emitted by the drum typically contain dust and sulphur dioxide in addition to ordinary exhaust gases.

The manufacture of process chemicals at the mine site may cause gas emissions into the air. For example, the production of burnt lime causes carbon dioxide emissions and the production of extinguished lime heat and water vapour.

The use of chemicals used in the concentration process, for example, in the precipitation and flotation process, and in washing filters, may cause gas emissions, such as hydrogen sulphide and nitrogen dioxide. Hydrogen sulphide is readily released into the air in precipitation processes that use hydrogen sulphide (reduction) or in froth flotation processes in which strong sulphuric acid comes into contact with sulphide minerals (in particular pyrrhotite). Bioleaching may also release carbon dioxide and hydrogen sulphide. Hydrogen sulphide is a toxic, very flammable gas with an unpleasant odour, which the human nose normally detects in extremely small quantities. The concentration of hydrogen sulphide in the concentration plant may rise above levels that are harmful to health but outside the mine area the harm is largely aesthetic (CICAD 2003). Nitrogen dioxide may be released, for example, when ceramic filters are washed in nitric acid, and strong nitric acid comes into contact with sulphide minerals. Nitrogen dioxide is classified as a highly toxic gas which can cause health risks in addition to impacts on nature.

In addition to the odours produced by hydrogen sulphide, odours may occur in the concentrating process from xanthates and starch-based depressant chemicals (e.g. Raisorb). The offensive odours from xanthates normally result from their extensive use. The odours associated with starch-based depressant chemicals generally increase with an increase in temperature, in particular during hot summer weather. The odours caused by xanthates and depressant chemicals are generally only aesthetic concerns.

The concentration process may also produce fuel emissions into the air. For example, processes that use an autoclave in leaching release nitrogen oxide and particulate emissions when the autoclave is heated using steam generators to achieve a sufficient reaction temperature.

Storage and transport of ore concentrate

Storage, loading and haulage of ore concentrate causes emissions into the air in the form of dust and vehicle exhaust (Table 18).

Storage of ore concentrate in an open area normally causes dust emissions and when dust settles as sludge with rain, emissions into surface water and groundwater are also possible. Dust emissions can also originate from the storage pile itself or from dry material that has fallen to the ground in the storage area in the process of loading. The volume of emissions in the storage of concentrate depends on the weather and the techniques used in ore processing and in drying the concentrate. Less dust will rise from the surface of the storage pile if the concentrate is kept sufficiently wet and if it contains as little completely dry material as possible. Pressure filtration of concentrate can achieve an even, suitable level of moisture but a drying drum, for example, generally produces drier material.

If concentrate is stored in covered storage halls, the air emissions are limited to the exhaust emissions associated with loading and transport.

Table 18. Air emissions caused by the transport, screening and grinding of ore and the storage and transport of ore concentrates at Finnish metal ore mines/production facilities.

Mine/production facility	Ore haulage	Screening and grinding	Storage and haulage of concentrates
Kemi mine	No emissions into the environment (underground mining and hoisting)	Screening and grinding indoors, minor dust emissions from the dust removal system	Minor dust and exhaust emissions from the concentrate loading site, concentrates stored indoors for the most part
Kittilä mine	Dust emissions, exhaust emissions (CO_2, NO_x and SO_x emissions calculated based on fuel consumption)	Screening and grinding indoors, minor dust emissions from the dust removal system	No dust emissions from storage, as no concentrate (= Doré bars) is stored in the area; Doré bars are transported on from the area
Pyhäsalmi mine	No emissions into the environment (underground mining and hoisting)	Screening and grinding indoors, minor dust emissions from the dust removal circuit	Dust emissions mainly from storage and loading areas for concentrates; total deposition at a distance of less than 200 m is 155 kg/ha/month
			Minor exhaust emissions from vehicles in loading, minor dust and exhaust emissions from rail transport in open cars of sulphur and zinc concentrates
Talvivaara mine	Dust emissions, exhaust gases	Screening and grinding indoors, minor dust emissions from the dust removal system	Minor exhaust emissions from rail transport, transport of concentrates in closed containers
Orivesi/ Jokisivu mine	Dust emissions, exhaust gases	Carried out at the Sastamala concentrating plant	Carried out at the Sastamala concentrating plant
Vammala concentrating mill	see Orivesi/ Jokisivu mine	Dust and noise emissions from circuit built outdoors	No dust emissions from storage and loading of concentrates, storage and loading take place in a hall
			No dust emissions from transport (loads covered), minor exhaust emissions from vehicles
Lahnaslampi mine	Dust emissions, exhaust gases	Crushing and storage indoors, only minor dust emissions from the dust removal system	No dust emissions from the storage and loading of concentrates, filter-dry concentrate stored and loaded indoors

4.2.3.2
Emissions into water bodies

During mining operations, the surrounding water bodies may be polluted by dewatering water, the concentrating process and the storage of waste rock and tailings. In addition, emissions into water may be caused by the spread of dust and emissions into the soil. The following section provides a more detailed account of the environmental load caused by excavation and ore concentration.

Excavation

Groundwater and surface water running into the mine are pumped to the surface in order to keep the mine dry for excavation. The need for pumping varies from mine to mine depending on the hydrology of the area. The quality of the water pumped is determined by the composition of the ore and the explosives used in blasting. Depending on the type of ore, heavy metals, metalloids or sulphate may dissolve into the water during excavation (Table 19; cf chapter 4.1 Tables 15 and 16). For example, in extracting sulphide ores the dewatering water is typically acidic and metal-bearing as a result of the oxidation of sulphide minerals. In addition, nitrogen compounds may dissolve into the water from the explosives used. Furthermore, the dewatering water often contains fine-grained sludge (rock material washed from the surface of rocks) and may also contain oil that has leaked from mining equipment or in the transport of ore.

The explosives used in blasting almost always contain ammonium nitrate, which can dissolve from the explosives into mine water. Earlier, the use of the explosive ANFO was common in mining. It is a highly water-soluble explosive consisting of a mixture of ammonium nitrate and fuel oil (94% ammonium nitrate and 6% fuel oil). Today, ANFO is often replaced by poorly soluble explosives from which less ammonium nitrate dissolves into water. One example is the water-oil emulsion KEMIITTI 800, which is pumped into the charging hole and whose ammonium nitrate content is 75%. In addition, increasing use is being made of two components that together form an explosive mixture in the charging hole - a fumigant and the KEMIITTI 810 matrix. In these explosives, the fumigant is typically an aqueous solution containing sodium nitrate and sodium thiocyanate. The KEMIITTI 810 matrix is an intermediate product of an emulsion explosive and is 75–85% ammonium nitrate. The two explosives may also be on the market under different trade names.

Explosives that remain unexploded in blasting are carried along with the ore to the concentrating plant or in gangue to the waste rock area. The ammonium nitrate in the explosives dissolves in water at the plant, in the tailings ponds and in the waste rock storage area and causes nitrogen loading in the water bodies in the area.

During excavation, minor oil emissions (e.g. a 10–50 litre oil leak from a broken hydraulic hose) are possible, for example, as a result of damage to the hydraulic systems on mining equipment. The oil either becomes mixed with the ore being loaded and goes on to the concentrating plant, or migrates into the dewatering water pumped from the mine. In the flotation process at the concentrating plant, most of the oil will rise with the froth into the concentrate and may impede frothing. Oil in mine water will travel with the water to the pumping station, where it is recovered using oil separation equipment.

Water pumped from the mine is collected in a tank or basin, from which it is, where necessary, conducted further to be treated – for example in settling ponds or the tailings area – before being channelled into the surrounding environment. Reduction of emissions that are caused by dewatering water is dealt with in detail in section 6.2.2.2.

Table 19. Quantity and quality of dewatering water at Finnish metal ore mines in 2009.

Mine/Production facility	Pump water m^3/year	pH of water	Main components of water mg/L
Kemi mine	748 000		N, suspended solids
Kittilä mine	1 573 000	7.3	As, Sb, N, suspended solids
Pyhäsalmi mine	908 261	2.8	Fe 440, SO_4 6960, Cu 38, Zn 350
Talvivaara mine	720 000	5.0	Ni 4–5, Zn approx. 9
Orivesi mine[1)]	138 760	7.4	suspended solids 6.4, total nitrogen 31
Jokisivu mine	Small amount of water (not measured)	8.0	As 0.009, Ni 0.007
Lahnaslampi mine – seepage water from waste rock pile	800 000 155 000	5.0–6.0 3.5	Ni approx. 1, Ni 50

[1)] includes runoff from the surroundings due to measurement location

Concentrating

Ore concentrating can cause emissions into water bodies from the ore itself or the chemicals used in the concentrating processes (Table 20, cf. chapter 2.3.4). In the concentrating process, ore is broken up mechanically and/or chemically and reduced in size into different mineral fractions. In the processing of ore, the crystal surfaces of the minerals are broken and their chemical balance changes, whereupon metals and sulphur, for example, are released from the surfaces into the process water.

Of the chemicals used in the concentrating process, collectors and flocculants are typically ones that do not cause very significant emissions into water bodies, because most of the chemicals adhere to the concentrate if the amounts fed into the process are appropriate. Where excessive amounts are used, the excess may pass into the process water and thereby into the environment. For example, when using collectors that contain phosphorus, excessive use may increase the nutrient load on water bodies. Of the collectors, xanthates easily decompose in water solution and normally do not cause significant emissions into water bodies (chemical residue: Na and/or K). In addition, activators adhere for the most part to the surface of the concentrate and only a small proportion of them end up in waste water. Similarly, only small amounts of cyanide, which is a toxic and very reactive substance, can end up in the environment through waste water (e.g. in gold production), since cyanide is decomposed/decayed in waste water before it is channelled away from the process (see chapter 6.2.2.3). Cyanide decays easily, for example, due to the effect of oxygen. Other process chemicals pass for the most part into process waters, causing variable emissions into water bodies.

The water from the concentration process is generally pumped with tailings into the tailings pond, where it undergoes sedimentation and/or is treated and returned to the process or channelled into water bodies. Some of the compounds in the process chemicals continue to decay to some extent or precipitate in the tailings pond. We still do not know all of the emissions associated with process chemicals. For example, the use of sulphuric acid may cause significant sulphate emissions (cf. Heikkinen *et al.* 2002, Heikkinen *et al.* 2009), as the sulphate does not decay or normally precipitate in the tailings pond.

Table 20. Emissions into water and air from the concentrating process at Finnish metal ore mines in 2009.

Mine/production facility	Emissions into water / a	Emissions into air / a
Kemi mine[1)]	Average 34 t, tot. P 679 kg, tot. N 10 t, Ca 420 t, Fe 33 t, tot. Cr 28 kg, soluble Cr 5 kg	Minor dust emissions in the exhaust from the dust removal system of the concentrating plant
Kittilä mine[2)]	Fe 97 kg, Mn 206 kg, Ni 4.7 kg, Sb 490 kg, As 10.1 kg, SO_4 141 t	Sulphur and particulate emissions in the exhaust from the pressure oxidation process/autoclave
Pyhäsalmi mine	Cu 133 kg, Zn 641 kg, Fe 2676 kg, Ca 3790 t, SO_4 9230 t, Cd 1.2 kg, Pb 2.1 kg	No emissions into the air from the concentration process
Talvivaara mine	No emissions into water bodies from bioleaching, leachate recycled into the metal extraction process; leachate emissions possible only in the case of accidents	No dust emissions into water bodies, as the surface of the bioleaching pile is wet continuously
	Emissions into water are form at the metal recovery plant (following secondary treatment)	Hydrogen sulphide and CO_2 emissions from metal recovery (odours)
Sastamala concentrating plant	Only 28 000 m^3 wastewater discharged; minor nickel concentrations in the water	No air emissions from the concentration process
Lahnaslampi mine	Waste water discharge ended in 2010, internal water recycling (2009: As 59.3 kg, Ni 91.2 kg)	No air emissions from the concentration process

[1)] Figures based on 2008 operations, as production at the mine was suspended for a number of months in 2009.
[2)] Emissions into water are primarily caused by mine dewatering water.

4.2.3.3

Wastes generated in mining and related emissions

Extractive waste and process waste

The mining wastes typically generated by metal ore mining are waste rock loosened in excavation, tailings formed as part of the concentration process and overburden removed in construction (in particular in the case of open pit mining) (Table 21). In addition, mineral precipitates and sludges may form during operations that are to be classified as waste, examples being residual material of the leaching process or precipitation reactions (e.g. gypsum and metal hydroxide precipitates) or of the settling of suspended solids in mine water (e.g. sedimentation of dewatering water pumped from the mine).

Waste rock

Waste rock is excavated in both open pit and underground mining in order to extract ore. In underground mining the proportion of waste rock is generally smaller than in open pit mining, in which the amount of waste rock removed might even be greater than that of ore proper (Table 21, see also chapter 2.3.1).

Waste rock resulting from underground mining is typically used directly to backfill the mine and is not stored above ground, except during the construction phase of the mine, when there is no need for backfill as yet. At that time, waste rock can be typically used in building the system of roads at the mine, for instance. The waste rock

Table 21. Quantities and use/storage of waste rock and process wastes at Finnish metal mines in 2009.

Mine	Ore extracted t/a	Waste rock extracted t/a	Use/storage of waste rock	Process waste t/a	Disposal/ storage
Kemi mine[1)]	1 324 780	497 628	Waste rock from underground mine used as backfill, waste rock from open pit used as backfill and small amount sold	Tailings 500 565	Storage in waste pond
				Lumpy rock 158 578	Use in underground backfill
Kittilä mine[2)]	780 000	8 990 000 (open pit)	Stored in stacks, classified according to chemical properties	NP tailings 1 000 000	Stored in separate ponds
		489 000 (underground)		CIL tailings 50 000	
Pyhäsalmi mine	1 396 450		Placed in pits	Tailings 732 325	Stored in waste pond
				Tailings 178 423	Returned as backfill
Talvivaara mine	10 800 000	4 300 000	Some used to fill base of secondary leaching heap (initial phase), most stored in waste rock storage area	Gypsum precipitate	Stored in pond
				Iron precipitate, other metal precipitate	Stored in pond
Orivesi mine			Placed in pits		
Jokisivu mine	35 950	382 270	Storage in disposal area (overburden 48 740 m^3 for noise abatement barrier)		
Sastamala concentrating plant				200 000	Stored in pond
Lahnaslampi mine	427 754	110 597	Stored above ground/ pit backfill	254 502	Stored in a waste pond, 28 741 put to use

[1)] Figures based on 2008 operations, as production at the mine was suspended a number of months in 2009.
[2)] NP tailings are a mixture of tailings and neutralising precipitate and CIL tailings are waste from the gold leaching circuit.

Figure 19. Waste rock area at the Lahnaslampi Mine (Photo Mondo Minerals B.V. Branch Finland)

produced in open pit mining is stored at the mine site (Figure 19) if it cannot be used for example in earthworks at the mine site. The opportunities to exploit waste rock depend on its geotechnical properties and environmental acceptability (see chapter 5.4.2 and Appendix 6). Environmentally acceptable waste rock may also be suitable for sale for use in earthworks outside the mine.

The piles of waste rock stored or disposed of in the mine area may cause emissions of mineral dust and emissions into water bodies. Waste rock is usually stored as large rocks, which prevents significant dust emissions. However, there may be gaps between the rocks that contain finely ground mineral material, which easily rises as dust. The possible weathering of waste rock, the lack of a layer of topsoil that would support vegetation and the considerable height of the piles of waste rock increase the risk of wind erosions and the dust this causes.

The nature of emissions into water bodies from waste rock depends primarily on the mineralogical and chemical properties of the rock (see chapter 4.1). If, for example, a pile contains sulphide minerals and is acid generating, it may discharge metal-bearing acidic drainage waters into surface or groundwater in the surroundings (cf. Table 16). The water flowing from waste rock piles will also contain residues from explosives, which cause nitrogen loading in surrounding bodies of water.

Tailings

The waste produced by ore concentration consists of finely ground ore and waste rock minerals as well as residual amounts of the chemicals used in the concentrating. This waste is typically disposed of as a water slurry pumped into a dammed pond in which the solid matter settles to the bottom and the decanted water is piped to be treated, recycled or conducted directly into a body of water (Figures 20 and 21). As the amount of material grows, the height of the dam surrounding the tailings pond is raised to increase its storage capacity (see chapter 5.4.4.2).

Most of the tailings formed are disposed of in tailings ponds (Figure 20), as opportunities for further use are limited. The limitations include the tailings' physical (e.g. fine granularity, strength) and chemical properties (e.g. sulphidic tailings have acid-generating potential and metals harmful to the environment; see chapter 4.1). The quantity of tailings requiring final disposal may often be reduced, however, by using the coarsest part of them as backfill in an underground mine. When tailings are used in this way, a small amount of hardening agent is typically added (cement, blast furnace slag, fly ash) to make the material better suited to the task of reinforcing the mine. The use of backfill is important for activities at many mines. The new paste backfill technology makes it possible to use almost all tailings as backfill. In that technology tailings are thickened and turned into a paste-like material, which is pumped into the underground mine for use as backfill (INAP 2009, EC 2009).

Tailings ponds may cause water and dust emissions and occasionally, to a minor extent, odours as well. The tailings pumped into the tailings pond as a slurry are very fine grained and can cause significant dust emissions if they dry. This is exacerbated by the large surface area of the ponds and their typically being located higher than the surrounding terrain. When the concentration plant is operating and the tailings are spigotted around the entire perimeter of the dam, drying of the pond surface is less likely than, for example, where tailings are discharged at a single point. When tailings are pumped into the pond from the edges, the finest material travels towards the centre of the pond and the coarsest remains near the discharge outlets. Particularly when the weather is dry and windy, dust may rise from the dry dam embankments and from the area between the dam and the water-filled section of the pond, where the material may dry out. Odours can be caused by the residues of concentration chemicals in the tailings or as a result of chemical and biological processes that take place in the pond (e.g. the production of hydrogen sulphide).

The most significant emissions from tailings areas are typically those passing into surface or groundwater bodies through either discharges or seepage. The quality of water being discharged from a tailings pond depends on, among other things, the composition of the ore deposit, the mineral processing techniques and chemicals used, the disposal technique of the tailings and the structure of the tailings pond (Table 15 and see also Heikkinen 2009). In the case of metal ore mines, drainage water is usually acidic and contains varying amounts of the heavy metals or metalloids found in the ore (Table 15, chapter 4.1). Some processing chemicals may also cause nutrient loading (SO_4, P, Ca).

The amount of water in the tailings pond is regulated through a decant system. The water is typically conveyed into a settling pond, from where it is returned to the concentration process or discharged, after sedimentation, into a body of water. Especially dams built from tailings require a sufficiently extensive drying zone (known

Figure 20. Tailings area at the Pyhäsalmi mine. (Photo Pyhäsalmi Mine Oy)

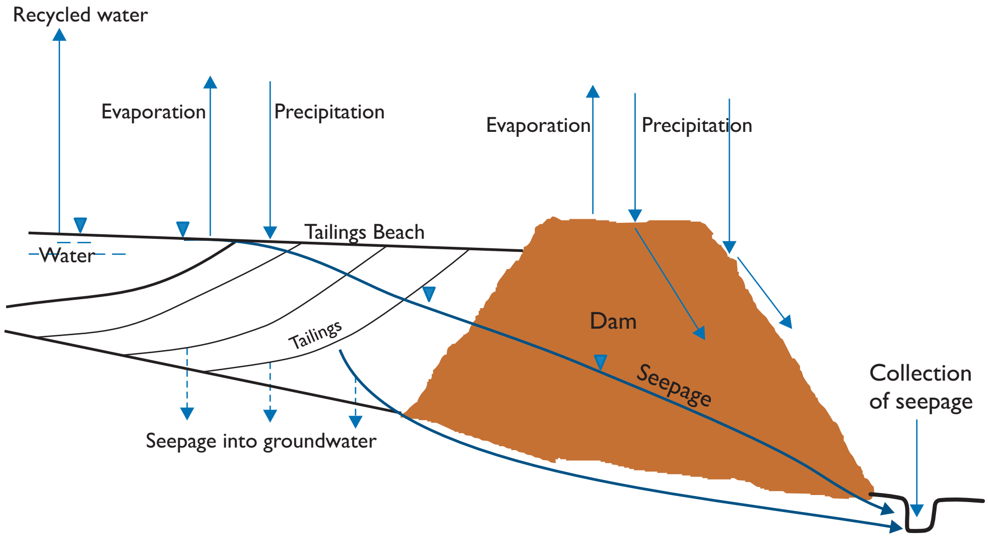

Figure 21. Water flow routes in the dam area of a tailings pond without an impermeable base layer.

as a beach) between the dam and the water in order to ensure the stability of dam structures (see chapter 5.4.4).

In addition to the normal discharge of water from a tailings pond, water may seep through or under the dam (Figure 21). Seepage is generally collected into a perimeter drainage ditch, from which the water can be returned to the pond if its quality makes it unsuitable for discharge into a water body. Water from tailings can also seep into the groundwater if the base of the pond is permeable material. Generally, the structure of the soil in the base of the pond is studied before construction and the base is lined, if necessary with an artificial liner, for example plastic, bentonite, or the like, to prevent seepage.

Overburden

When mining activities are begun, in particular where an open pit is dug, the surface of the ore deposit is uncovered by removing the overburden. This material is stored near the pit and used as opportunities arise in earthworks at the mine. Overburden can also be stored for use in after-care of the mine, in which case storage may be very long term. If the geotechnical properties or environmental quality of overburden removed prevent its being used in earthworks during or after the operation of the mine, it is disposed of in the area. The quantity and quality of the overburden removed depend, among other things, on the size of the pit and the thickness and structure of the local topsoil.

Mineral precipitates and sludges

Various mineral precipitates and sludges may form in mining activities as part of mineral concentration or water treatment. In concentration, mineral precipitates may form as part of, among other processes, the chemical treatment of the residual leachates of the leaching process or washing water. For example, in the post-treatment of extraction leachate during the recovery of precious metals, the Talvivaara mine produces some 800,000 t/a of intermediate neutralisation sludge consisting of gypsum and 700,000 t/a of metal hydroxides and gypsum. No beneficial uses for these materials have been found, and accordingly gypsum sludge is disposed of in waste rock areas with impermeable bases and metal hydroxide-gypsum sludge is placed in a separate water-tight pond (Environmental Permit Authority of Northern Finland 2007). The neutralisation sludge produced as a result of the pressure oxidation process used at the Kittilä mine is stored in the tailings ponds along with the tailings.

The treatment of water at a mine area may create mineral precipitates and sludges. Sludges composed of mineral precipitates, such as hydroxide precipitates, are produced in, among other instances, the chemical treatment of water, for example neutralisation or precipitation. Hydroxide precipitates are also produced in the aeration of water containing iron, for example in tailings ponds. The composition of the mineral precipitates involved depends on the quality of the water being treated and the chemicals used.

Depending on their composition and how they are stored, mineral precipitates and sludges may cause dust emissions or emissions into water bodies through runoff.

Other wastes

In addition to the mining and process wastes described above, mines produce other wastes, which are independent of the mining and concentration processes. These include:

- cardboard and paper wastes,
- waste metal,
- electrical and electronics waste,
- rubber and plastic waste,
- domestic waste water,
- etc.

Wastes are generally sorted and sent on for recycling or to landfills. Efforts should be made to reduce the amount of waste sent to landfills.

Domestic waste water is treated separately either in the mine's own biochemical water purification plant or at the municipal waste water treatment facility.

4.2.3.4
Noise and vibration

Environmental noise refers to sound or vibration that is harmful to health, significantly reduces the amenity values of the environment or markedly hampers work. Noise affects human health, causing, among other things, hearing damage and sleeping disturbances.

The principal sources of noise and/or vibration emissions in mining are blasting, the drilling of charging holes, the loading and transport of the loosened stone material, crushing, the breaking up of oversized rocks, and the screening and grinding associated with crushing. In mining, the processes from crushing onwards generally take place indoors, making it possible to minimise the impact of noise on the environment through structural planning. In some cases the sources of noise (blowers, etc.) in the concentrating plant and its associated operations may be significant due to the fact that the noise they produce is narrowband noise.

Noise emissions caused by mining operations are often described as the equivalent A-weighted sound level caused in the closest locations suffering from the noise produced by the sources of noise. The method calculates the corresponding level of equivalent steady noise for the noise produced by mining operations, for example during daytime, from 7:00 to 22:00 hours. The planning of noise abatement measures or development of a noise dispersion model requires knowledge of the sound power of each piece of equipment. Noise measurements are carried out at a mining site to determine the level of noise (Figure 22).

Blasting causes not only vibration of the ground but also vibration of the air, the frequency of which places it partially within and partially below the range of human hearing. This low-frequency vibration of the air is called an air pressure wave. The factors affecting the magnitude of the wave vary from blast to blast, which makes it difficult to estimate the magnitude of the wave. The propagation of the wave into

Figure 22. Noise measurement at the Kittilä Mine. (Photo: Agnico-Eagle Mines Ltd.)

the environment and at the same time the risk of damage it poses are affected by, among other things, the weather, the terrain, obstacles in the path of the wave and the direction from which the wave comes. Other factors relating to the generation of the air pressure wave are the air pressure and ground vibration impulses. The pressure wave is largest when the explosive is detonated in the air or as a surface charge.

4.2.4
Emissions during closure and after-care of the mine

When mining operations cease, after-care and closure procedures are carried out at the site (see chapter 2.4, Heikkinen *et al.* 2005) that are designed to minimise the emissions from the closed mining site. When production has ended, the level of emissions declines compared to what it was during operations. After closure, what is left at the site are primarily the mined out spaces and the storage piles of mining wastes on which after-care measures have been carried out. These sources may pollute the surface and groundwater. At mines that use heap leaching one also finds piles of residual crushed ore. These piles, which remain after precious metals have been extracted by leaching, will have been treated as part of after-care.

As mined out spaces fill with water, water may flow into the environment either in the form of overflow or through cracks in the bedrock. Similarly, depending on the after-care measures, runoff water may be discharged from piles of stored mining wastes by seeping through dams or the base of the pile if the structures of the base are not water-tight and the material at the base is permeable (Figure 21, chapter 4.2.3.3).

Seepage may sometimes continue for a long time following closure of a mine. For example, if a waste storage pile is covered with a water permeable cover, seepage may continue indefinitely depending on the amount of precipitation in the area.

The quality of drainage water depends crucially on, among other things, the type of ore deposit, the composition and chemical weathering of the waste material, the chemicals used in processing and the explosives used in excavation (cf. Tables and 15 and 16, chapter 4.1). In addition, the quality of drainage water is affected by the after-care measures that are carried out (see chapters 6.2.3 and 6.3). The quality of drainage can usually be improved through various water treatment methods before it is channelled into the environment (cf. chapter 6.2.2.1). For purposes of such treatment, the runoff is collected using a system of drainage ditches.

Mines closed in the past – before legislation requiring modern closure procedures – may cause not only emissions into water bodies but also dust emissions, from sources such uncovered tailings ponds or areas on the site where no after-care has been carried out. As in the case of water, the quality of dust depends on the mineralogical and chemical composition of the ore deposit. Depending on the type of mine, dust can contain heavy metals and metalloids that are harmful to the environment. Dust may also contain sulphide minerals, whose oxidation may cause acidification of the soil and thus of surface and groundwater as well.

The emissions associated with the closure of a mine and after-care solutions are dealt with in more detail in the Mine Closure Handbook (Heikkinen *et al.* 2005).

4.3

Environmental impacts

As used in this chapter, "environmental impacts" refer to the impacts described in section 2 of the Act on Environmental Impact Assessment Protection (see chapter 3.2.2), that is, the direct and indirect impacts of operations on human health, living conditions and amenity, the soil, water, air and climate, vegetation, organisms and biodiversity, the community structure, buildings, the landscape, townscape and cultural heritage. Over its life-cycle, a mine has both positive and negative impacts on the surrounding society and nature. The extent and nature of the impacts vary at different stages in the operation of the mine and depend primarily on the ore type and the size of the deposit, which have an effect on the scope of operations and the methods used to extract and process the ore (e.g. open pit vs. underground mine). The sections that follow describe the environmental impacts associated with the different stages in the life-cycle of a mine.

4.3.1

Impacts on the natural environment

Metal ore mining may have impacts on the following:

- soil and bedrock
- surface and groundwater
- air quality
- biodiversity
- organisms and
- the landscape.

4.3.1.1

Impacts of ore prospecting on the natural environment

The impacts of ore prospecting on the natural environment are generally minor. The nature and significance of the impacts depend on the phase of prospecting involved, the investigations required at that stage and the scope of the studies. The impacts of regional ore prospecting are largely confined to the temporary noise caused by aerial measurements. The impacts on the natural environment of targeted ore prospecting are generally minor and self-repairing, as outcrop mapping and surface sampling, boulder prospecting and geophysical and geochemical field work do not alter the state of the environment. The impacts of studies and sampling primarily affect the surface vegetation locally, for example, moss covering bedrock or the trees on a measurement line. The traffic required in ore prospecting uses forest roads or where there are no roads, movement takes place on foot or using light terrain vehicles. Motor vehicles may leave traces in the terrain in some places. This activity has no impact on the landscape, soil, surface or groundwater. The dust, noise and vibration associated with a given prospecting site are short term and cannot be considered significant (Table 22).

If ore prospecting progresses to further studies and more extensive exploration trenches are dug and bedrock drilling and/or pilot excavation is carried out, environmental impacts may occur. At such a point, the work no longer falls within the scope of everyman's right but requires an ore prospecting permit (Figure 23). The permitted measures depend on the conservation values of the areas and on the relevant legislation (see chapter 3.1).

Digging exploration trenches may require the removal of trees and cause turbidity locally in surface waters or changes in the area habitats. The harmful effects may well be significant; for example, where trenches are dug without a comprehensive, appropriate plan, springs, other valuable habitats and vegetation may be destroyed.

The environmental impacts of drilling depend on how heavy the equipment used is. Lighter tracked vehicles do not leave significant traces in the terrain but movement using such vehicles may require that trees be removed from the routes they use and from the drilling site and occasionally that a system of light roads is built. In addition, traffic between the drilling site and maintenance area may cause minor environmental impacts, for example damage to the surface root systems of trees. The water needed in drilling is taken from streams in the area and from earlier drill holes or is brought in in tanks. When drilling operations are finished, the drilling fluid is absorbed into the soil after passing through a sedimentation vessel. In drilling, groundwater under pressure may be expelled through the borehole. After drilling, a protective pipe is often placed over the borehole to make it available for future studies. The harm associated with pipe, which protrudes above the surface and is capped, is primarily aesthetic. If the protective pipe is removed, the hole will fill up over time with dirt

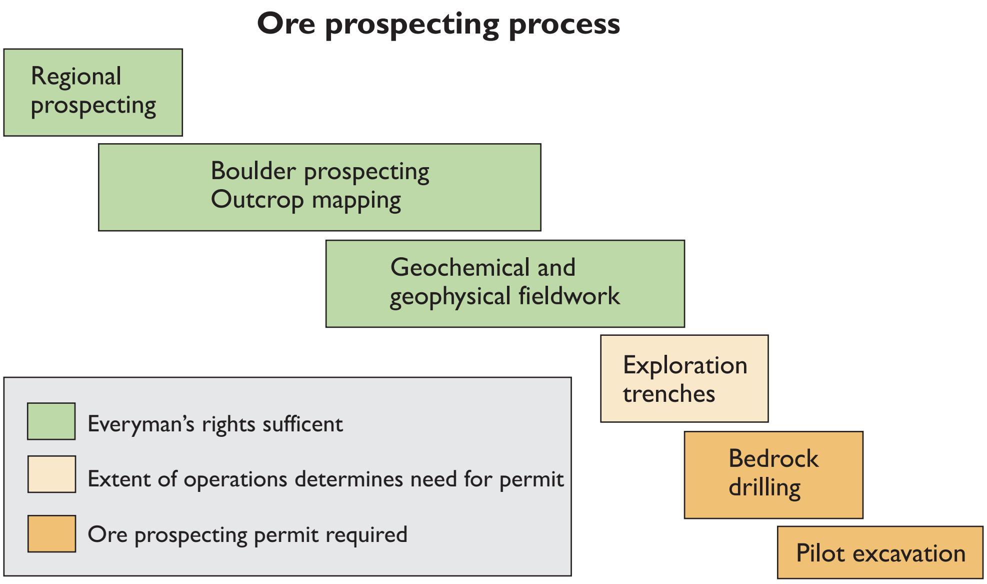

Figure 23. Diagram of the stages from regional prospecting on as impacts increase towards operations requiring an ore prospecting permit under the Mining Act. The notifications and permits required by the Environmental Protection Act are dealt with in chapter 3.

Table 22. Impacts of the different ore prospecting activities on the natural environment.

Impact/ activity	Landscape	Soil	Surface waters	Ground-water	Vegetation/ Organisms	Dust	Noise	Vibration
Outcrop mapping	No	No	No	No	Removal of moss for duration of mapping	No	No	No
Sampling of outcrop surface	No	No	No	No	Removal of moss for period of mapping	Minor	No	No
Boulder prospecting	No	No	No	No	No	No	No	No
Geophysical field work	No	No	No	No	Removal of trees from exploration lines	No	No	No
Geochemical soil sampling	No	No	No	No	Self-repairing impacts from moving equipment	No	Minor	No
Exploration trenches	Possible during exploration	Possible during exploration	Possible during exploration	No/ minor	Impacts at the excavation site during exploration	Minor	Minor	No
Bedrock drilling	No	No	No	No	Impacts from moving equipment	Minor	Moderate	Minor
Pilot excavation	Yes	Possible	Possible	Possible	Possible	Yes	Yes	Yes

and close up. Exploratory drilling does not affect the quality of groundwater, and the noise and vibration impacts associated with drilling are minor and local.

Pilot excavation changes the habitats and landscape of the location. The long-term pumping of dewatering water at the pilot excavation site may lower the water table and, for example, cause changes in the water resources of peatlands surrounding the site. Pilot excavation also causes noise (blasting and the use of drilling, transportation and similar equipment), emissions into water (sediment and metal emissions in dewatering water as well as nitrogen emissions from explosives) and the air (e.g. dust emissions from excavation, exhaust fumes from equipment). In addition, pilot excavation produces soil and rock waste (mining wastes) and other waste. All of these may cause pollution or the risk of it.

4.3.1.2
Impacts of the establishment of a mine on the natural environment

When a mine is being opened, earthworks are carried out as preparation for excavation (removal of the vegetation cover and surface soil, excavation of dimension stone and waste rock in an open pit, construction of the access tunnel into the underground mine and the mine heads) and water channelling work is done (extraction of water for use, recovery and recycling systems, cf. chapter 2.2). While a mine is being built, the pumping of dewatering water from the mine begins.

Construction at the mine site has impacts on the natural environment corresponding to those of construction projects of comparable scale. Construction alters above all the area's landscape, topography and land use, typically changing the mine district in a short period of time from what was primarily land used for forestry and recreation– an area in a nearly natural state – into an industrial area/environment. The changes in the area's surface features and landscape may be quite rapid and striking indeed during the construction phase. The landscape changes dramatically as soon as the vegetation is stripped and the required earthworks, building of the infrastructure and preparations for excavation are undertaken. Storage of unusable waste rock and overburden in the area also changes the landscape and topography. If the ore is processed on the same site as the mine, a tailings area is built, which also requires earthworks and, among other things, the building of dams. Changes in the landscape and topography are generally more extensive in the case of open pit mining than in underground mining, in particular if the waste rock excavated in underground mining can be used in supporting and filling drifts.

Construction and the start of mining also increase traffic, noise and dust. These, as well as the stripping of overburden and earthworks, have impacts on the biodiversity, the living and breeding conditions for fauna and flora, and the number of species of the area in that habitats become fragmented, disappear, decline in number or change in nature. In addition to the building of the mine itself, construction of power lines and road networks, as well as the traffic involved, may have impacts on the movement of organisms and on their territories over a broad area. In addition, the noise caused by construction, excavation (e.g. blasting) and increased traffic may cause changes in territories. In the case of some species of organisms, noise has been shown to have a harmful effect on reproduction, among other things. The spread of dust containing metals and sulphide minerals may affect the quality of the soil, change growing conditions for plants and cause elevated levels of metals in the mushrooms and berries in the area near the mine site. Dust created during construction may also have an effect on air quality locally.

Stripping of the vegetation and soil cover, construction and water drainage alter the hydrology of the area, changing, for example, the absorption and direction of flow of water and the amount of runoff. The stripping of vegetation and earthworks increase erosion and surface drainage, which in turn increase the quantity of solid material passing into water bodies and may lead to turbidity of water locally. Turbidity and changes in water flow conditions and the directions of flow have impacts on the living conditions of water organisms. Increased surface drainage also reduces the formation of groundwater in built areas. For their part, construction of stopes and pumping of dewatering water lower the groundwater table in the vicinity of the mine and reverse the direction of flow of groundwater, turning it towards the mine. Lowering of the water table may result in wells drying up in nearby areas. Changes in the water resources and hydrology of the area may also change the growing conditions of plants and result in changes in habitats and species composition.

In addition to the quantitative changes noted, solids, metal, nitrogen and other emissions affect the quality or surface and groundwater. These originate from the runoff in areas where the overburden has been removed, dewatering water, the seepage and drainage from waste storage areas and other water coming from the mine site. Qualitative changes in the water in turn affect the thriving, growth and reproduction of fish and other aquatic organisms as well as the opportunities to use water and bodies of water.

The nature and extent of the impacts in the construction phase depend on the extent of the construction work and the geology of the deposit. Compared to other phases of the mine's operation, the construction phase generally has the most significant impact on the landscape, the vegetation and the hydrology of the surface water. The changes normally take place for the most part at the mining site but in the case of the landscape, for example, they may be visible several kilometres away.

4.3.1.3

Impacts on the natural environment during operation

In the production phase of the mine, the pit becomes broader and deeper, the extracted ore is crushed and the crushed ore is either transported elsewhere for processing or is processed on site. In order to make excavating possible, the mine is kept dry by pumping out water. As mining progresses, the quantities of waste rock increase and when processing commences, the filling of the tailings pond begins.

The most significant impacts on the natural environment in the production phase stem from dust and changes in the area's water resources (Table 23). Dust can be caused by, among other things, excavation, handling of ore, traffic and the storage of ore concentrate and mine waste. As in the construction phase, dust deposition may affect the quality of the soil and water as well as the vegetation and its growing conditions. Where dust collects on the surface of plants, they absorb less light or the surface may suffer mechanical or chemical damage, which impedes photosynthesis and growth. If the dust contains metals or sulphide minerals that are harmful to the environment, the spread of dust increases the accumulation of metals in plants and the soil. This may cause acidification of the soil, which weakens the growing/living conditions of plants and organisms in the soil and, in addition, deteriorates the quality of surface and groundwater. Under acidic conditions, most harmful metals occur in soluble, bioavailable form, making their toxicity to organisms higher. Dust can also cause silting up or turbidity in water. This in turn harms the health of aquatic organisms or changes their habitat, thus causing changes in the species composition.

In the case of open pit and underground mines, the excavation of ore and the dewatering of mine spaces may cause quantitative changes affecting water in the area. Loosening ore by blasting changes the fractures in the surrounding bedrock, altering its hydraulic properties and thus the flow of groundwater. Dewatering lowers the water table and changes the direction of water flows in the surroundings of the mine, which may occasionally lower water levels in groundwater wells in the vicinity or cause wells to dry up. The size of the dewatering cone depends on the depth of the mine and the water conductivity of the soil and bedrock. In addition to dewatering of the mine, extraction of raw water may also lower the level of the raw water source. Efforts are usually made to reduce the need for raw water through recycling. Changes in the water levels may cause the disappearance or regression of plant and animal species that have adapted to the previous state of the site. The significance of impacts depends on the natural conditions of the environment and the conservation values of the vegetation and fauna in the area.

Qualitative changes in the surrounding water bodies may be caused principally by drainage water from the mine waste storage area, waste water, surface drainage water from the concentration plant area and the mine dewatering water. The nature of the changes (the composition of the water) depends above all on the type of ore (cf. chapter 4.1), the ore concentration method and water treatment. In the production of sulphide metals the formation of acidic waters containing metals and sulphate is typical. Acidification of water and metal loading cause harmful impacts on aquatic organisms and the domestic and recreational use of water bodies. In the worst case, these developments can lead to fish deaths. Water from the tailings pond and waste water from the concentration process may also contain residual amounts of process chemicals (e.g. sulphate, organic compounds, metals) which can result in nutrient loading or be harmful to organisms. For example, xanthates and pine oil have been shown to be harmful to aquatic organisms even in low concentrations (Bertills *et al.* 1986; Arizona Chemical 2008). Soluble metals (e.g. Cu, Cd, Pb) increase the harmful effects of xanthates (Bertills *et al.* 1986) and pine oil can increase the biological oxygen consumption of water, which can lead to fish deaths.

Oxidation of sulphide minerals also takes place in mined areas as excavation progresses. The dewatering water pumped from the mine may contain not only suspended solids, metals and sulphate released in the oxidation of sulphide minerals, but also residues of explosives. Explosives are most often ammonium nitrate based, whereby nitrates and ammonium may dissolve from them and pass into the mine water; these substances cause eutrophication. Explosives may also contain organic substances (e.g. mineral oils), which may harm aquatic organisms. During operation of the mine, the quality of the soil and water may also be deteriorated by the storage and handling of chemicals and the leakage of chemicals and oil from equipment. In addition, mine water may contain lubricants and oils from mining equipment and machinery.

The noise and vibration caused by excavation and traffic may disturb animals in the area. Then again, mine areas may form new habitats for organisms. For example the settling ponds in tailings areas often provide important resting and nesting sites for birds.

In addition to the noise they produce, site traffic, equipment and blasting cause a certain amount of carbon dioxide, nitrogen and carbon monoxide emissions to be released into the air. Similarly, power consumption produces – depending on how the power is generated – carbon dioxide, sulphur and nitrous oxide emissions and small particle emissions. Carbon dioxide is a greenhouse gas, which contributes to warming of the climate and nitrous oxides can damage vegetation and cause acidification and/or eutrophication of the soil and water. Sulphur dioxide causes acidification of water bodies and the soil and can weaken plant photosynthesis or cause needle damage. Carbon monoxide and small particles are harmful to health when inhaled.

During mining operations the landscape continues to change to some extent, particularly with the increase in the size of the piles of stored mining wastes. As in the construction phase, changes in the landscape are more likely in the case of open pit mines than in underground mines as the pit increases in size and the storage of waste rock on the surface becomes more extensive.

4.3.1.4
Impacts on the natural environment after mine closure

When mine operations have ceased, all structures and equipment are removed that cause harmful effects on the environment and are no longer needed in the further use of the area. The site is then rehabilitated to make it safe for possible further use. Once closed, a mine site generally only has rehabilitated and landscaped mine waste storage areas as well as the mined out spaces/open pit and related water treatment arrangements. Mined out spaces are supported and/or backfilled; the edges of the pit are shaped to prevent them collapsing; and the mine and pit are allowed to fill with water. As the mined spaces fill, the water table in the surroundings of the mine is restored and the directions of water flow change.

The principal risk to the natural environment from a closed mine is the water potentially discharged from mine waste storage areas and mined out spaces (Table 23). In sulphide ore areas, acid mine drainage may continue for years if the oxidation of sulphides in the waste areas and the mine is not brought under control. Acidic water containing metals from the waste storage areas can seep under a dam or through the base of the area into surrounding groundwater or directly through the dam into the perimeter drainage ditch and the surface waters (Figure 24). As the mine fills up with water, the oxidation products of sulphides that have formed on the walls of the mine and in the backfill are washed out and cause the spread of metal-bearing water along fractures in the bedrock into the groundwater or through overflow into surface waters. Control of the loading on water often requires water treatment and monitoring of water quality for a long time after the mine has been closed. For example, even after

Figure 24. Acid seepage containing iron precipitate (reddish brown) and metals, discharging from a waste rock pile containing oxidising iron sulphides. (Photo M.L. Räisänen)

Table 23. Environmental impacts of mining on the natural environment in different stages of the operations of a mine (shaded boxes). Impacts may be either positive or negative.

<table>
<tr><th>Phase of operations</th><th>Soil and bedrock</th><th>Landscape</th><th>Ground-water</th><th>Surface water</th><th>Vegetation and fauna</th><th>Air quality (dust, emissions into the air)</th></tr>
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<tr><td>Transportation</td><td></td><td></td><td></td><td></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td></tr>
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<tr><td>Landscaping</td><td></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td></td></tr>
<tr><td>Rehabilitated mine waste storage areas</td><td></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td></td></tr>
<tr><td>Mined spaces</td><td></td><td bgcolor="#b0d49a">Open pit mining</td><td bgcolor="#b0d49a"></td><td bgcolor="#b0d49a"></td><td></td><td></td></tr>
</table>

the mine has filled up with water, oxidation of sulphide minerals continues in mine walls that remain above the water surface.

Other risks to the environment from a closed mine site include subsidence of the ground and collapses at the mine or waste rock piles, which can, for example, harm the health of animals.

Although a mine site cannot normally be restored to its pre-mining state, landscaping and revegetation of the area can make it fit in better with the surrounding landscape and prevent impacts from dust. With the spread of vegetation it can be assumed that the area's biodiversity will be restored. In the closure phase, landscaping, covering the waste storage areas and revegetation will cause changes in the area's hydrology that are opposite to those that occurred in the construction phase (e.g. reduction in surface runoff, increased infiltration of water, reduction in suspended solid loads).

4.3.2
Social impacts

In all phases of operation, mining activities have significant social impacts, which occasionally give rise to intense public debate. Social impacts are significantly project-specific multiplier effects and thus differ in nature from other impacts, which are largely based on measurable natural scientific data. The nature and significance of the social impacts caused by mining activities depend not only on the size and location of the mine but also on the flow of information and quality of the dialogue between the mining company and the stakeholders in the area impacted by the mine.

The biophysical and socioeconomic changes that bring about the social multiplier effects of mining activities are often similar to those set out in Table 24.

In the area most affected by the mine, impacts are most clearly felt in terms of livelihoods, amenity and the domestic or recreational use of nature. Impacts are caused by traffic, noise, dust, smoke gases, vibration and waste water.

Farther from the mine site, primarily at the level of the municipality, the favourable impacts on the economy and employment are realised. Through various multiplier

Table 24. Biophysical and socioeconomic processes of change often associated with the establishment of mining activities.

Changes caused by mining activities			
Biophysical changes		Socioeconomic changes	
Terrestrial nature and waters	Protection of conservation values	Habitation	Changes in habitation
	Areas to be protected		Location of new habitation
	Plant species to be protected		Formation of the mining community
	Animal species to be protected	Livelihoods	More active business life
	Surface and groundwater		Changes in present livelihoods
	Impacts on the landscape		New livelihoods and enterprises
	Noise and dust	Economy	Change in the level of services
	Pollution of nature		Increase in tax revenues
	Pollution of waters		Increased wealth, increase in well-being
	Traffic pollution	Employment	Increase in employment
			Indirect jobs
			Training needs relating to mining activities

and indirect effects and the strengthening of the public economy, the impacts affect nearly all citizens. The increased number of workers and people which the mine brings has an effect on the local way of life and improves the supply and availability of municipal and private services.

During the prospecting and planning phase that precedes the building of a mine, perhaps the most prominent concern is the uncertainty of the local residents and primarily the "Not In My BackYard" (NIMBY) thinking. In Finland, prospecting for uranium has met categorical resistance, which has been described using the term BANANA (Build Absolutely Nothing Anywhere Near Anybody).

In Finland the tradition has been that a permanent mining community is nearly always established in conjunction with a mine. Accordingly even today there is uncertainty and concern regarding the effects a mining project will have on the population and what kind of new community will form – and with what potential social problems.

During operation of a mine, the social impacts always affect the focal community as well as the current, broader societal structure. The impacts may be direct, for example those on the economy and employment or the land being excluded from other uses as tracts of land are used for mining (as happens to reindeer herding in areas where the livelihood is practised). Impacts may also be indirect, such as those on the recreational use of the area when the environment changes. Table 25 summarises the most common factors comprising the social impacts of a mining project and the criteria for measuring them, and provides a brief description of the changes that may occur.

The location of the mine and, for example, how work shifts are organised, places various requirements on the location and permanence of the housing for those working at the mine. The social impacts in these circumstances are crucially different. In the case of work and housing arrangements, it should be clarified whether development is to be based solely on demand or supply and what the respective roles of the municipality and the mining company in planning are.

Table 25. Components of the social impacts of a mining project, evaluation criteria and potential changes caused by the project. (See Reinikainen and Karjalainen 2009)

Components of the social impacts	Criterion for measuring impact	Changes possibly caused by the project
Way of life	Population	Changes in the size and structure of the population
	Habitat	Changes in the social character of the area nearest the mine and the municipality
	Economic self-sufficiency	Changes in the domestic and recreational use of nature, e.g. with the change in the physical and social character of the area
Services	Municipal services	Changes in the supply and availability of municipal services
	Commercial services	Changes in the supply and availability of private commercial services
Impacts on reindeer herding in the reindeer herding area	Profitability	Profitability of herding cooperatives. Changes in pasture and calving areas and in pasture rotation impact profitability.
	Number of reindeer	Changes in the number of reindeer
	Image of reindeer products	Changes in how markets perceive reindeer meat and other reindeer products
Municipal economy	Employment	Changes in the number of employed individuals
	Number of enterprises	Changes in the number of enterprises
Tourism	Wilderness image	Changes in the wilderness character of the area and in its marketability

5 Environmental studies

The environmental permit application applied to mining activities shall include comprehensive studies on the emissions and impacts of operations and on the state of the surrounding environment, including the environmental impact assessment report if necessary (see chapter 3.3). The purpose of the environmental studies is to assess the potential impacts on the environment, as well as to mitigate and prevent the formation of detrimental impacts prior to initiating operations, during operations and following the decommissioning of operations. The necessity and scope of these studies depend on the extent and type of operations as well as the location and its environmental conditions. In each mining project, it is recommended that discussions are held with the controlling and permit authorities about what studies are required well in advance of submitting the permit application. In respect to the permit application, the planned operations, including the emissions and impact assessments, should be as far as possible based on the chosen method of implementation.

A significant number of environmental studies (e.g. baseline study, Natura assessment) are conducted prior to the commencement of activities as part of the environmental impact assessment and/or environmental permit application. The condition of the environment and the loading subjected to it is monitored during operations (see chapter 7), the findings of which can be used as the basis for employing potential mitigating methods for managing loading (see chapter 6). Determining the sources of uncontrolled emissions or loading often requires independent studies during operations. Following the closure of the mine, monitoring is used for inspecting the environmental impacts of rehabilitation measures and the functioning of such. These measures may also be subject to study.

5.1 Baseline study

Prior to commencement of mining activities, a so-called baseline study is conducted with the purpose of surveying and illustrating the requirements and pre-conditions set for implementation and the methods of implementation. Furthermore, the intention of the study is to describe the current state of the environment of the region before taking action that causes significant changes (see Salminen *et al.* 2000, Heikkinen *et al.* 2005). At the very latest, baseline studies for mining projects are conducted before larger scale earthmoving or excavation work is performed in the ore prospecting or mining area.

The baseline study provides a good starting point for the assessment of the environmental impacts caused by operations, and for the placement of facilities while taking local environmental conditions into account. In the later stages of operations, the initial state surveyed for the baseline study works as a good basis for comparison for the monitoring of operations, assessment of impacts caused by operations and the setting of rehabilitation objectives. Consequently, the baseline study should focus on the factors/conditions:

1. on which future mining operations may have an impact on conditions (e.g. quality of water and/soil, heights of surface and groundwater, flow rates and directions, natural springs, population or flora and fauna of the region, valuable habitats, land use), or
2. that may be significant with regard to the generation of impacts (e.g. hydrogeological characteristics of the soil and bedrock, landforms, precipitation and wind direction; cf. Emissions and environmental impacts, chapter 4).

For example, the physical and chemical descriptions of water and soil shall cover all potential loading factors subjected on the baseline state of the region by operations (e.g. harmful substances, nutrients, chemicals, radiation) or in respect to the changes on the quality of the environment. In addition, one of the most central tasks of the baseline study is to conduct sufficient studies on the soil and bedrock to determine the placement of mining waste areas (cf. chapter 5.4.3.1). Using drilling data, an estimate of the environmental compatibility/acceptability (cf. chapter 5.4.2) of waste generated, in particular concerning waste rock, is usually appended to the baseline study. The extent of the baseline study is made to correspond to the extent of the project.

The baseline study usually includes description of the planned operational area and its impact region with respect to the following:

- natural state (e.g. landscape, landforms and elevations, nature types, flora, fauna, birds),
- climate and air quality,
- geology and environmental quality (e.g. structure of soil and bedrock, geochemical and hydrogeological characteristics; geochemical composition of mosses, humus and aquatic sediments),
- surface and groundwater (e.g. catchment areas, groundwater areas, hydrology and hydrogeology, geochemical and physical quality, water use, use of water areas and fishing, estimate of the bearing capacity of the receiving waterway),
- land use and the cultural environment (e.g. types of land use, social structure, properties and infrastructure, planning, traffic, exploitation of natural resources),
- conservation (e.g. conservation areas and grounds for protection), and
- socio-economic conditions (e.g. population and structure, housing, living conditions, contentment, services, business).

In projects with the intent of excavating uranium or deposits containing uranium, the baseline study shall also cover the radiological baseline state of the area (occurrence of uranium and other radionuclides in the environment as well as radiation levels).

The contents of the baseline study are described in more detail in the EIA guide for mining projects (Salminen *et al.* 2000) and in the Mine Closure Handbook (Heikkinen *et al.* 2005). The baseline study usually acts as foundation for the environmental impact assessment as intended by the EIA Act and for the environmental permit application. Appendix 4 shows an example of the table of contents for a baseline study.

5.2

Determining environmental impacts

Legislation requires for all of the environmental impacts associated with the operations of the mining projects to be studied prior to initiating activities (e.g. Environmental Protection Act 86/2000 section 5, Environmental Protection Decree sections 9 & 11, Nature Conservation Act 1096/1996 section 65, Act on Environmental Impact Assessment

Procedure 468/1994, Mining Act 621/2011). This obligation is based on the general duties stipulated in the Environmental Protection Act for operators to have sufficient knowledge of the environmental impacts of their activities, the environmental risks and of ways to reduce the harmful effects (Environmental Protection Act, section 5).

The correct timing for the environmental impact assessment can already be during the ore prospecting projects if, for example, operations are planned to be located in an area that belongs to or is proposed for the Natura 2000 network, or in an area located close to these (see chapter 5.2.2; cf. e.g. Idman & Kahra 2007), if ore prospecting forms earth and rock waste (Mining Act 621/2011), or if pilot excavation and/or concentration is performed (cf. Mustonen *et al.* 2007). In other cases, the impacts are usually assessed no later than in connection with the submission of the application for the environmental permit.

The scope of the studies to be conducted depends on the scale of operations. In ore prospecting projects the impacts are assessed in the waste management plan for mining waste and in smaller mining projects as part of the environmental permit application, but in larger projects the EIA procedure is implemented as intended by the EIA Act (cf. chapter 3.2.2).

5.2.1
Environmental impact assessment

The assessment of environmental impacts shall be conducted no later than when applying for the environmental permit. Depending on the extent of operations, impacts are either assessed as part of the waste management plan for mining waste (part of the ore prospecting projects) or as part of the environmental permit application, or during the independent EIA procedure that was conducted prior to submitting the environmental permit application (cf. chapter 3). The environmental impacts for assessment shall include the direct and indirect impacts focused on the natural environment, cultural environment, people and society, which may be either positive or negative. The assessment shall inspect the impacts during the entire lifetime of the mining project, from the construction stage to closure and rehabilitation.

A prerequisite for conducting a successful environmental impact assessment is to obtain sufficient information on the baseline condition of the area (see chapter 5.1) and a precise plan of the production process intended for the mining project (e.g. extraction, concentration processes, emissions generated, lifetime). The environmental impacts of operations cannot be sufficiently assessed if there are deficiencies in the operational plan and the data pertaining to the quality and quantity of emissions.

The environmental impact assessment is an important part of planning for the entire project, as only once the environmental impacts have been predicted can the necessary measures be planned and implemented for the prevention or mitigation of detrimental environmental impacts. For instance, the planning of the structures and water management necessary for the mining waste areas requires the conducting of an environmental impact assessment based on the characterisation of the environmental compatibility of mining waste (cf. chapter 5.4). The environmental risk assessment can be used for helping to focus risk management measures (see chapter 5.2.3).

In mining projects, the most important environmental impacts are e.g. (cf. Tables 22, 23 and 25):

- The impact of the construction of the mining area on the landscape, natural conditions in the area, land use and hydrology, as well as on the quality of water, air and soil
  - Earthworks, preparation for excavation, construction of the infrastructure, construction of haulage and power line connections, increase in traffic, noise and dust, stockpiling of soil masses

- Emissions generated from excavating and crushing and the impacts of such on people and the environment of the region
  - Impacts of noise, dust and vibration
  - Impacts of pumping dewatering water on the water levels and flow directions in the area, as well as on the use of waterways and the natural environment
  - Impacts of excavations and the use of blasting agents on water quality
- Emissions from concentration and storage of concentrate and the impacts of these on the air, soil and water quality
  - Process water/waste water produced, impacts of concentration process chemicals on the waterways, dust dispersion
  - Airborne emissions generated by bioleaching and chemical handling
- Water management and conducting arrangements (raw water intake, waste water, dewatering water)
  - Impacts on water quality, quantity, flow directions and recreational use
- Impacts of emissions from disposal of mining waste and final disposal on the quality of air, water and soil
  - Characterisation of mining waste, quality of drainage and seepage (including concentration chemical residues)
  - Dust dispersion
- Use of chemicals and storage
  - Impacts on the quality of water, soil and air (chemical residues in water, chemical leaks in storage or transportation)
- Traffic and transportation
  - Impacts of noise and dust, airborne emissions, emissions to the soil
- Impacts of the project on people, society and the cultural environment
  - Impacts of emissions on health
  - Impacts of changes in land use on livelihoods, recreational use, exploitation of natural resources, built-up environment and properties, and on the values of such
  - Impacts on the social environment (e.g. population, livelihoods and services, housing, familiar safety and contentment, employment)
- Decommissioning of mining activities and closure of the mining area
  - Impacts of measures employed for closure
  - Impacts of structures remaining in the area, in particular mine waste areas and excavations filling with water; impacts on water quality, risk of collapse
  - Impacts on the land use and landscape of the area.

A number of independent studies on the condition of the environment as well as emissions generated by operations and the dispersion of such are required for the basis of impact assessments. Typical studies conducted for mining projects include, for instance:

- Baseline study (see chapter 5.1)
- Nature studies and surveys (vegetation, nature types, fauna, birds, aquatic ecology, fish populations, nature and conservation values, biodiversity); assessment of habitat changes
- Characterisation of the environmental compatibility of mining waste produced (see chapter 5.4.2) and the assessment of emissions associated with the waste areas
- Gathering of environmental data of concentration process chemicals and material safety sheet data
- Estimates/calculations of the extent of the pit dewatering drainage cone, including quantity and quality of pumped dewatering water

- Estimate of the quantity and quality of waste water produced, and the tolerance of the receiving waterway
- Water balance calculations and estimates of changes in flow rates
- Calculations for migration of harmful substances in the surface water and groundwater
- Estimates/calculations/modelling for quality and dispersion of dust and gaseous emissions (incl. exhaust emissions)
- Landscape analysis
- Noise modelling
- Vibration calculations
- Estimation of transportation and traffic numbers, accident inspection
- Interview and questionnaire studies aimed at the local inhabitants for the purpose of the social impact assessment.

The EIA procedure shall present alternatives for the implementation of the project in respect to the operations and the environment in order to find the most reasonable overall solution. Implementation alternatives presented for mining projects can include e.g.:

- the placement of mining and concentration functions in a single facility or as separate facilities (ore haulage elsewhere for concentration)
- placement of the main functions of the operations in the mining area (concentration plant area, areas for waste rock and tailings)
- realisation of ore concentration and further refinement of the concentrate
- water management (raw water intake, conducting of waste water)
- organising transportation (realisation of transportation, transportation routes).

The contents of the EIA procedure and EIA assessment for mining projects are described in more detail in the publication of Salminen *et al.* (2000). In addition, for instance Stakes and the Ministry of Social Affairs and Health have published guidebooks on the social impact assessment focused on people (e.g. Juslen 1995, Ministry of Social Affairs and Health 1999, Kauppinen & Tähtinen 2003, Nelimarkka & Kauppinen 2007). The websites of the ELY Centre (i.e. Centre for Economic Development, Transport and the Environment) and Finland's Environmental Administration show examples of EIA procedures that have been recently implemented and are ongoing (Finnish Environment Institute 2010b, Centre for Economic Development, Transport and the Environment 2011).

5.2.2
Natura assessment

A Natura assessment shall be made for mining projects with operational areas located in areas that have been proposed or incorporated for the Natura 2000 network, in the vicinity of such or upstream from such area. The assessment assures that the mining project will not have harmful impacts on the justifications for protection used for the incorporation of the Natura area. The assessment shall be made when applying for the ore prospecting permit, or no later than when applying for the mining or environmental permit (cf. chapter 3; Söderman 2003, Idman *et al.* 2007). If the EIA procedure is also required for the mining project, the Natura assessment is usually done as part of the EIA procedure (Söderman 2003).

Prior to conducting the actual Natura assessment and statement issuing procedure, an evaluation of the need for the Natura assessment (i.e. Natura needs assessment) may be conducted, the purpose of which is to examine whether or not the project requires the actual Natura assessment and statement procedure (cf. chapter 3.2.3).

The EC Court of Justice rulings have always stipulated for the Natura assessment to be performed if there is some uncertainty as to whether impacts will be incurred by the Natura area (Ylitulkkila *et al.* 2009). In practice, mining projects usually conduct the Natura assessment regardless.

The Natura assessment describes a detailed estimate of the impacts of mining operations on those natural values of the Natura area that were used as the justification for the inclusion of the area to the Natura 2000 network. Justifications for protection are nature types and/or habitats of species (so-called SCI or SPA areas). The assessment is done by nature type and species by assessing the direct and indirect, short and long term one-off and joint impacts of the various implementation alternatives for the mining project on the protected nature values (including factors that impact nature types and the living and growing conditions for fauna or the area coverage of such) and the integrity of the Natura area (in other words the living viability of the ecological structure and operations of the area) during the different stages of the lifecycle (e.g. EC 2001, Söderman 2003). Furthermore, the measures employed for the prevention or mitigation of harmful impacts are described, including a description of the methods used for arranging the monitoring of impacts. The most important task is to estimate the significance of the impacts. The assessment is usually focused on the part of the Natura area to which the impact region of the mine extends.

As the basis for Natura assessment, vegetation and nature type surveys will be conducted on the Natura area, including a bird population study, or existing survey data will be used. In addition, the assessment requires the data produced in the baseline study and environmental impact assessment about the condition of the environment in the area, and the quality and extent of mining operation impacts (e.g. findings of noise and dust modelling).

In the Natura assessment for mining projects the impacts typically assessed can be e.g.

- overall alteration of the mining area and the impact of the placement of mining operations (pit area, industrial area, mining waste areas) on species and their habitats
- the impact of dewatering of the pit area/underground mine and other water conducting arrangements on the groundwater and surface water levels (e.g. drainage of water areas, changes in flow rates or flow directions) and through this to the habitats of species
  - conic inspection; hydrology of soil and bedrock, and fracture interpretations
- impact assessment of airborne emissions
  - impacts of dust dispersion (direct and indirect) caused by excavating, crushing, rock material haulage, traffic, and the moving and storage of soil masses (waste rock, overburden masses, intermediate storage facilities for ore, tailings areas) on species and habitats (estimation of dust dispersion and quality),
  - the impacts of gaseous emissions from traffic and work machinery (SO_2, NO_2) on species and habitats (quality and dispersion of gases)
  - impact of airborne emissions generated by the ore processing on species (quality and dispersion of gases)
- impacts on the habitats of species caused by the mining area drainage water, seepage and drainage water of the waste rock and tailings areas, and the excess water of the water storage basin and pit/mine workings
  - water quality and quantities
- detrimental impacts of noise on Natura species during the construction and operational stages

Table 26. Examples of Natura assessments conducted for mining projects.

XNVS	Kevitsa multi-metal mining project	Sokli phosphor mining project	Vaaralampi soapstone mining project
Natura assessment stage	As an independent study in connection with the EIA procedure for the purpose of the environmental permit	As an independent study in connection with the EIA procedure for the purpose of the environmental permit	Application for mining area (concession)
Distance from Natura area(s)	Part of the Natura area lies within the mine impact region (at a distance of >0.5 km); some of the road traffic alternatives travel along road connections leading to the other Natura area	Four Natura areas within the impact region of the mine	Part of the Natura area lies within the planned mining area (concession)
Studies conducted	Studies performed for the EIA procedure and the supplementary studies performed for the Natura assessment: – vegetation study, including nature type survey, – bird population study, – fish population studies, – traffic survey, and – waterway and soil studies.	Studies performed for the EIA procedure and the supplementary studies performed for the Natura assessment: – nature type inventories, – data on the occurrence of flora species, – map and aerial photograph data, – existing vegetation and nature studies, – geological and limnological studies on the impacts of the project on surface and groundwater, and – modelling for dust and noise impacts.	Existing studies: – nature type and vegetation inventories, – data by species, e.g. ecology, – baseline study for the area, and – peat studies and specification of bog regions.
Implementation of the assessment	Impacts were assessed for the protected nature types of the Natura areas before and after conducting measures planned to mitigate impacts.	The direct and indirect impacts of the project were assessed for the conservation grounds of the Natura areas in relation to the various functions of the project during its life cycle, and in respect to the implementation alternatives described in the EIA procedure. The assessment contains a description of measures for the mitigation of impacts, as well as an estimate of the impacts before and after conducting these measures.	Assessment of direct and indirect impacts of the project on the grounds for the protection of the Natura area during different stages of the life cycle of operations.
Statement of the ELY Centre	Supplementary studies were acquired before processing the environmental permit, e.g. for – vegetation inventories, – noise studies, – modelling of airborne emissions, and all – impacts focused on nature types.	The Finnish Environment Institute regarded the assessment to be sufficient for some implementation alternatives, but supplementary reports were requested for e.g. – impacts and the assessment of the significance of such, and – specification of the impact region. The impacts of some implementation alternatives were insufficiently assessed. Consequently, in these respects the Natura assessment needed to be supplemented. Some of the implementation alternatives were regarded as significantly weakening the conservation objectives of the Natura areas. According to statement, with regard to these no permit should be granted for the project.	The Finnish Environment Institute regarded the weakening of nature values in the Natura area to be insignificant.
References	Jokimäki & Hamari 2007	Ylitulkkila *et al.* 2009	Nikkarinen 2004
	Lapland Environment Centre 2007	Lapland Environment Centre 2009	Environmental Permit Authority of Eastern Finland 2007

- impacts of extra traffic and infrastructure;
  - areas covered by or close to the infrastructure to be constructed (transport connections, power lines)
  - emissions and noise
- the direct detrimental impacts of construction and operation of the mining project on the bird population.

The accuracy and extent of the Natura assessment are affected by e.g. the size and nature of mining operations, the distance of the mining project from the Natura areas and the characteristics and value of the grounds for conservation of the Natura area (cf. table 26 and Söderman 2003). The contents of the Natura needs assessment and Natura assessment are described in e.g. the guidelines issued by the European Commission (EC 2001) and the guide published by Söderman (2003). Appendix 5 shows an example of the contents of a Natura assessment.

Natura assessments associated with mining operations have been conducted in recent years in, for example, the Kevitsa multi-metal mining project, Sokli phosphor mining project and the Vaaralampi soapstone project (Table 26). In the Kevitsa and Sokli projects, the Natura assessment was performed in connection with the EIA procedure for the application for the environmental permit, but as an independent study (Jokimäki & Hamari 2007, Ylitulkkila *et al.* 2009). In the soapstone project the assessment was conducted for the purpose of the mining area (concession) application.

5.2.3
Assessment of environmental risks

Risk assessment is a process that identifies a certain hazard and the likelihood of it occurring is specified. The seriousness of the detrimental impacts illustrates the magnitude of the hazard. Efforts are made in the assessment of risks to use scientific means for forecasting harm in the future. The most significant advantage of this procedure is that control measures can be focused on the basis of the researched (modelled) data. Risk management will be implemented using the precautionary principle in cases of uncertainty and where no risk assessment has been conducted, which means control measures may be erroneously focused in relation to the true harm caused.

The integrated environmental risk assessment based on the current model includes the assessment of health risks and ecological risks (e.g. Nikkarinen *et al.* 2008). The assessment of health risks of chemical substances conventionally contains the following sections: 1) hazard assessment, 2) dose-response description, 3) exposure assessment, and 4) risk characterisation. Of these, the first two describe the properties of the substance/exposure agent, assessment of the exposure a situation in relation to which the risk is estimated, and the risk characterisation describes the actual risk in question (magnitude). A similar method is also utilised for the risk assessment of other exposure agents.

In the Ecological Risk Assessment (ERA), harm is a negative event for fauna when it leads to a reduction in the viability of the fauna. Ecological risks may appear on different levels (cell-organism-population-community-ecosystem), but in the assessment of risks, the focus of interest is usually wide-ranging, comprising the detrimental impacts focused on the entire structure of the ecosystem and operations. In practice, the ERA concentrates on ecotoxicological impacts that are usually easier to assess than ecological impacts.

In mining operations, environmental risk assessment can be timely and necessary during any stage of the lifetime of operations. For instance, risk assessment can be used in connection with the environmental impact assessment or the planning of the mine for designating risk management procedures. For the time being, there are no

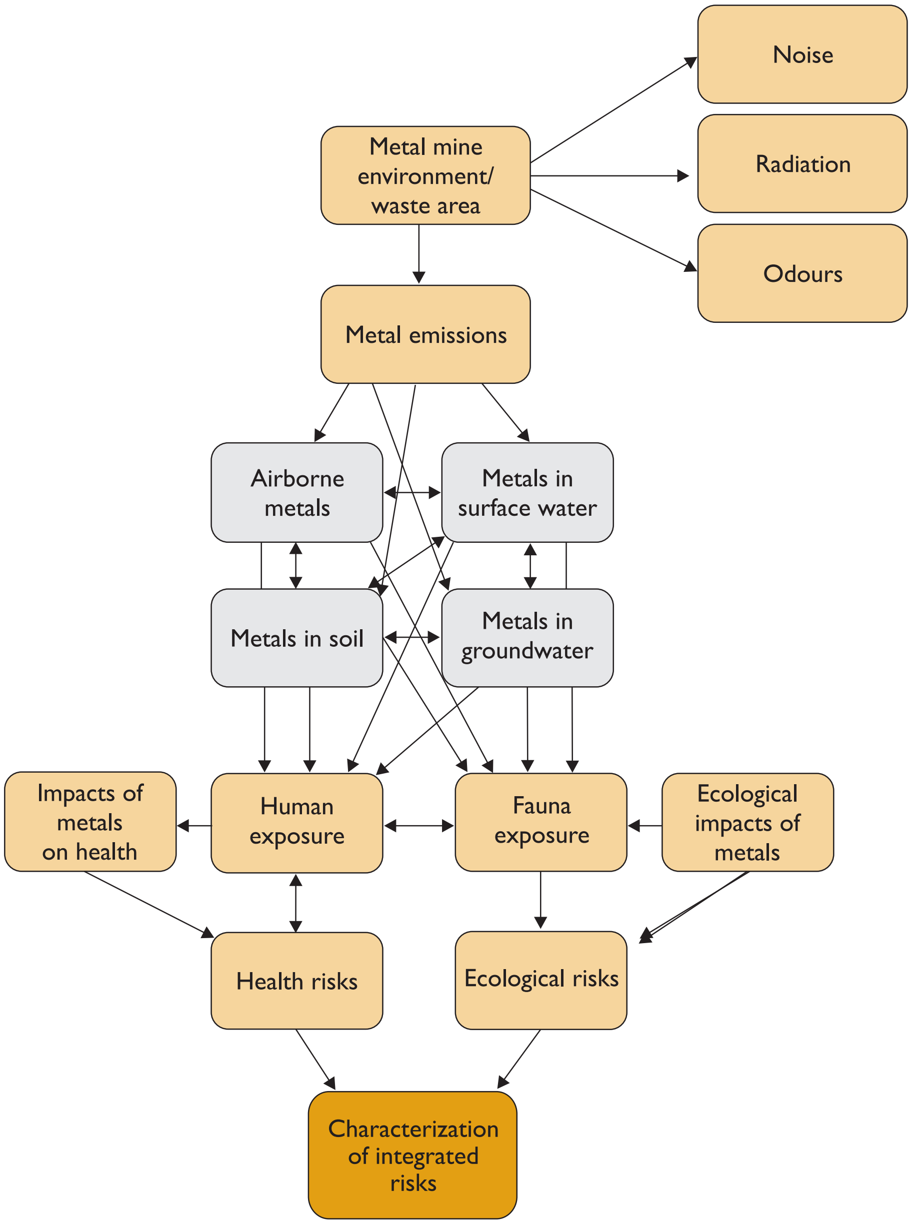


Figure 25. An example of the general level of the conceptual model of integrated risk model for a mining environment.

established practices for the environmental impact assessment procedure for mining projects, and therefore the level and scope required in risk assessment are usually specified on a site-specific basis. Risk assessment is recommended for identifying hazards in all sites, and for preliminarily assessment of the need for risk management.

Risk surveys and rough classifications of risks may be performed using, for instance, the following methods:

- analysis of potential problems (hazards are identified and classed in a group brainstorming session)
- systematic cause-and effect ratio analysis (process charts are made for each operation and emissions source, on the basis of which the potential transport and exposure scenarios are estimated)
- anomaly inspection (the inspection seeks imaginary emergency situations that may cause changes to normal quantities).

Different methods are described in more detail in e.g. Mine Closure Handbook (Heikkinen *et al.* 2005).

In mining projects, in particular during emergency situations, the risk sites causing the risk of accident for the environment can be e.g.

- dam structures for waste areas
- basal structures for concentrate and heap leaching piles
- storage facilities for required chemicals
- tailings and waste rock areas that are prone to dusting.

The risk assessment of a site under normal conditions is usually implemented in stages, shifting when necessary from the draft assessment to more detail assessment. The assessment is initiated by visualising the overall situation and defining the problem. The information available about the site is gathered for the purpose of defining the problem. Next, the limits of assessment are specified, such as area, timing and the risks to be assessed. In support of this specification, an overall model for conceptual risk assessment will be made that illustrates the associations between the cause of the hazard, through its exposure to the site subjected to exposure (Figure 25). In the overall model, the factors relating to the cause of the hazard and environmental concentrations are common for ecological and health risk assessments. Site assessment usually includes the following work stages:

- Gathering information on the area
  - historical data, maps, loading substances
- Gathering measurement data from the area
  - emissions, soil, groundwater and surface water, fauna
- Selection of critical substances
  - properties and concentration data
- Assessment of the migration of critical substances
  - environmental conditions and the mobility of substances
- Assessment of exposure
  - exposure routes and selection of exposure sites
- Assessment of impacts
  - dose-response connection
- Characterisation of risks
  - description and probability of risk.

The overall model can be made during the various stages of the mining operations, such as during the planning of operations, during operations, and during the closure and rehabilitation stages of the mine.

If necessary, the conceptual model may be taken to the calculated model, which provides numerical data regarding the migration/transport of harmful substances from the emissions source, via a medium to the target fauna or people. The relevant exposure agents and elements are chosen for the model by site. Three parts of the calculated model should be used for specifying variables: causality, data and formula. The calculated model provides an estimate of the level of exposure, on the basis of which the risk estimate is conducted. The concentration obtained in the estimate is compared to concentrations or dosages that are usually regarded as being harmless. The comparison indicates the magnitude of the safety margin between the exposure experienced and the concentration or the dose that caused the hazard. In mining projects, for instance the overall model for site-specific integrated risk assessment of metal emissions developed in the FINMERAC project (Nikkarinen *et al.* 2008) may be used as the basis for the calculated risk assessment.

The most significant harmful substances in mining operations are metals. Development of methods for metal risk assessment has been conducted widely over the past few years in the EU in e.g. the MERAG and HERAG projects (ICMM 2007, EBRC 2008).

Favourable properties of a good assessment of risks are:

- Clear goals and limits
- Transparency and comparability
- Intelligibility and informativeness
- Involvement of stakeholder groups and taking their opinions into account
- Availability of original material
- Fairness of the process
- Starting points and assumptions to be approved by the end user.

5.2.4
Study of present conditions

Environmental studies concerning present conditions at the site (later "current state studies") are generally conducted at mines in operation and in closed mining areas. The purpose of the current state study is to survey the environmental impacts already caused by current operations, as well as to ascertain the reasons of such with the aim of mitigating loading. In order to assess the quality and extent of environmental impacts, the findings of the current state study are compared to the baseline study and the monitoring data gathered from the area.

The content and tasks of the current state study are specified on a case-by-case basis depending on the objectives of the study. The study may be conducted as a comprehensive general overview covering the entire mine site or for focusing on the study and mitigation of certain environmental impacts. At operating mines and former mining sites, the current state study is usually made as a basis for the rehabilitation and after-care of the area and/or the basis for planning the expansion and monitoring of activities. For decommissioned and operating mines, the current state study has often been made for clarifying and mitigating the environmental loading of tailings areas.

Current state studies are also conducted in connection with the completion of ore prospecting measures, especially if large-scale overburden removal or excavation has taken place during prospecting. In this case it should be examined whether or not prospecting measures have had significant impact on the environment of the area and what the potential environmental impacts have been.

The content and scope of the current state study are also affected by the quality and scope of the available baseline study. The baseline study for mines that have long been in operation or are closed can be deficient or completely lacking. In this case, the current state study usually requires wider ranging studies. For instance, in former mining sites where contamination of the groundwater has been noticed, it is normally necessary to conduct a more thorough examination of soil stratigraphy and hydrology in order to investigate the reasons for contamination and clarifying the route of transport.

Current state studies can include, for instance, the following research:

- Mapping of impacts on surface water and groundwater, as well as on soil
- Stratigraphy and hydrology of the soil in the area
- Physical and chemical current state studies of waste areas (seepage, chemical altering)
- Current state study of the functioning of the water management and treatment system
- Noise dispersion studies

- Dust dispersion studies (incl. moss studies)
- Nature studies
- Aquatic studies
- Sediment studies
- Studies for the utilisation of by-products.

5.3

Assessment of the quality and treatment need of water emissions

During the operational stage of the mine, emissions may be focused on the surface water and groundwater, especially from the dewatering of the mine, the concentration process, and from the storage of tailings and waste rock (seepage, settling pond water). Determining the quality and quantity of water discharge prior to the commencement of activities is one of the most important matters of the environmental impact assessment and for planning mitigation techniques. The surveying process roughly progresses as follows:

1. Identification and characterisation of different emissions sources (harmful substances),
2. An estimate of the occurring harmful substances and the leaching of such into water,
3. Calculated estimates of the concentrations of harmful substances and the migration of such into receiving waterways (water quality, water quantities, flow directions, concentrations compared to local flow rates),
4. Estimate of treatment requirement by comparing calculated concentrations to the quality classification, minimum nutrient ratios and/or ecotoxicological data (fauna subjected to concentrations) of the receiving waterway, and to quality standards set for domestic water. Furthermore, the tolerability of the receiving waterways shall also be taken into account.

The basis for the assessment of the quality of discharged water is the identification and characterisation of emissions sources, in particular in relation to harmful substances. In practice, this requires the chemical and mineralogical characterisation (cf. chapter 5.4.2) of the ore deposit and generated mining waste (waste rock, tailings, mineral precipitates), and a description of the concentration and excavation process with the chemicals (blasting agents, concentration chemicals, fuels) used in such (see chapter 2.3). The possible harmful substances in the ore and mining waste can be identified by defining the total concentrations of chemical elements. Prior to the commencement of activities, samples are taken from the waste rock in connection with the inventory drilling of the deposit and the ratios of the main rock types in the deposit are determined. Characterisation shall cover all waste rock fractions generated. The composition of tailings, however, is determined in connection with concentration tests. In the assessment of dewatering water quality of the excavations, alongside the ore deposit consideration also needs to be given to the use of blasting agents and fuels, as well as to the potential emissions caused by backfilling. Correspondingly, the assessment of emissions caused by waste rock shall take into account the residues of blasting agents and in respect to tailings, the residues of chemicals used in the concentration process. The composition data for the chemicals used are available from e.g. safety data sheets or alternatively by conducting independent chemical analyses. The harmful substances associated with water discharges from metal mining operations are usually metals (e.g. Cr, Cu, Pb, Mo, Ni, Zn, V, U, Fe, Al), metalloids (As, Sb), salts (e.g. sulphates, chlorides, cyanides), nutrients (e.g. nitrogen compounds) and/or organic compounds (e.g. xanthates, mineral oils). Additionally, the water of metal mining operations contain substantial quantities of alkali-earth and alkali metals (e.g. Ca, Mg, Na, K) and the dewatering water and mining waste drainage in particular are often acidic. Dewatering water and process water can also contain significant quantities of suspended solids.

A variety of different methods are available for assessing/simulating the quality of drainage prior to the commencement of mining activities. The generation of acid mine drainage is typically assessed using static and kinetic tests (see Appendix 6). The leaching of harmful substances from the waste rock and tailings is also assessed on the basis of selective extractions and leaching tests, mineralogical composition and mineral weathering data, water analyses conducted in connection with concentration tests, and geochemical modelling (see INAP 2009). In addition, comparison data on the water discharges of operations may be obtained from working or decommissioned mining sites (quantities of chemicals and fuels used, water quality monitoring data). For instance, the impact of blasting agents on the quality of dewatering water can be assessed on the basis of the use of blasting agents in working mines and mine water quality monitoring data. Correspondingly, comparison data for the quality of dewatering water and the seepage from waste rock and tailings areas can be obtained from mines dealing with similar ore types, where the ore has been handled and processed using methods applicable for the ore type in question (cf. Plumlee 1999). The data obtained in the baseline study concerning water quality can also provide basic information on the water discharges of the operations, if natural loading on the water is caused by the bedrock in the area.

The loading by harmful substance is calculated from the water quality data for discharges according to the estimated water quantities generated at the emissions source (e.g. dewatering water, other drainage water) and correlated with the water quantities, water quality and tolerance of the discharge and conducting channel and receiving body of water. For instance, the quantity of mine dewatering water can be estimated using mathematical models, using e.g. the so-called well equations or on the basis of experience gained at other mines. Site-specific data is required for conducting the calculation, and in respect to surface water and groundwater e.g. data concerning water catchment/formation areas, water levels, water balance, flow rates and flow directions, original water quality and local climate conditions (especially precipitation and thaw water quantities) is required. Information is also required on the hydrological properties and dimensions of the emissions sources (tailings, waste rock, excavated spaces). The simplest way of calculating loading is using the so-called dilution coefficient calculation, which does not take into account the potential retaining of harmful substances and/or remobilisation. More complex mathematical models can also be used for the calculation, such as flow and transport models. The latter can also simulate the reactions of harmful substances along the route of transport. The assessment should also cover seasonal/annual fluctuations in the quantities and qualities of water.

The emissions of mining activities focused on bodies of water shall not cause increases in concentrations of harmful substances, acidity of the water or changes in other properties that significantly compromise the condition of the waterway downstream from the discharge point. In Finland, environmental quality standards are established by the Government Decree on Substances Dangerous and Harmful to the Aquatic Environment (1022/2006), in particular with its amendment 868/2010, which may be used for comparison of actual concentrations caused. In addition to concerning toxic organic compounds, the environmental quality standards also concern the concentrations of mercury, cadmium, lead and nickel, as well as the compounds of such (868/2010, Annex 1). The greatest permissible concentrations of the abovementioned metals in lake water are specified in the annex to the decree as the sum of the environmental quality standard based on ecotoxicity findings and natural background concentrations (EQS, see Verta *et al.* 2010). The quality standards (soluble concentrations) are: 0.1 μg/l for cadmium, 21 μg/l for nickel, 7.3 μg/l for lead in lakes with low humus content, 7.4 μg/l for lead in humus lakes, 7.5 μg/l for lead in lakes with high humus content, 7.5 μg/l for lead in the rivers of moorland and clayey soil, 7.7 μg/l for lead in rivers of peatlands, with the corresponding figures for mercury being 0.20 μg/l, 0.22 μg/l, 0.25 μg/l, 0.20 μg/l and 0.25 μg/l (868/2010, Annex 1). In sites where concentrations are high due to geological reasons, derogation from the background values used in the quality standard determination of the decree can be permitted based on the expert estimate stipulated in Annex 1 of the decree (868/2010) (see also Verta *et al.* 2010).

In some cases, the harmless concentration levels for the aquatic ecosystem are significantly lower than the level achievable using best available technique cleaning devices or methods. For example, when nickel emissions are reduced using the best available technique, the nickel content of the treated water usually remains at a level that is substantially higher than that of the environmental quality standard. In this case, on the basis of application by the mining company, the environmental permit can specify a mixing zone in accordance with section 6b of the aforementioned decree (1022/2006), which states that concentrations of one or more pollutants within such mixing zones may exceed the relevant EQS if they do not affect the compliance of the rest of the body of surface water with those standards. The extent of the mixing zone shall be restricted by the environmental permit to the vicinity of the emissions source, in such a way that it is in the correct proportion with the concentrations of pollutants at the emissions source, and that the general principles intended by section 4 of the Environmental Protection Act applied for activities that pose the risk of pollution are adhered to (e.g. precautionary principle, best available technique principle).

The quality standards for domestic water (STM 461/2000) show concentration limits for metals, e.g. antimony, arsenic, chrome, copper, lead and nickel. The quality standard has been made for the use of domestic water and therefore does not directly indicate the acceptable concentrations for waterways. For instance, the 2 mg/l chemical quality requirement issued for copper can cause detrimental impacts for many aquatic fauna. The environmental permit applicant shall clarify concentration levels for all harmful substances conducted into bodies of water by its operations that will no longer cause detrimental impacts in the waterways. The substances to be studied in mining operations include e.g. metals, metalloids, sulphate, thiosulphates, nutrients, pH, concentration chemicals and the residues of such, and suspended solids.

The nitrogen loading caused by mining activities is often so large that excess nitrogen is constantly available downstream from the discharge point for basic production purposes. This can cause, for instance, increase in the production of algae and related harm downstream from the discharge point. The impacts are more distinctly evident in areas where the minimum nutrient restricting the production in the waterway was originally nitrogen.

5.4

Environmental studies associated with the mining waste produced by metal ore mining activities

The environmental risks associated with mining waste are the most significant risks of metal mining activities. The following sections describe the planning for the management of these and studies related implementation.

5.4.1

Waste management plan

Prior to the commencement of mining activities, a waste management plan shall be made, which is then appended to the environmental permit application. Describing the functional applicability of placement of mine waste is central to the waste management plan, taking into account the properties of the waste and prevention of environmental impacts, as well as the management of such during and following the operational stage (Government Decree 379/2008, section 4). The waste management plan is appended with the monitoring and rehabilitation plan for the waste areas. If alterations are made to the management of waste, the waste management plan will be revised during the operational stage if necessary, and more commonly when the environmental permit application is revised.

The waste management plan shall include e.g.:

- descriptions of the mining waste produced from operations and the total quantities of such,
- descriptions of the properties of mining waste (characterisation of waste, see Chapter 5.4.2 and Appendix 6),
- descriptions of waste areas (location, topography), the natural stratigraphy of soil deposits, possible basal and dam structures for waste areas (see Chapter 5.4.3),
- descriptions of the hydrology and hydrogeology in and in the vicinity of the waste area, and the condition of groundwater and surface water (see Chapter 5.4.3.1),
- descriptions of the potential and/or verified environmental impacts of the waste areas (soil, groundwater, surface water) and the preventative measures applied, such as e.g.
  - prevention/slowing down chemical alteration (potential acid formation, potential leaching of harmful substances),
  - water management system, and
  - dust prevention plan,
- description of the classification of the waste area (waste area posing the risk of major accident or other mining waste area),
- description of the rescue plan (preventative measures, safety management system), if the waste area is classed as a waste area posing the risk of major accident,
- reports on the methods for reducing waste quantities, waste recycling/utilisation and objectives for the development of recycling/utilisation,
- descriptions of water quality monitoring of the waste area and monitoring of water quality discharged from the waste area during the operational stage, and
- descriptions of the closure plan for the waste area, rehabilitation and post-closure monitoring (waste area stability and water quality).

The sections below describe the implementation of mining waste characterisation in more detail, soil investigations of the waste areas, selection of technical solutions and possible dam structures.

5.4.2
Characterisation of mining waste

The central objective for the characterisation of mining waste is to determine the placement of waste, disposal technique and the geotechnical properties guiding rehabilitation, and the physical and chemical properties that are also of significance in the management and prevention of environmental impacts. The specification of properties and selection of methods are guided by the geological data of the deposit, in accordance with which the primary estimate may be made of the potential acid formation and neutralising capacity of the waste rock and tailings waste produced by the processing of ore, as well as of the occurrence of chemical elements regarded as harmful. On the basis of the primary estimate, applicable mineralogical specification and chemical analysis methods are chosen for each waste fraction. Figure 26 shows a chart for the procedures used for the characterisation of mining waste (see also Appendix 6).

The starting point for the specification of mining waste are background data on the geology of the ore deposit, descriptions of the excavation of ore, and the concentration of ore in so far as the various waste fractions are generated (Government Decree 717/2009, Annex 3). The geological description of the deposit includes information about the following:

- ore deposit, host rock/rock types of the ore,
- ore mineralogy of the ore deposit,
- hydrothermal alteration, and
- rock types surrounding the ore deposit, i.e. waste rock.

The general data is appended with a description of the excavation method and the waste rock generated by excavations. The second part of the general description of operations describes the ore concentration process and the waste fractions produced by such.

The extent of the specification of the properties of mining waste are directed by the sulphide mineralogy of the ore deposit and surrounding waste rock, and by the abundance of sulphide sulphur (and/or sulphate sulphur). On the basis of the sulphide mineral composition, waste fractions can be divided into three groups (Figure 26): non-sulphide waste, waste with iron sulphides and other sulphide waste. The fundamental characterisation of each of these mining waste fractions includes the mineralogical and chemical composition of the waste material, as well as the specification of the chemical residues contained in the material (Government Decree 717/2009, Annex 3).

If waste does not contain sulphide sulphur, or its total quantity of sulphide sulphur is less than 0.1% and the concentrations of acid-soluble harmful substances in the waste do not exceed the threshold values specified by Government Decree 214/2007 or the background values for the soil in the surroundings, the material shall be classed as inert waste (Government Decree 717/2009, Annex 1, see also Luodes *et al.* 2011). No acid-forming specification or other chemical supplementary analyses need to be conducted on these waste fractions, unless on the basis of geological origin fractions include easily weathering salt minerals containing harmful chemical elements, or other potentially harmful substances that remain in the waste fraction during the processing of the ore. Waste with a total concentration of sulphide sulphur in excess of 0.1% shall also be tested for acid-formation capacity and neutralising properties

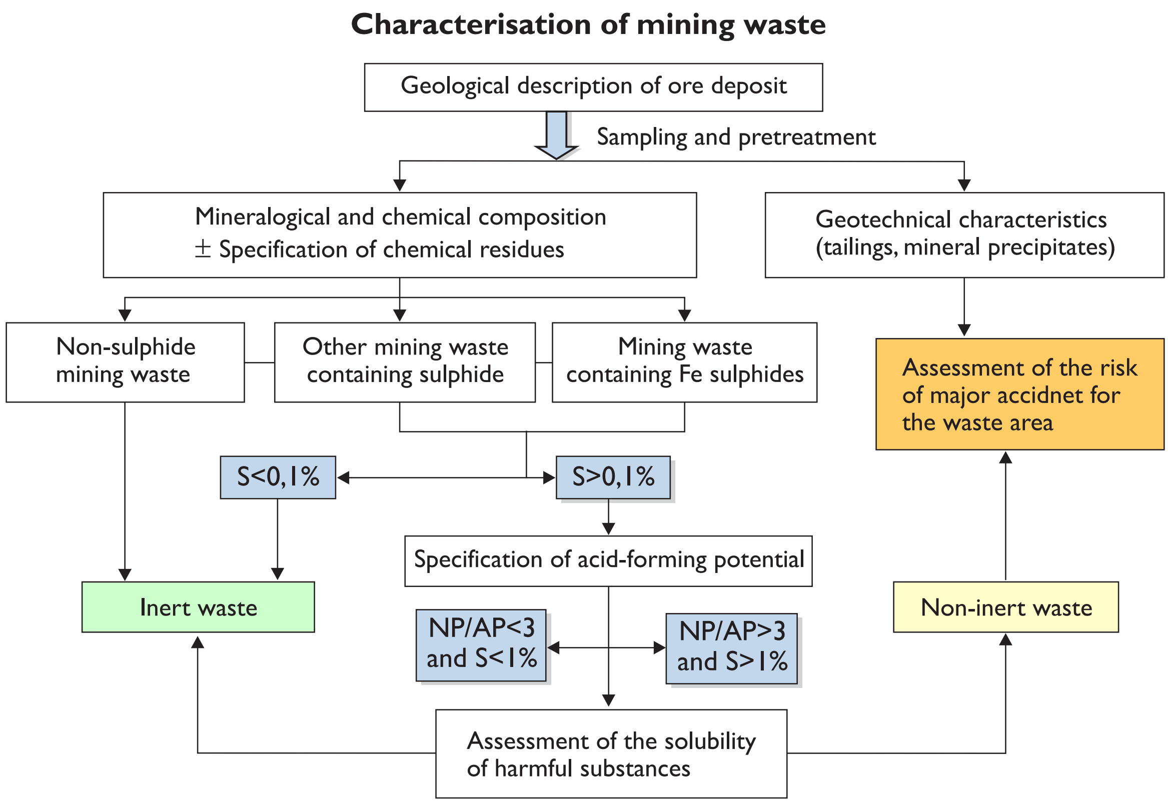


Figure 26. Characterisation procedure for mining waste.

(Appendix 6). In addition, the neutralising minerals (carbonate minerals, silicates rich in Mg-Ca) and the quantities of such are identified from the rock and mineral material of this waste group.

According to the Mining Waste Decree (Government Decree 717/2009), waste with sulphide minerals that does not contain harmful substances, with the total concentration of sulphide sulphur less than 1%, and the ratio between the neutralising potential (NP) and acid-forming potential (AP) of the waste is greater than three, can be classed as inert waste. Classification may also be conducted on the basis of the national list. A publication by Luodes *et al.* (2011) shows a national list of waste rocks excavated in Finland that are classed as inert waste. Furthermore, the characterisation of waste classed as non-inert shall include the specification of solubility of harmful substances and the potential for generating acid mine drainage (Government Decree 717/2009).

Appendix 6 provides a general description of the sampling procedures and methods used for specifying chemical and physical properties of mining waste.

5.4.3

Selection and design of waste storage areas

The ultimate deposition sites for mining waste shall be selected from the alternatives presented in the baseline report. Selection of placement site and disposal technique are dependent on the properties of the waste and waste classification, soil and hydrogeological properties, as well as the functional suitability of the placement site as follows (Figure 27, revised EC 2009):

- Acid formation and neutralising properties of waste
- Potential concentrations of harmful substances and solubility of such in the short and long term.

- Environmental factors associated with the placement site (safety, proximity of housing, conservation status of fauna, other land use)
- Requirements stipulated for the soil base and basal structure of the waste area (according to waste classification)
- Need for building earth dams
- Management and prevention of potential environmental impacts (dusting and impacts on surface water, groundwater and soil/fauna and people)
  - Climate factors, e.g. susceptibility for flooding and occasional heavy precipitation
  - Wind conditions and vulnerability to dusting (topography, height of tree stand)
  - Frost endurance of placement site and dam structures
  - Proximity of housing
  - Proximity of protected areas
- Other land use of the surrounding area
- Rehabilitation demands related to long-term prevention or minimisation of acid formation and the long-term safety of the waste area
- Potential recycling/utilisation of waste.

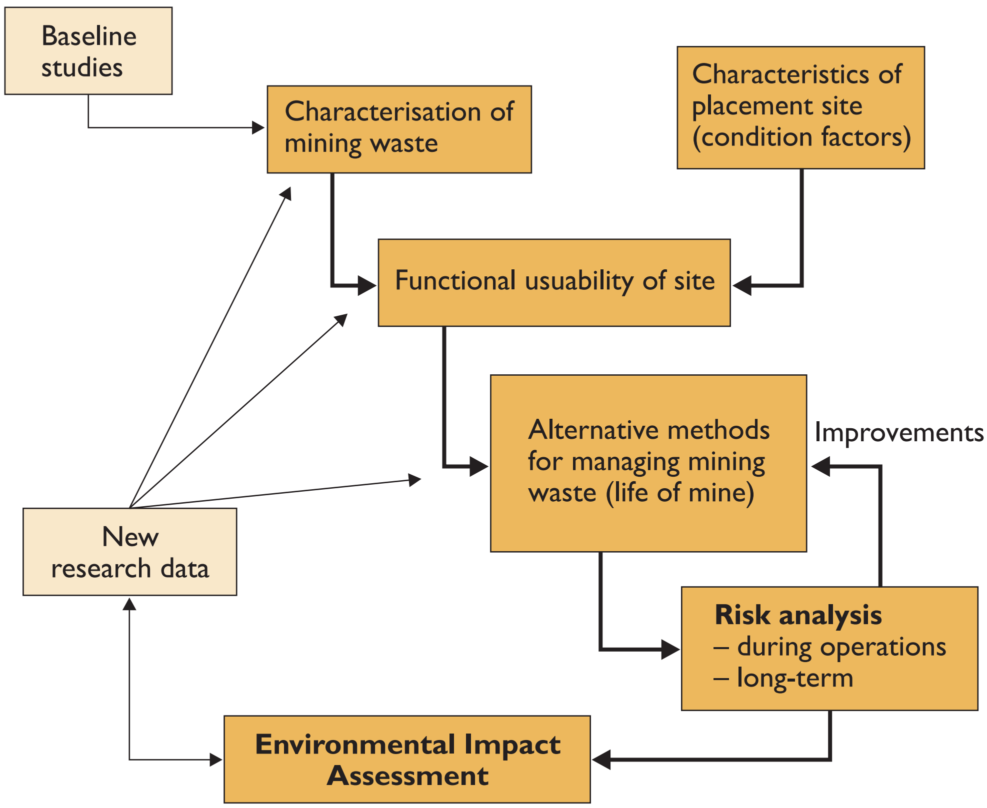


Figure 27. Planning for the waste storage area and site selection (modified after EC 2009).

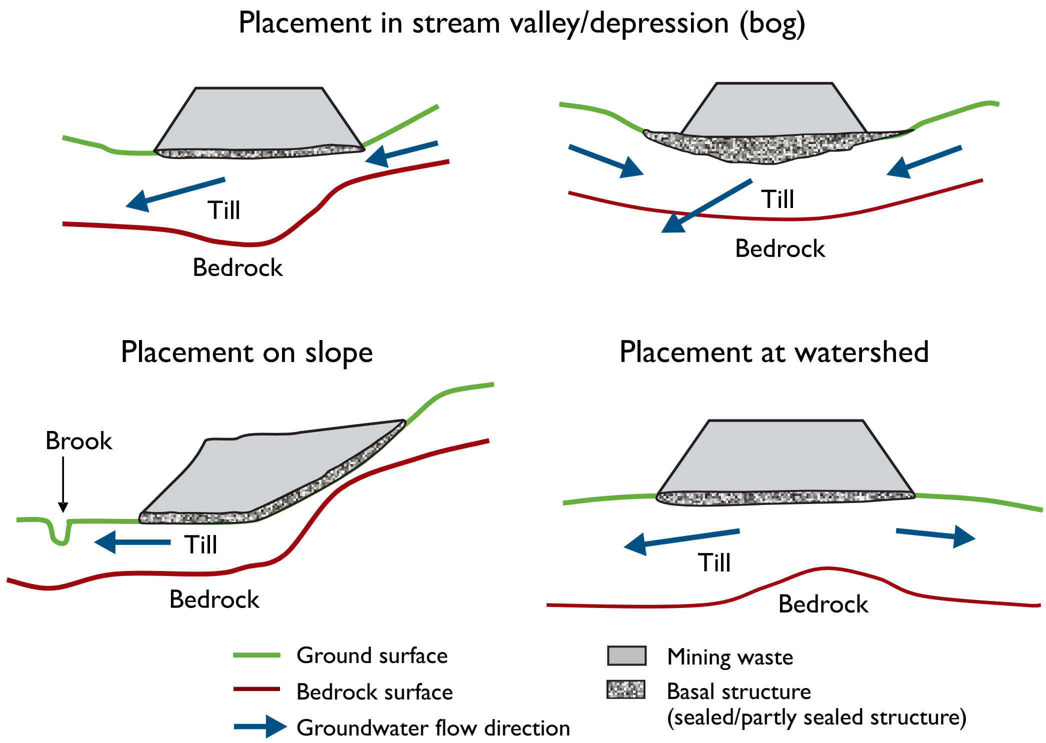


Figure 28. The directive influence of bedrock surface topography of the mining waste placement environment on the direction of groundwater flow. The soil base of the placement site is load-bearing till on top of the bedrock. The basal structure of the waste area comprises watertight or partly watertight natural soil (compact peat or compacted peat) or geotextiles and/or plastic lining structure.

Figure 28 shows examples of the impacts of waste area placement on the flow directions for groundwater in various different terrains and bedrock topographic areas. On the basis of the topography of the bedrock and permeability and compaction of overburden, the flow direction of groundwater may be estimated, as well as the possible alteration of such during waste disposal and following the decommissioning of activities. These properties may also affect the infiltration directions in the waste areas following the closure of the waste facility, in addition to having impacts during disposal. However, a groundwater monitoring plan could be made on the basis of hydrogeological data to direct monitoring to potential leak sites.

5.4.3.1
Soil investigations and basal structures of the waste areas

The purpose of the soil investigations conducted in the planned waste areas is to collect sufficient information about the Quaternary deposits to dispose each waste type in an area where environmental impacts can be minimised and managed (cost minimisation) during operations and following decommissioning. The content of the investigations depends on the extent of the disposal area, quantity of waste fractions, and on waste class (EC 2009). The baseline study usually holds the basic data pertaining to the Quaternary deposit types and formations, and hydrology (e.g. catchment area boundaries, surface water flow directions; cf. Chapter 5.1) found in the waste disposal area alternatives, which can then be used to select the appropriate sites for different waste types (Figure 28). Supplementary soil surveys conducted on waste placement sites include soil base investigations of the disposal area and inventory surveys on soils suitable for the structures (basal structure, dam structures) of the waste areas (Sivonen & Frilander 2001, Leskelä 2009). Depending on the site, research methods that can be used are geophysics (ground-penetrating radar, seismic measurement) or research trenches and/or drillings.

The soil studies for the waste disposal areas can include the following information, e.g.
- thickness of overburden
- depth and topography of bedrock surface
- stratigraphy of the quaternary deposits (changes in soil type and the thickness of the various soil type layers)
- height of the groundwater table measured from the surface of the ground (+ estimate of seasonal changes in heights) and groundwater flow directions
- catchment boundaries (watersheds) for surface water and groundwater
- topography of ground surface and natural flow direction for surface water.

The geotechnical studies on the properties of the natural soils of various soil types and structures to be used in the waste areas include the following information (Rantamäki *et al.* 1979, Leskelä 1992 and 2009):
- distribution of particle size, content of fines (<0.06 mm) and clay content (<0.002 mm)
  - measured from samples; screening, SediGraph particle size analysis (or areometric specification)
- permeability (vertical and horizontal fluctuation throughout the base soil of the waste area)
  - measured from the samples
  - field measurement
- bearing capacity/subsidence properties
  - estimate according to particle size distribution (content of fines, stone content/abundance of coarse material)
  - shear strength/consolidation measured from the samples
- compaction characteristics
  - estimate according to soil type (peat, fine-grained soil/literature assessment)
  - measured from the samples
- frost characteristics
  - estimate according to particle size distribution/content of fines
  - field measurement or information from the frost statistics of the area.

The base for mining waste disposal can be a natural soil structure or artificial basal structure on top of the load-bearing natural soil. The selection of basal structure is directly linked to dam structure designs and the selection of the water management system for the waste area. Depending on the waste class, the basal structure can either be completely watertight, slightly permeable or permeable (Table 27). Permeable basal structures are only suitable for inert waste or by-product disposal sites. The sealing qualities and thickness of the base for non-inert waste is determined on the basis of the acid formation properties of the waste and/or the potential concentrations and risk of leaching of harmful substances. Selection of the materials to be used in the basal structures takes into consideration the extent of the waste area, the availability and cost of structural materials, as well as waste characteristics, such as the possible long-term environmental risks caused by chemical alteration. The demands set for the basal structure will ultimately be resolved by case-specific discretion in the decision issued on the environmental permit application. According to the Environmental Protection Act, contamination of the soil and groundwater is forbidden.

Table 27. Soil base and material alternatives for the basal structures of various types of mining waste. These examples have been taken from existing waste areas.

Mining waste	Natural soil / bedrock (layer structure)	Basal structure (layer structure)	Sealing properties and thickness of basal structure
Waste rock			
Inert	sandy till or bedrock	limited to subsoil base	permeable (10^{-6} m/s), thickness 3–10 m
Non-inert (non-hazardous)	till (highest) bedrock (lowest)	compacted peat[1)] (highest) compacted gyttja (lowest) or compacted peat[2)] (highest)	impermeable (10^{-9} – 10^{-12} m/s), thickness 0.2–0.5 m
Non-inert (non-hazardous)	till (highest) bedrock (lowest)	levelled, rock aggregate with neutralising capacity	permeable (10^{-3} m/s), thickness >1 m
Non-inert (non-hazardous)	sandy till (highest) bedrock (lowest)	protective layer (highest) HDPE liner (1.5 mm) protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.3 m
Hazardous waste	till or peat (highest) till (lowest)	protective layer (highest) HDPE liner (1 mm) + bentonite liner protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.4 m
Tailings			
Inert	till	limited to subsoil base	poor permeability (10^{-7}–10^{-8} m/s), thickness ≥ 1 m
Non-inert (non-hazardous)	till (highest) bedrock (lowest)	compacted peat[1)] (highest) compacted gyttja (lowest) or compacted peat[2)] (highest)	impermeable (10^{-9} – 10^{-12} m/s), thickness 0.3-0.8 m
Non-inert (non-hazardous)	till or bedrock	bituminous geomembrane liner (highest) protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.3 m
Non-inert (non-hazardous)	sandy till (highest) bedrock (lowest)	protective layer (highest) HDPE liner (2 mm) protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.3 m
Hazardous waste	till or peat (highest) till (lowest)	protective layer (highest) HDPE liner (2 mm) or HDPE liner (1 mm) + bentonite liner protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.4 m
Water treatment ponds (mineral precipitate sludge)			
Non-inert (non-hazardous)	till (highest) bedrock (lowest)	peat[3)] (highest) gyttja (lowest)	permeable, peat acts as filter layer
Non-inert (non-hazardous)	sandy till (highest) bedrock (lowest)	protective layer (highest) HDPE liner (1 mm/1.5 mm) protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.3 m
Hazardous waste	till or peat (highest) till (lowest)	protective layer (highest) HDPE liner (2 mm) or HDPE liner (1 mm) + bentonite liner protective layer (lowest)	impermeable (10^{-9} – 10^{-15} m/s), thickness 0.2-0.4 m

[1)] thickness of natural peat 0.5–1 m or >1 m, when compacted ≥0.3 m
[2)] thickness of compacted peat at least 0.5 m
[3)] peat land basin, acting as wetland for water treatment

5.4.4
Mine dam structures and associated studies

5.4.4.1
Mine dam structures

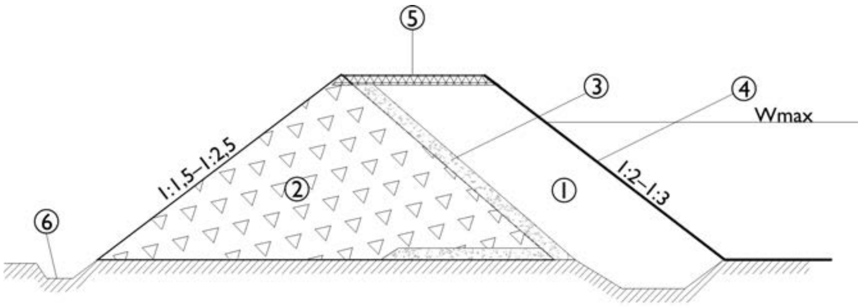
Mine dams are usually earth dams or rockfill dams. Concrete mine dams are rarer. Earth dams are divided into homogenous earth dams or zone dams. Homogenous earth dams are usually constructed entirely using one and the same material that is sufficiently permeable. Zone dams, however, are constructed from a variety of materials with varying water permeability. Till is conventionally used as the construction material for the sealing layer in both dam structures. Blasted rock is usually used in foundation embankments or as support embankments in zone dams. Constructing a rockfill dam is usually cheaper if the waste rock of the mine can be used as construction material. Waste rock or tailings can be used in raising the mine dams, if these have geotechnical and chemical properties that allow use in construction.

In zone dams, the flow of water through the dam is prevented using a separate sealing section (Figure 29). The sealing layer shall be sufficiently impermeable and must endure internal erosion. The sealing section can be located in the core of the dam or on the section of the dam facing inwards as far as the upstream slope surface (Sivonen & Frilander 2001). In practice, the sealing section of the mine dam is almost always constructed in the upstream slope up to the surface of the slope. If free water rests against the sealing layer made from till the slope shall be covered with riprap. Depending on the conditions, the sealing structure of the dam can utilise clay, silt or till. The hydraulic conductivity of the sealing structure shall be less than $K=10^{-7}$ m/s. The material should be of a material that is of as uniform quality as possible and has good erosion endurance properties (Leskelä 2005).

The sealing layer can also be made from synthetic materials, e.g. plastic or bituminous liner (Figure 30). The foundation for the plastic or bituminous liner needs to be sufficiently even and without depressions to ensure the layer does not break under strain. The installation base is often rock-free till (Figure 30), sand or fine-grained aggregate (crushed rock with fines). A stone that has a diameter greater than the thickness of the plastic liner can cause strain failures in the HDPE liner over time, which could ultimately lead to the tearing of the liner. It is recommended that a bentonite liner be installed between the installation base (sand or fine-grained aggregate layer) and plastic liner/bituminous geomembrane liner to reduce the risk of damage. The joins of the plastic and bituminous liner are welded together to ensure the seals are impermeable. Synthetic sealing structures are used in ponds that are to be made entirely waterproof, for instance if the pond is used for impounding acid generating waste materials.

The dam structures used for the storage of chemical mineral precipitate sludge do not differ very much from the dam structures used in tailings impoundments. In Talvivaara, for example, the soft soil layers have been removed from the gypsum pond and the foundation of the dam and replaced with blasted rock and till. The foundation is drained using covered drains filled with small-grade aggregate. The base and walls of the ditch were covered with filter cloth before backfilling. The upstream slope of the basin is covered with HDPE liner underlined by a bentonite liner (Figure 29).

The filter structures are used to attempt to control the seepage through the dam in such a way, that no internal erosion is caused. The water is recovered on the downstream side of the dam into a seepage drain or covered drain, from which it is either conducted back into nature or pumped back into the pond, depending on the seepage quality. In order to assure the stability of the downstream slope of the homogenous earth dam and to prevent internal erosion, an independent filtering system shall be built for the dam (Figure 31).



1 Sealing section (till)
2 Support embankment (Blast rock)
3 Filter and filter cloth
4 Plastic or bitumen lining
5 Crest(wedge fastening and crushed rock)
6 Seepage collection drain

Figure 29. An example of the structure of a zone dam of a tailings pond/mineral precipitate sludge pond.

The commonly used filtering materials are sand or gravel. The shape of the grading curve for the filtering material should be similar to that of the protected sealing material. Fines (d <0.06 mm) shall not exceed 5%. The permeability of the filtering material should be 10–100 times greater than the protected material (Leskelä 2005).

The purpose of the support embankment is, together with the other sections, to assure the stability of the dam, and to protect the filter and sealing structures. The purpose of the slope covering is to protect the support embankment from damage caused by precipitation and waves. In mine dams, the covering used for the slope is primarily coarse crushed rock or small-grade aggregate. If no free water lies against the dam in the tailings impoundment, till may also be used to cover the dam slopes. The cut-off wall can prevent excess water flow below the dam, e.g. in the interface between bedrock and dam. Not all of the abovementioned features can be found in all dams.

Figure 30. Rubber bitumen used as the covering structure for the upstream slope of the mine dam, Kevitsa Mine. Beneath the bituminous geomembrane liner (+ bentonite liner) is a layer of till with compacted upper layer that borders the blasted rock (left-hand side, see also Figure 29). (Photograph: Timo Regina)

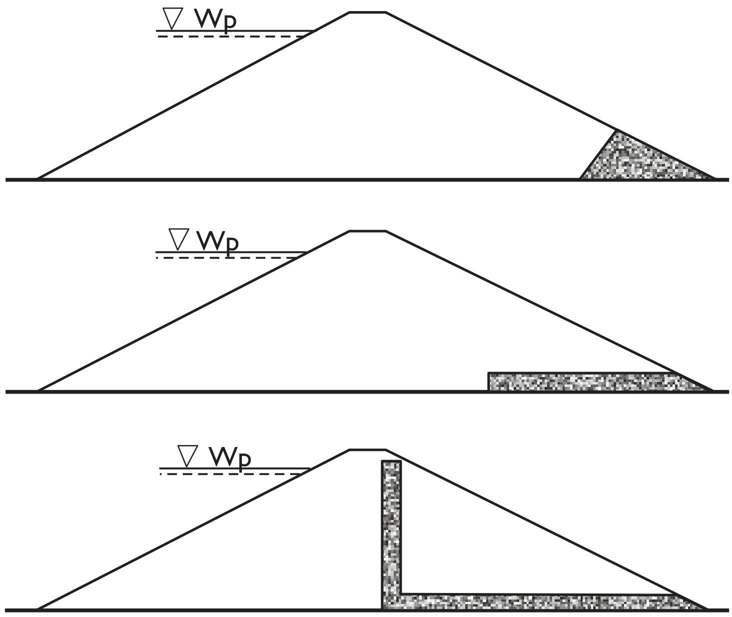


Figure 31. Location of filter in a homogenous earth dam. (Holm & Leskelä 1979)

The support embankment material is not essential for the functioning of the earth dam if the sealing, filtering and drainage structures, and the external protection of the dam slopes have been managed in the appropriate manner. Material that is as strong as possible and very permeable is worth using as support material. Blasted rock should be used in the support structures, if easily available.

Selection of dam type

In addition to the availability of material and the purpose of the dam, factors that influence the selection of dam type include e.g. the geotechnical conditions of the dam site, necessary working dam arrangements and the time available for constructing the dam (Table 28). If significant depressions are expected, it is not recommended to choose a dam with a rockfill structure that has an inclined sealing section. Other factors limiting the selection of dam type are e.g. size of the available area, special loading requirements (e.g. overflow), unfavourable construction period (wintertime construction, wet summer) and the usual gradual construction of mine dams (Leskelä 2005).

Table 28. Advantages and disadvantages of the dam types. (Leskelä 2005)

Dam type	Advantages	Disadvantages
Homogenous dam	Simple to build, monitoring of sealing easy	Larger masses, risk of downstream side becoming waterlogged
Zone dam	Various materials may be used for different conditions, total masses smaller than for the homogenous dam, some dam types allow part of the building to be performed in winter	Work supervision is more demanding, filtering criteria important at material interfaces, a variety of form-changing properties can cause problems
Rockfill dam	Particularly when sealed with artificial materials, the dam will endure e.g. strain caused by rapid fluctuations in water levels, needs little space, can be modified to enable overflow	Requires a sturdy base, material acquisition sometimes costly

5.4.4.2
Raising mine dams

The mine dams are normally raised every few years to increase storage capacity. The raising is often done using waste rock or tailings from the mine, if these are suitable for use in the raised sections according to geotechnical and environmental compatibility properties (see Chapter 5.4.2 and Appendix 6). The raising can also be done using till. Due to its geotechnical characteristics (or environmental characteristics), tailings is not the best possible construction material, but often the most economically sensible choice, as in some cases no usable till is available in the mine surroundings. If tailings are chosen for the dam raising material, the tailings used for this purpose shall be excavated from the inside of the impoundment and placed on top of the dam to "dry" before using in construction. Alternatively, the section of the impoundment to be used for extracting the material for construction can be dried prior to taking the material. Tailings slurry is often pumped into the tailings area from the edges of the dam, which means that the coarser material will remain close to the dam and the finer material settles further inside the dam. In this way, coarser material is available for dam construction, which is suitable for raising the dam.

The raising of the mine dam is either filled upstream (Figure 32), downstream (Figure 33) or on both sides of the existing dam (Figure 34).

The most common method for dam raising is upstream filling, where the crest of the dam is moved inwards each time it is raised (Figure 32). Upstream filling is the most cost effective method, as it uses the least material. Raising of the dam is usually done partially on top of the finer, less durable and slower compacting material (Saarela 1990). In this way the stability of the dam can be somewhat compromised with raising. With upstream filling, the management of seepage is also more difficult than for other methods. Especially if the dry section between the dam edge and

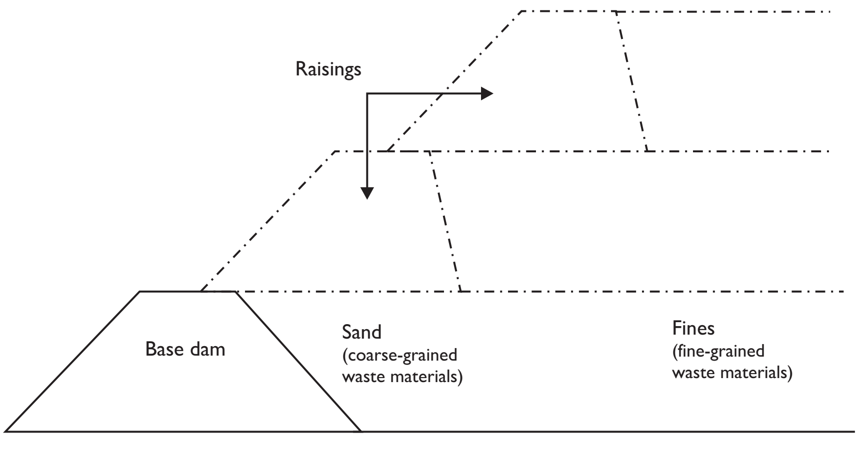


Figure 32. Dam raising using the upstream filling method.

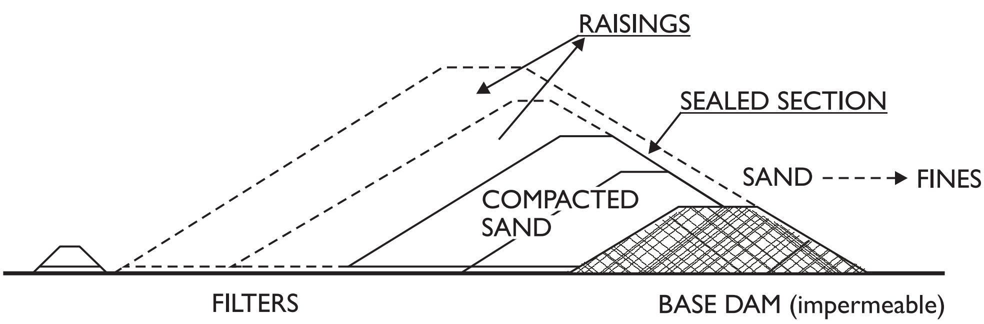


Figure 33. Dam raising using the downstream filling method (Saarela 1990).

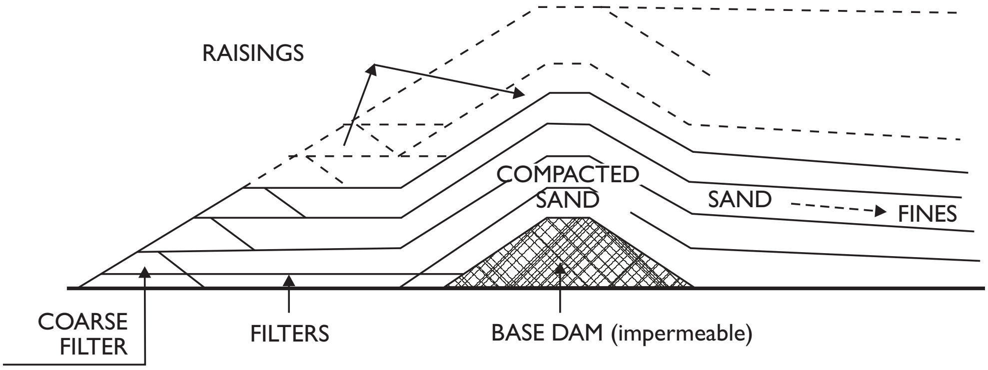


Figure 34. Dam raising by filling on both sides of the centre line (Saarela 1990).

liquid to be impounded is too small, the seepage can rise excessively and cause dam breakage. The coverage of the impoundment and relative capacity are reduced with upstream filling.

Downstream filling is the best dam safety option. The crest of the dam is moved outwards and is therefore stable (Figure 33, Saarela 1990). The relative capacity of the pond also increases as the pond coverage increases. The disadvantage of this option is the enormous need for material and space. This method is usually used for impounding large quantities of liquid.

When filling the dam on both sides of the crest, the advantages of both of the aforementioned methods will be achieved (Figure 34). The crest of the dam remains in place, which means the stability remains good and the need for space will not increase unreasonably. Filling on both sides of the centreline of the dam is not usually used for the impounding of large quantities of liquid (Saarela 1990).

Dam raising can also be done by combining the various alternatives mentioned above. For instance, the first two raisings can be done using rockfill in the downstream direction, and the next raising will be done upstream using tailings. This will facilitate more capacity for the impoundment and the so-called basic dam is larger and more stable prior to raising with tailings than a dam which has been merely raised with tailings upstream.

5.4.4.3
Studies conducted during the planning and construction of the mine

Studies conducted during the planning stage

Dams should be constructed on impermeable and load-bearing ground. The bearing capacity of the ground and the availability of suitable dam materials are studied using soil surveys, such as drilling (weight sounding, dynamic probing tests, static-dynamic penetration tests, percussion drilling), geophysical methods (ground penetrating radar surveys, seismic surveys, electric ground resistivity, gravimetric analysis) and/or test pits. Studies investigate the following from the construction site for the dam, e.g.:

- load-bearing and stability properties of the dam foundations,
- permeability of soil layers as deep as the load-bearing and impermeable base layer,
- location of the bedrock surface, and
- quality and fragmentation of bedrock (Slunga 2004).

During the planning stages, the sealing material used in the dam will be specified for at least optimum water content, maximum dry density value, consolidation characteristics, shear strength parameters, permeability, grain size distribution and plastic characteristics.

Studies conducted during the construction stage

Samples need to be taken during the construction stage to ensure the applicability of the dam foundations to at least establish grain size distribution, water content and if necessary, also permeability. The soil samples taken from the material used for making the dam will be studied for e.g. optimum moisture, maximum dry bulk density, permeability and grain size distribution. The usability of filtering material will be verified using grain size distribution samples. In addition, during the construction stage, depending on the dam material the density of the dam will be monitored using Troxler devices, falling weight deflectometers, plate bearing instruments or volumetric devices. If compaction measurements are done using the Troxler device, it is recommended that some of the measurements are done using a volumetric device. Compaction requirements are shown in the plans. Commonly used compaction requirements are: 90–95% measured with the Troxler device, and a compaction ratio of E_2/E_1=2.2–2.4 using a falling weight deflectometer or plate bearing instrument.

5.4.4.4

Requirements for dam designs

The plans show seepage flow, stability and deflection calculations for the dam. The stability of the dam shall be calculated for at least the situation during construction, the situation during regular use, and following the quick drop in the water level (Maijala 2010). The freeboard of the dam is determined according to the greatest wave height and frost heave.

Table 29. Requirements associated with the dimensioning and designing of a dam.

Characteristic	Requirements
Stability	Subsiding and stability dimensioning shall be conducted in such a way that no landslides may occur.
	The phi factor (overall working coefficient) of the earth dam in permanent seepage flow situations shall be at least 1.5.
	During the construction stage situation and in cases of sudden drops in water level (HW-NW), the phi factor shall be at least 1.3.
Dam filtering structures and drainage	The filtering and drainage facilities of the dam shall be capable of handling ten times the theoretical seepage quantity, and the filter structures or sections of the drainage system shall not retain water.
	The permeability of the filter structure shall be ten to one hundred times that of the protected material.
	The compacted core of the dam shall extend down to the impermeable subsoil and cut-off walls can be used down to the bedrock if necessary. If the bedrock is fragmented, it will be injected in such a way that no water will be able to access the cracks.
Freeboard	The freeboard is defined according to wave height or frost depth.
	The freeboard shall be at least 1.75 times the greatest wave height.
	Frost depth is usually used for defining freeboard for mine dams.
	Frost depth shall be calculated using maximum depths occurring once every ten years (F10) for class 1 and 2 dams, and depths occurring once every five years (F5) for class 3 dams.
Dam safety margin	The safety margin (difference between the top of the sealing section to the HW level) for class 1 and 2 dams shall be at least 0.4 metres, and for class 3 dams at least 0.3 metres. The subsiding margin for the structure and subsoil must be added to the measurements.
Crest of the dam	The width of the dam crest shall be at least four metres in class 1 and 2 dams.
	If the height of the dam exceeds 10 metres, a width of 0.5 metres shall be added for the start of each 10-metre-high increment.
	Special considerations are given for class 2 dams less than four metres in height allowing a crest width of 3.5 metres. The crest width of a class 3 dam shall be at least three metres.

Efforts shall be made to remove any subsiding soil layers from the dam placement site. If the dam is to be constructed on subsiding ground, flexible material (if possible) needs to be used in the making of the watertight sections of the dam (Slunga 2004). Table 29 shows requirements associated with dam dimensioning and designing.

5.4.4.5
Safety of mine dams

During operation of the mine, large quantities of water and silt, as well as the dam structures surrounding these, pose risk of accident focused on the environment and human health. Consequently, the plans for dam construction and raising shall be made by well-established experts in the field who are also responsible for quality supervision of construction. Constant and diligent monitoring of dam structures and waste impoundments is also required during regular operation, in addition to the scheduled inspections to be conducted by an expert.

Dam classification

Mine dams (in the same way as other dams) are classed into three classes (classes 1–3) as intended by the Dam Safety Act.

- Class 1 dam, which in the event of an accident causes danger to human life and health or considerable danger to the environment or property,
- Class 2 dam, which in the event of an accident may cause danger to human life and health or minor danger to the environment or property,
- Class 3 dam, which in the event of an accident may cause only a minor danger.

Classification need not be made if the dam safety authority considers that the dam does not cause any danger. A preliminary assessment of the dam class shall be made in the project/master plan stage prior to permit processing. Ultimate classification will be made following the completion of the dam and prior to commissioning, and once the dam safety documentation has been updated with the true data.

With permit applications concerning the construction of the dam (environmental permit for mine dams), the dam proprietor shall describe to the necessary extent the risks caused by the dam and the impacts of such on the principles of dimensioning the dam. The dam shall be classed prior to commissioning along with approval of the damage risk report and monitoring programme. The dam proprietor shall conduct a more detailed damage risk assessment for class 1 dams. The dam safety authority may also stipulate the conducting of detailed damage risk assessments for other dam classes, if regarded as necessary for classing the dam. A safety plan shall be made by the dam proprietor for class 1 dams that informs what measures need to be taken in case of accident or failure.

Commissioning and inspections of dams are described in more detail in chapter 7.2 (see also 8.1.1.2) and prevention of dam failure in chapter 6.2.3.3.

6 Mitigation techniques for emissions and environmental impacts

Reducing and preventing emissions are the most efficient means employed for mitigating impacts on the environment caused by emissions. Measures focused on the environment itself are usually "rectification of damages" that do not necessarily achieve lasting impacts. A typical example of rectifying damage is for instance, the localized liming of acidified soil and waterways resulting from the processing of sulphide ores. In some instances, the environmental permit also issues obligations for compensating impacts, e.g. fish stocking could be demanded for revitalising and improving the preservation of fish populations (Figure 35).

Contingency plans and systems based on risk assessment are also important means for preventing emissions. For instance, the mine must have contingency plans made on the basis of risk assessment in case of gas emissions with potential health risks, as well as sufficiently effective warning systems for warning residents living in the surroundings. Similarly, contingency systems also need to be in place in case of water discharge to ensure minimisation of environmental damage.

The sections below describe by emissions source the techniques currently employed at mines for mitigating emissions.

Figure 35. Fish stocking at Kittilä Mine. (Photograph: Agnico-Eagle Mines Ltd)

6.1

Reducing emissions during the construction stage of the mine

In mines, construction activities often occur at the same time as production operations. At new mines, the construction stage usually takes 1–2 years. The mining emissions during the construction stage are similar to the mining emissions during the production stage. Therefore, the same techniques can be used for reducing emissions as those described in the sections below for employing during the operational stage. When mitigating emissions, it is essential that the building company is aware of the risks of pollution caused by the construction stage, and commissions and maintains techniques for mitigating operational emissions throughout the construction stage.

6.2

Reducing emissions during the operational stage of the mine

6.2.1

Airborne emissions

A variety of technical solutions are available for managing dust emissions generated in mining activities, such as filters and dust collection devices (crushing, screening). In addition to these measures, dusting is also prevented by keeping the material causing the dust sufficiently moist (roads, blasting fields), containing operations that

Table 30. Preventative measures and mitigation techniques for dust and gas emissions.

Method	Action	Description of measure
Dust dispersion	Blasting, excavating and haulage of ore/ waste rock	Sizing and staging of blasting charges (irrigation of blasting field); tagging blast holes; shift of operations deeper into the open pit or underground; dust removal systems in drilling rigs and in underground mines; extraction and treatment of drilling dust; sprinkling of rock for haulage; sprinkling of roads, use of dust-binding agents; covering loads, washing tyres (long-distance hauls)
	Crushing and screening	Crushing and screening is placed in an enclosed space/section of underground mine; dust removal system (suction, electrical deposition, containing, washing/ sprinkling, filtering, use of dust-binding chemicals); regular servicing of dust removal devices
	Ore concentration (drying)	Controlling dryer temperature, filtering system (alternative to drying), containing
	Loading and haulage of concentrates	Storage and loading of concentrates in sheltered facility; outdoors: asphalt surfacing of storage area base/impermeable base structure; washing of asphalt surfaced loading area and vehicle tyres (drainage/collection of ablution for treatment plant); sprinkling of stockpiles/covering (seepage collection for treatment); covering of loads/spreading of dust-binding agents on top of load
	Mining waste areas	Covering + revegetation, sprinkling (water, hydrated lime)/water cover in waste impoundments
Gas emissions	Blasting	Sizing and staging of blasting charges, selection of blasting chemical; ventilation of underground mine space and cleaning of exhaust air
	Use of machinery (excavation, haulage)	Choosing machinery with low emissions; use of low-sulphur fuel; regular servicing of vehicles
	Ore concentration	Recovery and cleaning system for gas emissions (washing, neutralising); correct chemical dosage and sufficient dilution of acids; regular servicing and overhaul of appliances

generate dust or by covering the sources of dust. Mitigating of gaseous emissions is particularly based on selection of devices (e.g. mining machines, power plants) and the use of various cleaning techniques. Gaseous emissions generated by machinery and appliances may also be reduced by, for instance, using fuel with low sulphur content, choosing machinery with low emissions, and regular servicing of vehicles.

Table 30 shows various techniques employed for mitigating dust and gas emissions produced in different operations, which are briefly described in the following sections. Table 31 shows the measures implemented at functioning mines in Finland for the mitigation of airborne emissions. Management of waste area emissions are discussed in more detail in Chapter 6.2.3.

Table 31. Examples of contemporary means for mitigating airborne emissions and associated environmental impacts used in operating metal mines in Finland.

Mine/production facility	Prevention of airborne emissions/mitigation of environmental impacts
Kemi Mine	Dust removal systems operating in the mine and concentration plant.
	Dusting of roads and waste areas is prevented by sprinkling and using dust-binding agents.
	Concentrates are stored indoors. Loading areas are asphalt surfaced and are washed regularly during the summer. Concentrate stored outdoors is sprinkled in the summer.
	Hydrated lime has been tested in the tailings pond for the prevention of dust.
	Covering and landscaping of the tailings areas as soon as these are full.
	Contingency system in place in case of environmental damage.
Kittilä Mine	Dusting of roads and waste areas is prevented by sprinkling and using dust-binding agents.
	Crushing partly performed in a contained facility. Exhaust air is screened using cloth filters from which the solid matter is placed on the crushed rock conveyor.
	Exhaust air generated by pressure oxidation is washed using gas scrubbers.
Pyhäsalmi Mine	Rotary dryers for concentrates are replaced by pressure filters.
	Nitric acid has a dilution system for the prevention of NO_2 emissions.
	Cu and Zn concentrates are stored in a warehouse.
	The open storage and loading area has asphalt surfacing. The area is regularly washed.
	The waste area is treated with hydrated lime when necessary to prevent dust.
	Contingency system in place in case of environmental damage.
Talvivaara Mine	Open pit drilling rigs are equipped with dust removal devices.
	Dust emissions from temporary crushing are reduced by containing and sprinkling.
	Roads are prevented from dusting by sprinkling regularly.
	The crushing plant and screening facility have dust removal devices.
	Vent gas scrubbers for the prevention of hydrogen sulphide emissions in the metals recovery process.
	Concentrates are stored indoors and transported in containers.
	The surfaces of the gypsum ponds are kept moist to prevent dusting.
Vammala concentrating mill	The crushing plant will use sprinkling if necessary, if there is no risk of freezing.
	Investigations are being conducted into making dust removal more effective.
	Concentrates are stored and loaded in a warehouse and covered when hauled.
	Dust formation in the tailings area is prevented by sprinkling and covering with clay.
Sotkamo (Lahnaslampi-Punasuo) Mine	In the summer, dust formation on roads is hindered using sprinkling and dust-binding agents.
	The intermediate storage facility for ore has been moved indoors.
	Dust emissions occurring occasionally in the waste area are prevented using dust-binding agents, sprinkling and landscaping.

6.2.1.1
Excavation and haulage of ore

Dust generated by loading can be reduced by sprinkling the rock material to be loaded. Dust emissions dispersed on the haulage routes for ore and waste rock are usually prevented by sprinkling the roads and/or spreading dust-binding agents on the roads. Calcium chloride is the most commonly used dust-binding agent, but the use of it can lead to an elevation in chloride concentrations in surface and groundwater. Nowadays, other more eco-friendly chemicals are available for binding dust, such as potassium formate.

On long hauls, dispersion of dust from ore haulage loads is most effectively prevented by covering the loads. Exhaust emissions of vehicles above and below ground are reduced using cleaning techniques, such as catalytic converters. In the reduction of exhaust emissions, it is important to choose mining machinery with low emissions.

The dust emissions generated by blasting can be reduced by staging charges, correct selection of blasting chemicals and by optimising dosage. The dust quantity can also be reduced by extraction of drilling dust into the cleaning facility. Being heavier than air, the carbon monoxide produced in blasting will deposit on the base of the blasting area, and is removed from underground mines using ventilation.

6.2.1.2
Crushing and screening

The mitigation means for dust emissions caused by crushing and screening depend on whether the crushing and screening circuit is located indoors or outdoors. Dust emissions generated by an indoor crushing and screening circuit are prevented using a dust removal system with contained devices as stipulated by occupational health and safety requirements. In addition, an extraction system is used for dust removal. Dust emissions can also be reduced with sprinkling or using dust-binding chemicals. The use of chemicals for binding dust may be restricted by the detrimental impact of these in the concentration process. Electrical dust deposition systems may also be used for the dust prevention in the crushing and screening circuit. Filters or scrubbers effectively prevent dust emissions from the system into the environment. The effective operation of dust removal systems also requires the devices are in good working order and well serviced.

The dust emissions from outdoor or partly outdoor crushing and screening circuits can be reduced by containing the devices and using controlled discharge of dust through filters. However, sprinkling devices that spray fine mist through nozzles are usually used for binding dust. In Finland’s climatic conditions, the use of water sprinklers is not always possible due to below-freezing temperatures. Dust-binding chemicals (chlorides and formats) are better at enduring freezing temperatures.

6.2.1.3
Concentration

The gas and dust emissions of the concentration process are mainly formed by the drying of concentrates, use of concentration chemicals, and the chemical reactions occurring during the concentration process.

Rotary dryers and other drying devices that use fuel oil usually have a flue gas scrubber for reducing airborne emissions. The operating efficiency of the scrubber depends on the even operation of the drying process and the technical condition of the scrubber. Efforts are made to avoid sudden fluctuations or excessive temperature increases in the functioning of the process by adjusting the drying process. However, the drying process is usually compensated by enhancing the concentrate filtering system in such a way, that the final moisture of the concentrate is sufficient without drying. In some cases, the adjustment of the filtering system can be economically impossible or the ultimate moisture requirements for the concentrate may demand the use of dryers.

Efforts are made to reduce gas emissions from the concentration process generated by the use of chemicals and from chemical reactions by adjusting the process and preventing undesired reactions using technical means. For instance, the reaction between concentrated acid and sulphides or organic substances that produces hydrogen sulphide (H_2S) or nitrogen oxide (NO_2) can best be prevented with precise dosage of chemicals and sufficient dilution of the acid before using. Hydrogen sulphide can also gain access to the environment in connection with sulphide precipitation. In this case, hydrogen sulphide emissions can be reduced by oxidising the hydrogen sulphide with, for instance, hydrogen peroxide. Hydrogen sulphide can also be removed with gas scrubbers by using a diluted lye solution.

6.2.1.4
Loading and haulage of concentrates

The dust emissions generated by the storage and loading of concentrate can be more effectively reduced by storing and loading the concentrates in a sheltered warehouse. The dust emissions generated by concentrate stockpiles stored outside can be reduced by partly covering or sprinkling the heaps. However, partly covering the heaps will hinder loading, and the sprinkling of the concentrate stockpiles can cause water discharges. In open areas, the dust emissions of concentrate stockpiles are also reduced by surfacing and draining the area in such a way that it may be cleaned with brushing and washing with water.

With the haulage of concentrate, the most effective way of preventing loads from generating dust is covering the loads. In rail transportation dusting is prevented by using covered carriages or by covering the loads with tarpaulin. With truck haulage, covering of loads is an established practice. During rail transportation, dusting may also be prevented by spraying dust-binding agents, for instance lignosulphonate (e.g. Lignobond) or potassium formate (e.g. Kemdust), as an aqueous solution on the surface of the carriage load. However, the use of dust-binding agents is not as effective as covering the loads.

6.2.2
Emissions to bodies of water

The point of departure for planning the management of mine waste water are the hydrological and hydrogeological data of the baseline studies and/or independent studies of the mining area, as well as estimates of the quantity of water required by the mine and the quantity of waste water produced. The plans must include the following data (see also EC 2009), e.g.:

- annual changes in precipitation of catchment area(s), occurrence of precipitation peaks
- change in surface topography of the area, natural flow routes of surface water, natural fluctuation in strata of lake water (e.g. temperature, oxygen content, pH, Eh/Redox, nutrient content)
- aquifers; groundwater yield of overburden, discharge sites (abundance of natural springs)
- fractures of the bedrock; bedrock groundwater yield in the open pit area/underground mine; estimate of quantity of dewatering water
- quantity of process water required for the concentration of ore; process water intake from natural surface water – possibility for internal recycling

- extent of waste area and an estimate of the quality and quantity of drainage water and seepage
- extent of constructed area and product storage and loading areas (industrial area) and an estimate of the quality and quantity of surface water
- road network density; extent of the ore/mining waste haulage routes
- trenching.

The basis for ensuring the functioning of the water management system is to survey all sites that form water that could potentially pollute the environment, and to conduct this water in a controlled manner for treatment before recycling the water back into the ore concentration process and/or before discharging into the natural waterway (Heikkinen *et al*. 2009). The water formed at different facilities can be centrally recovered into the same basin treatment or divided according to the cleanliness of water fractions for processing in separate basins (Räisänen & Juntunen 2004). The basis for the division is usually separating clean surface water or nearly clean surface water from water that contaminates the environment. In this way, the quantity of water to be processed is reduced and water treatment costs are saved.

Water discharges can be usually reduced by increasing internal recycling and making the use of water more effective (by minimising use of water) in the processing of ore. The starting point for the mitigation and prevention of environmental impacts of water discharge is a functioning water collection system and treatment method. Table 32 shows techniques for reducing water discharge and Table 33 shows the water discharge of operating mines and the means employed for mitigating the environmental impacts of the water emissions. The following sections first describes waste water treatment methods in more detail, then a description of the means employed for reducing the water discharge of various operations is presented.

Table 32. Conventional techniques for reducing water discharge in mining operations.

Method	**Description of measure**
Internal recycling	Dewatering water and/or treated process water is recycled to be used again in the ore concentration process
Reducing the quantity of water to be treated	Survey of the water discharge of the operating mining area: only unclean water will be conducted for treatment
Minimisation of supply water for the process	The requirement for ore process water is made more effective/ reduced (improvement/development of the method)
Reducing diffuse loading	Watertight basal and dam structures/reactive basal structures constructed for the water treatment basins (retention of harmful substances)
	Impermeable basal and dam structures will be constructed for the waste areas to prevent seepage from accessing the groundwater
	Recovery of water with the potential of polluting the environment from the waste area for treatment
	An impermeable basal structure will be constructed for the ore storage area, the loading bay will be surfaced with asphalt; collection of surface water for treatment
	Making of ditches along haulage routes for ore and waste rock and conducting ditch water for treatment

Table 33. Examples of methods used in metal mines in Finland for the mitigation of water and waste water loading and the consequential environmental impacts of these.

Mine/production facility	Prevention of emissions/mitigation of environmental impacts
Kemi Mine	Almost all the water required for the concentration process is recycled from the settling pond of the waste area.
	All surface water of the mining area is conducted to the settling pond.
	Contingency plan in place in case of environmental damage.
Kittilä Mine	Prior to discharging, the dewatering water of the mine is conducted onto the overland flow area that will retain solid matter, arsenic and metals.
	Waste rock shall be disposed on the basis of chemical properties into environmentally compatible and potentially acid-forming. Potentially acid-forming rock matter will be encased within carbonate-rich rock, which will neutralise potential acidic seepage water. The quality of seepage is monitored from the water of the lysimeter installed inside the waste rock pile. The seepage from the waste area is conducted for process water treatment.
	The base of the intermediate ore storage is watertight. Seepage and drainage water will be collected and conducted into the process cycle.
	Efforts are made to maximise the recycling of process water.
	The base of the waste basin has an impermeable bituminous membrane liner.
	Cyanide is destructed from the process water at the plant prior to discharging into the waste impoundments.
	Fish stocking is being performed.
Pyhäsalmi Mine	The metals of the mine dewatering water are precipitated with lime in the waste pond.
	The recycling of waste water back into the process is done as much as possible without causing gypsum precipitation.
	All surface water within the mining area will be collected using ditches and conducted to the waste area for neutralising.
	Waste impoundments have been constructed on impermeable ground and seepage is collected in perimeter ditches, from which it is pumped back into the pond.
	The ultimate waste water is aerated during winter in order to reduce oxygen consumption prior to discharging into the waterway.
	Financial support is provided for stocking of fish.
	Contingency plan in place in case of environmental damage.
Talvivaara Mine	All water pumped from the mine is used as bioleaching circuit water.
	The bases of waste rock areas and waste mineral precipitate ponds are made from impermeable HDPE and bentonite liners. No water is discharged from the gypsum ponds into the environment, as this is returned to the process cycle.
	Pipelines are placed inside plastic channels in order to avoid emissions during failure. Any leakages are recovered in the secondary ponds.
Jokisivu Mine	The base for the waste rock area is made from till.
	Settling ponds for the suspended solids of the pumped dewatering water have been constructed, the inside of which is sealed using clay.
Vammala concentrating mill	All the supply water for the concentration plant is taken from the water pumped from the nickel mine.
Sotkamo (Lanhaslampi-Punasuo) Mine	Reuse of approximately 10% of tailings has been achieved.
	The water pumped from the mine is used as process water following the precipitation of nickel.
	Waste water is recycled back into the process.
	Arsenic is precipitated from the process water using ferric sulphate and nickel using lye.
	The seepage of the waste area is pumped back into the waste pond or following wetland treatment (passive treatment), into the environment.

6.2.2.1
Waste water treatment methods

Nowadays active and passive methods are used for the treatment of water from mining operations (Table 34). Active treatment of waste water requires the addition of chemicals that promote the water treatment, which consumes energy. In comparison, passive treatment of water is based on natural biochemical reactions and use of natural energy (gravity, microbiological metabolic energy, photosynthesis) (Tremblay & Hogan 2000, Walton-Day 2003). Microbiological treatment methods can be either active or passive. Active treatment requires the addition of carbon, the source of bacterial energy (organic matter/CO_2), and potentially the addition of *bacterial inoculum* (Table 34). On the other hand, with treatment based on passive sulphate reduction, for example, the degradants of plant remains in the wetland function as sources of bacterial energy.

The most commonly used active treatment method in Finnish mines is the adjustment of the pH of the water using lime to neutralise acidity and to precipitate metals and metalloids as hydroxides and/or carbonates (Table 34a). Lime can be either hydrated (calcium hydroxide) or burnt (calcium oxide). Alternatively, lye (NaOH) or finely grained carbonate mineral powder (calcite/dolomite) can be used for pH adjustment and the precipitation of metals. Other chemicals can also be used for the precipitation of metals and/or metalloids. For example, ferrous or ferric sulphate, which is used for promoting the oxidation of arsenic, is suitable for removal of soluble arsenic.

The removal of suspended solids from the waste water is usually based on the settling of finely grained material in the ponds (cycling the water with low flow rate through two or three ponds) or with the use of flocculent or coagulant compounds that promote sedimentation. The latter promote the growth in the size of precipitate particles, which speeds up sedimentation in the ponds. The mineral precipitate sludge produced in the treatment remains on the bottom of the pond for final disposal.

Passive treatment methods do not require the regular adding of chemicals that promote treatment or the use of energy (PIRAMID Consortium 2003). However, assuring the functioning of treatment during different seasons may require constant monitoring of water quality. Treatment of water is either based on aerobic or anaerobic chemical or biochemical reactions or a combination of both (Table 34b, Walton-Day 2003). Aerobic reactions are based on the oxidation of iron or manganese and the subsequent precipitation and the retaining of other metals on the surface of the precipitates (adsorption) or into the precipitate itself (fixation). Anaerobic treatment is based on the reduction of sulphate through bacterial activity, which leads to the precipitation of metals as sulphides in the base layers of the basin. Passive treatment facilities comprise water collection ditches, water basins and/or filter beds and secondary settling ponds. A passive treatment facility can also operate as a secondary facility for an active treatment facility.

Table 34. Active (a) and passive (b) treatment methods for waste water. (Tremblay & Hogan 2000, EC 2009, PIRAMID Consortium 2003, Lottermoser 2007)

a)

Active treatment of water	**Active chemical / natural compound**	**Treatment principle**
Alkali treatment (basin/ container treatment, automation tank treatment, additions to slurry feed prior to basin treatment)	Lime [$Ca(OH)_2$ or CaO], lye (NaOH) or carbonate powder (calcite/dolomite)	Raising of pH, which assists with the neutralising of the water and precipitation of metals as hydroxides or sulphate salts
Aeration (pumping of air into the basin or containers/water collection system)	No	Promotes the oxidation and precipitation of iron (Fe^{2+}) which assists in retaining metals and metalloids (As) in iron (Fe^{3+}) precipitates
Addition of oxidising chemicals	Ferrous sulphate / ferric sulphate	Promotes the oxidation of soluble arsenic (As^{3+}) and retention as poorly soluble (As^{5+}) in iron hydroxides
Nitrogen removal	Bacteria addition + CO_2	Nitrification (oxidation: ammonium → nitrite → nitrate), denitrification (reduction: nitrate → nitrogen gas)
Sulphate removal	Addition of lime and $Al(OH)_3$ or Ba salt	Sulphate is precipitated as ettringite [$Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$] or Ba-sulphate
Removal of sulphate and metals (bacteria addition to container/pit water)	Bacteria inoculated membrane/ pig manure sludge addition or addition of other organic matter containing bacteria	Promotes the reduction of sulphate as sulphide and the precipitation of soluble metals as metallic sulphides
Removal of solids		
Sedimentation in basin	No	Water is cycled through numerous basins with slow flow
Addition of flocculating/ coagulating agents	Organic polymers/Fe or Al salts	Promotes the settling of fine-grained suspended solids/increase in size of precipitate particles leading to settling

b)

Passive treatment of water	**Reactive structure**	**Treatment principle**
Constructed wetlands	Basal structure of organic matter – carbonate aggregate (or alkaline slag) – organic matter	Reduction of sulphate using bacteria promotes the precipitation of metals/metalloids as metal/ metalloid sulphides; retention of metals in organic matter (complex bond); neutralisation of water
Filter beds/backfill	Organic matter (peat, composts, composted manure) and/or alkaline slag that binds metals	Promotes the adsorption of metals/metalloids on the surface of solid matter (physical or chemical adsorption); neutralisation of water
Reactive ditches	Carbonate containing blast rock/alkaline, coarse-grained slag	Promotes the neutralisation of acidic water; flow adjustment and covering can promote a) the precipitation of iron, b) staying soluble, c) prevention of accumulation of precipitates in the structure and blocking
Reactive dam/embankment/ underground wall	Organic matter (peat, composts, composted manure)/alkaline slag that binds metals, coarse-grained slag	Promotes the adsorption of metals/metalloids on the surface of solid matter (physical or chemical adsorption); neutralisation of water

6.2.2.2
Water discharges from excavations

The conducting of water pumped from the mine into the waterway can be reduced by using the water as fresh water in the process whenever possible, or used in other suitable applications. Fine-grained sludge is removed from the dewatering water by sedimentation in the slurry basin either above or below ground prior to recycling water back into the process – or conducting into the waterway. Flocculants can be used to make sedimentation more effective. At many mines, following the sedimentation basins, the dewatering water of the pit or underground mine is conducted together with the process water of the concentration plant and tailings into the tailings pond, from which it is pumped for further treatment in the settling ponds prior to the internal recycling of the water and/or discharging into the waterway.

Chemical treatment is used to remove metals or metalloids from the dewatering water that are harmful for the environment before discharging into the waterway. The section above describes alternatives for the removal of metals from the water. Removal of blasting agent residues also requires separate treatment. Mineral oils originating from leaks in the hydraulic systems are separated from the water using oil separators.

Blasting agent residues can be problematic in chemical treatment of water if the removal of metals from the water requires a high pH. In this case, ammoniac is released from the ammonium nitrate of the blasting agents, which is harmful for aquatic fauna even in rather small doses.

Removal of nitrogen from the water requires separate biological treatment. In Finland the subject has been researched by e.g. the KAIRA project led by the Finnish Forest Research Institute METLA (Mattila *et al.* 2007). According to the study it is possible to remove nitrogen from the water, but it requires removal of suspended solids prior to the removal of nitrogen. The nitrogen removal method is a complicated and costly process, which is why it is not yet widely used in the mining industry. Indeed nowadays the removal of nitrogen from dewatering water is based on the recycling of water via the tailings areas, which means that nitrogen is removed from the water during long retention particularly if the pH of the water in the waste area is sufficiently high. The retaining of nitrogen in the waste ponds is typically 50–60%.

6.2.2.3
Water discharge from the concentration process

The overall emissions from the concentration process into water comprise the quantity of water discharged and the chemical element concentrations in the water. Emissions can be reduced by reducing the quantity of water to be discharged and/or by making water treatment more effective. The best environmental practice is to increase the internal recycling of water and to reduce the intake of fresh water. The quantity of water to be treated is also reduced by the separation of clean drainage (or natural water accessing the mining area) of the mining area from contaminated water.

Treated process water and pit dewatering water can be used for the recycling of water. For instance, waste water clarified in the tailings impoundment is recycled back into ore processing. Water can also be recycled in the process as "internal" recycling in the process stages where the quality of the water is suitable for using in the concentration process. Suitable water can be, for instance, the excess water from the thickener, filter filtrate water and cooling water. Alternatively, or with the recycling of the process water, some fresh water can be replaced with pumped pit dewatering water either directly after sedimentation or following sedimentation and simple chemical treatment (e.g. precipitation of metals, cf. Table 34, Chapter 6.2.2.1 and Figure 42, Chapter 8.3.3.2).

In addition to recycling, the reduction of waste water discharges may require an enhancement of the chemical treatment of the process water. For instance, treatment is often associated with pH adjustment and the precipitation of metals, in order that the emissions or concentration limits stipulated in the permit regulations and other set objectives are met prior to discharging the water into the waterway. Chapter 6.2.2.1 describes in more detail the methods suitable for water treatment (see also Figure 42, Chapter 8.3.3.2).

When handling sulphide ores, the waste water often contains sulphates in addition to heavy metals. Sulphate concentration can be somewhat reduced using lime precipitation (forms gypsum, Ca sulphate). More effective methods for the removal of sulphate are the precipitation of sulphate using barium salt or by raising the pH of the waste water and precipitating the sulphate using aluminium oxide (ettringite precipitation, Table 34a). Treatment methods based on membrane filtration represent more modern technology (reverse osmosis/nano filtration, see Chapter 8.3.3.2). Biological methods such as sulphate precipitation into metal sulphide using sulphate reducing bacteria (or by reducing to hydrogen sulphide) may also be suitable for the removal of sulphate.

Waste water can also contain compounds (e.g. sulphur compounds, such as thio compounds and hydrogen sulphide) that increase oxygen consumption and oxidise slowly during the winter. The oxidation of these is enhanced particularly in the winter using either mechanical aeration devices (similar to those used in treating domestic water) or oxidising chemicals (e.g. hydrogen peroxide, H_2O_2). However, the use of oxidising chemicals is significantly more challenging than aeration in relation to process adjustment and safety. The warm water during the summer and extended retention time in the basin are normally sufficient for the oxidation of compounds (e.g. precipitation of iron). Oxidation can lead to a drop in the pH and require subsequently the increase in lime treatment (or addition of lye).

If chemicals are used in the process that can cause particular danger to the environment or human health, these shall be chemically removed prior to discharging into the environment. For instance, the cyanide from sodium cyanide that is used in the concentration of gold can be chemically removed using e.g. alkaline chlorination, ozone oxidation, hydrogen peroxide oxidation or sulphur dioxide-air oxidation (Inco process, more information available from EC 2009 and INAP 2009).

6.2.3 Mitigation techniques for the emissions of mining waste areas

Knowing the chemical and physical characteristics of various waste fractions, waste rock, tailings and mineral precipitate sludges is the point of departure for the mitigation of mining waste emissions and the prevention of the environmental impacts of such. This is vital for directing planning of the waste areas. The impermeability of the basal structures of the waste areas, the collection and sufficient treatment of facility water and the precipitation received by the impoundment significantly reduce the emissions of waste areas. During the operational stage, the techniques employed to mitigate environmental impacts are particularly focused on preventing the dusting of waste areas and the recovery of seepage, removal of suspended solids from the water and the chemical treatment of the water. The prevention or slowing down of chemical alteration (mineral weathering) and the controlled use of harmful process chemicals, as well as destruction (e.g. cyanide) if necessary are important in improving the quality of waste area seepage before conducting water into the waste impoundments or onwards from the waste areas.

During the operational stage, chemical alteration can be reduced by building a cover for areas where disposal has reached completion. This is also important for reducing seepage quantity and improving quality. Retaining waste under water or as water saturated also slows down chemical alteration. An impermeable cover or water covering can prevent/slow down the oxidation of iron sulphide contained in the waste material, which in turn prevents or slows down the increase in acidity and the leaching of harmful chemical elements (see Figures 40 and 41, Chapter 8.3.2.1). The formation of acidic drainage associated with sulphide oxidation can also be prevented with correct selection of disposal technique and the basal and dam structures for the waste area. The techniques for preventing acid formation shown in Table 35 are based on the prevention of oxygen from accessing the waste area or the sulphide mineral surfaces of the waste rock (cf. Table 43, Chapter 8.3.2.2). Alternatively, acid generation can be reduced by increasing the neutralising capacity of the waste or by reducing the iron sulphide concentration of the waste.

Table 35. Methods for the prevention of acid formation applied in the planning of waste areas and during operations. (EC 2009, Tremplay & Hogan 2001, Räisänen 2005)

Methods for the prevention of acid formation	Principle of the method and suitability for different waste types
Water cover	Waste is disposed as water saturated or discharged into a pond with water; water cover prevents the diffusion of oxygen into the waste (diffusion of oxygen in water is 10^4 times smaller than in air), suitable for tailings or mineral precipitate sludge
Paste cover	Covering using water retaining (10^{-7}-10^{-8} m/s), fine-grained rock powder or tailings material containing fines (paste) slows down/prevents oxygen from accessing the waste. Suitable for tailings and waste rock. For instance, the magnesite tailings cover (≥2 m) of the Luikonlahti tailings area.
Placement in underground mine	Waste is backfilled into underground cavities as supporting backfill. Suitable for coarse-grained tailings (hardening paste filling)/waste rock; e.g. Pyhäsalmi Mine
Placement into open pit (water filling)	Waste is placed in the section of the open pit where excavations have been completed or is backfilled into a closed pit filled with water. The backfill will remain covered by water or will be covered with till and water (wet cover). Suitable for waste rock (acid forming, non-acid forming) and the neutralising tailings to be disposed with the waste rock (blending/layering).
Iron sulphide removal (depyritisation)	Iron sulphides are fully/partly removed from the waste prior to placement in the waste area. Sulphide removal reduces the acid-forming potential of the waste. Suitable for tailings.
Selective sorting	Waste is sorted prior to disposal into neutralising and acid-forming waste fractions that will be disposed to separate waste areas, which will reduce the area coverage of potential environmental impacts. Suitable for tailings.
Mixed disposal	Sorting of waste according to environmental compatibility. The acid-forming waste fraction is encased inside neutralising (containing carbonate mineral) waste fraction. Suitable for waste rock in aboveground disposal or backfilling.
Impermeability of dam/basal structures	The sufficient sealing properties of basal and dam structures of the waste area prevents the flow of oxygenated groundwater from below/sides of the waste facility. The impermeability of the dam structures (upstream side) slows down the transport of oxygen with wind flows through the slope and into the waste. Sealed structures are suitable for waste rock, tailings and mineral precipitate sludge that are potentially acid-forming and/or contain harmful substances.
Reactive basal structure	The use of reactive basal structures is based on the capability of these to neutralise (alkaline basal material) acidic or low-acidic drainage or the ability of these to bind harmful substances (compacted peat, thickness at least 0.3 metres).
Chemical addition, increasing neutralising capacity	Lime is added to the waste fraction prior to disposal. Suitable for tailings and mineral precipitate sludge.

6.2.3.1
Dust emissions of waste areas

In order to prevent dust emissions from the tailings area becoming airborne due to wind, the tailings are kept damp during operation or lime milk is sprinkled on the flat surfaces of the tailings. Lime milk is particularly used in dried areas where it forms a hard crust on the tailings thereby preventing dusting of waste. However, the lime milk crust does not endure mechanical strain or remain over the winter, which means the treatment needs to be repeated in the spring. The moisture content of the tailings is adjusted with disposal methods or by keeping the water-space of the pond as large as possible, taking into consideration dam safety issues.

The dust generated by the dam embankments of the waste area can be reduced using a covering of blast rock or using vegetation, for instance by planting grass seeds. Rock covering is done as the embankment height increases. The covering of embankments with vegetation can be initiated already during the operational stage.

The dust emissions generated by the waste rock piles are reduced by covering the heaps or by introducing vegetation already during the operational stage in areas where disposal has reached completion. Dust emissions generated by the waste rock areas can also be reduced by reducing the amount of waste rock intended for final disposal, whereby environmentally compatible waste rock can be used inside or outside the mining area in earth constructions and as backfill of the mine/pit.

6.2.2.2
Water discharge from waste areas

The mitigation of water discharge from the waste areas is associated with the reduction in the quantity of used process water, recycling of water back from the waste areas into the process and the management of waters around the waste areas (see Chapter 6.2.2). The discharged water accessing the environment from the waste area as diffuse load can be reduced by making impermeable basal structures for the waste area and with controlled conducting of seepage and drainage from the waste area to the treatment ponds. The impermeable structure of dams in a waste area with a sealed base significantly reduces the quantity of seepage from the waste pond (management of waste facility water using e.g. decanting well).

Correct placement of the waste area can affect the dispersion of emissions. For example, waste areas can be placed in sites where the drainage water of the waste pond can be conducted in a controlled manner for treatment (topographic location; soil conditions). The quantity of drainage water for treatment can also be reduced by conducting the clean environmental water to bypass the waste areas. With respect to unpredictable water discharges, it is recommended that safety ponds be designed for mitigating damage, or dam structures constructed to prevent the dispersion of emissions. Unpredictable emissions may be generated, for instance during floods or as a result of dam failure or collection drain wall breakage.

Potential contamination of groundwater can best be prevented by placing waste areas (tailings, mineral precipitate sludge) on compactable soil or by constructing an impermeable basal and dam structure (see chapters 5.4.3.1 and 5.4.4.1). The placement of mining waste into underground mine cavities and/or decommissioned open pits (or open pit section) can reduce the area required for the waste areas aboveground and thereby also reduce water discharge. The partial landscaping and covering of waste rock piles already during the operational stage also reduces the amounts of water discharge, as well as playing its own part in improving the quality of drainage water, particularly if the covering structure is made from material with low permeability properties (see Table 35).

6.2.3.3
Water and dust emissions of mine dams and prevention of dam failure

Water seeping from the waste area through or beneath the dam to the surface water is collected in perimeter drains to prevent uncontrolled emissions and conducted for treatment or pumped back into the waste pond. Dams for retaining waste that is potentially acid-forming and/or contains harmful substances will be constructed as impermeable, which prevents waste water seeping from the dam area into the soil and groundwater (see Chapter 5.4.4.1). The dusting of the dam areas is prevented using covering (blast rock, till) and by vegetating the dam slopes during operations in areas where such is possible. It is also important to make precautionary plans in case of extreme weather conditions.

Table 36 shows the types of dam failures and the means employed for preventing such damage. Dam failures can be divided into three main types: external erosion, internal erosion and mass slide. Dam failure is often the outcome of a number of causes, not merely a single reason.

Table 36. Types of dam failure and means for preventing failures.

Type of failure	Description and reason for failure	How failure is apparent	Prevention of failure
Internal erosion	Uncontrolled flow of seepage through the dam	Depressions on the ridge	Correctly functioning filter and drainage structures
	Deficient filter structure	Craters	Correct backfill for penetrations/sealed flange structures
	Incorrect penetration structure		Sufficient frost dimensioning
	Frost		
External erosion	Pond overfill	Overflow	Greater freeboard
	Breakage of tailings pipe	Erosion on the slopes	Thicker slope covering made from coarser material
	Waves	Water travelling along new routes	Binding of surface e.g. using vegetation, covering or sprinkling
	Floods caused by rain and thaw water		
	Blockage of drainage systems due to e.g. wind erosion		
Mass slide	Excessively steep slopes	Ground level below begins to rise	Gentler sloping slopes
	Seepage or groundwater level too high	Collapse of sliding surface	Back embankment
	Excessively quick construction and insufficient sealing		Effective drainage systems

6.2.4
Noise emissions and vibration

Noise prevention methods can be divided into mitigation of noise emissions and prevention of noise propagation, as well as detailed and predictive planning. It is important to plan noise prevention throughout the entire lifecycle of the mine.

Noise emissions can be reduced (see also Table 37)

- with regular servicing of appliances, containing and shielding noise producing devices.
- using noise barriers. Construction shall utilise overburden or stockpiles that does not harm the environment.
- by understanding the nature of the dispersion of noise emissions and by designing operations to reduce noise e.g. by placing grinding and screening functions into the underground mine or partly underground, placing devices that generate

noise close to one another and at a lower level compared to the ground level (also reduces the extent of the impact region), keeping the doors of the concentration plant and crushers shut.

- choosing the direction for excavation in such a way that operations remain behind the quarry front in respect to housing.
- leaving unexcavated embankments as noise barriers for in the direction of housing.
- leaving tree stands and vegetation on the edges of the mining area or in the surroundings of noise emission sites.
- by limiting the charge size used in blasting, and by staging the charges and optimising the quantity of blasting chemicals used.
- by issuing notifications about blasting and by concentrating blasting to certain times of the day and at the same time, if possible. Blasting causes loud yet brief noise, so prior notification will have a positive impact on the attitudes of those impacted by the noise.
- planning of haulage routes and timing of transportation during times of the day when disturbance is minimal.

The Uusimaa Centre for Economic Development, Transport and the Environment (ELY Centre) maintains a noise information system that facilitates inputting of noise assessments performed on various operations, on for instance land use planning, the environmental permit procedure and reports associated with the EIA projects. Noise reports based on calculations or measurements can be updated on the information system, as well as the locations of functions causing noise and noise barriers. The purpose of the information system is to enhance the utilisation of noise reports to serve various user groups (Laurila & Hakala 2010). More information about the information system is available from the website of Finland's Environmental Administration (Uusimaa ELY Centre & Ministry of the Environment 2011).

Vibration caused by excavations will not be possible to completely remove, but using the appropriate actions its harm can be minimised. Blast vibrations spreading in the environment can be reduced with correct work performance and plans for blasting. Vibration can be reduced by (see also Table 37)

- selection of excavation direction,
- accounting for bedrock properties,
- correct selection of blasting agents,
- planning the timing for charges according to the state of tension and oscillation of the bedrock (short delay blasting cap),

Table 37. Examples of measures employed at operating mines in Finland for mitigating noise and vibration.

Mine	Measures employed to mitigate noise and vibration
Kittilä Mine	Temporary crushing work is done behind the waste areas.
	Noise prevention of crushing plant using structural solutions.
	Measures for reducing noise caused by grinding using structural solutions are being investigated.
	Noise barrier from the open pit to the ore storage facility and on the housing side of the ore storage facility in order to reduce noise caused by haulage and loading.
	Noise barrier between the atmospheric gas plant and office buildings to reduce process noise.
	Retaining of as many tree stands as possible within the mining area.
Jokisivu Mine	A noise barrier has been built around the pit that has been made of overburden masses and waste rock.

- reducing blast hole charges and by reducing the degree of charging or by reducing the size of the field to be blasted (order of detonation, small momentary quantity of blasting agent),
- employing competent drilling management.

6.2.5
Energy consumption

In mining activities, energy consumption represents such a significant expense that development projects aimed at saving energy are routine at mines (cf. Table 38). Energy consumption is intensely dependent on the quality of the ore and the process techniques it requires. If the ore is hard, extracting, crushing and grinding consume distinctly more energy than the corresponding processing of soft ore. An approximate understanding of the amount of energy required for grinding ore may be defined by using the so-called Bond Work Index that indicates the theoretical energy requirement per ton of ore. This ore specific theoretical value puts some limitations on how much energy saving may be achieved.

Nevertheless, efforts can be made to optimise energy consumption used in grinding using, for instance, the following measures:

- Optimisation of the crushing and grinding process. Measured by ton of ore, crushing consumes much less energy than grinding up to a certain point (c. 10 mm). With respect to optimal operation, different crushers have a certain crushing ratio (e.g. jaw crusher 3–7, gyratory crushers approximately 6), which when exceeded can lead to significant maintenance costs. Consequently, crushing stages need to be added if the fineness of the product is increased. In this case, screening stages also need to be added. As the number of devices increases, so does the energy requirement. The designing of grinding is indeed a challenging optimisation task where energy consumption is important, but by no means the only criteria.
- Appliances with as good an operating efficiency as possible are selected for the crushing circuit, the capacity and crushing ratio of which are within a favourable range and no “idling” occurs.
- Planning of the grinding circuit and selection of method attempt to attain the best possible throughput capacity in respect to energy consumption. It should be noted, however, that energy consumption is not the only design criteria. Maintenance costs and consumption of required substances (e.g. grinding rods and balls) can be significant cost factors for mines. Planning of the operation of other appliances generally associated with the grinding circuit (e.g. classifiers) undertakes to find efficient functioning.

A multi-stage concentration process that produces a number of concentrates naturally requires more energy than a simple process. Also in this case, the designing of the concentration process and associated appliances have an essential significance with regard to energy consumption. Planning should take the following into account:

- Energy efficient devices should be selected (motors, pumps, frequency converter control).
- Optimisation of size/quantity of appliances. As the size of units expands and the number is reduced, the energy consumption per ton falls. However, size cannot be increased indefinitely without disturbing the functioning of the process, rather it is a question of optimisation between energy consumption and the process.
- The processing of ore shall be planned to be as simple as possible.
- Energy efficient concentrate dryers shall be selected. For instance, in general pressure filtration consumes less energy than the conventional disc filtration

and drum dryer. A ceramic filter consumes even less energy than the disc filter or pressure filter. However, selection cannot always be made on the basis of energy consumption as, for example, different devices have different optimal functioning ranges in relation to the fineness of concentrate. Requirements stipulated for the ultimate moisture content of concentrate are also affected by the selection of method and devices.

At old mines where processes have often been designed and built using older, less energy efficient technologies, the energy perspective shall be considered when replacing devices. The making of a detailed energy report is also recommended, that
- accurately surveys current energy consumption,
- potential "energy losses" are investigated (e.g. leaks in the compressed air network, etc.) and
- sites are investigated where energy savings can be made if necessary by making modification to the process or devices.

Table 38. Examples of ways for improving the energy efficiency of mining operations.

Mine	Measures for enhancement of energy efficiency
Kemi Mine	Ore haulage is minimised between the levels
	Efforts are made to reduce specific charges in order to reduce blasting gases
	The consumption of specific energy at underground mines has reduced as the increase in grinding in the ore chute occurred as a result of the greater fall height
	The specific electricity consumption for the concentration plant has reduced mainly due to the improved separation efficiency, which has increased capacity
Pyhäsalmi Mine	Energy report/survey completed
	Replacing the drum dryer with pressure filters
	Recovery and utilisation of heat from the water pumped from the mine in the heating of ventilation air
Kevitsa Mine	Frequency changers, liquid resistance starters, etc. in use for adjusting the speed of large pumps, start-up of conveyors and in the optimisation of operational conditions for the grinding mills
	The selected low-voltage motors completely comply with energy efficiency class IE2 and mostly energy efficiency class IE3

6.3
Mitigation of emissions following decommissioning of operations

Rehabilitation measures are employed for the mitigation of airborne emissions and emissions to water bodies caused by the structures remaining in the mining area following the decommissioning of activities, for instance by covering the waste areas and treatment of water. The primary objective for the rehabilitation measures shall be the prevention of the generation of emissions, with the secondary objective being the reduction in loading strain caused by the emissions (see Chapter 8.4). The most effective way of mitigating emissions following decommissioning is to consider closure measures already during the planning and construction stages of the mine, for instance when planning waste areas and excavations (see Chapter 8.3.2).

6.3.1

Emissions from the mining waste areas

Following closure, the emissions generated by the waste areas comprise the drainage formed by the disposal area and the dust formation of surfaces containing dry, fine-grained material. The quantity of emissions generated by the waste areas is reduced using various covering techniques (see chapters 6.3.1 and 8.4.1.1) and using structural and/or technical disposal solutions (see Chapter 8.3.2) as early as the construction stage for the mine. Emissions can be more effectively reduced by choosing a covering structure that not only slows down the chemical and physical weathering of waste (alteration), but also prevents the formation of dust in the waste areas and reduces the quantity of runoff (see Table 35, Chapter 6.2.3).

The chemical condition (weathering stage) of the waste has a significant impact on the quality of seepage generated in the waste area, which means the covering can also affect the quality of water emissions. In addition to covering, the mitigation of waste area water emissions often requires separate treatment of seepage and drainage. Active or passive methods are suitable for the treatment of water, or a combination of the two (see Table 34, Chapter 6.2.2.1 and Figure 42, Chapter 8.3.3.2). Following closure, it is recommended that, wherever possible, passive methods be employed for the treating of water, as these demand less constant maintenance and consume less energy than the active methods.

In expansive waste areas, the mitigation of dust emissions is often initiated during the operational stage by covering or introducing vegetation to the closed parts of the waste areas, which will be continued after completion of disposal to cover the entire waste area. Dense vegetation is very effective at reducing dusting (waste rock piles, tailings facilities), as is using water to completely cover fine-grained matter (tailings area, waste areas for mineral precipitate sludge). The quantity of seepage can be reduced using an impermeable cover, which may also affect the quality of seepage. The best way to reduce the acid generated by waste is by water cover, which can be implemented in a waste area with sealed base and stable dams or for waste material disposed in mine cavities or in an open pit. The covering (rehabilitation) of expansive waste areas with multiple sections is initiated already during the operational stage, which enables the use of monitoring data obtained from the functioning of the covering structure in the final closure stage to facilitate improvements to the covering structure and possibly making the treatment of water emissions more effective.

Covering structures for waste areas are shown in Table 48 (dry cover, Figure 36 as an example) and 49 (water cover, Figure 41, Chapter 8.3.2.1). A dry cover structure can comprise a single layer of soil or a structure made from a number of soil layers and/or synthetic material. Correct selection of the properties and thicknesses of dry covering structures can affect the quantity of water infiltrating into the waste areas and thereby also the quantity of seepage. A multi-layered structure with one part being a sealed layer is the most favourable way for reducing seepage quantity and potentially the quantity of water for treatment. The selection and design of structures needs to give consideration to any possible gases and/or temperature reactions (heat expansion) formed by chemical alteration of the waste. A sealed covering structure could cause toxic gases to be formed (H_2S, CO_2) in the waste area and the travel of these to, for instance, sampling sites that are located close to embankments (KT ry 2006). This needs to be considered as an occupational health and safety hazard during the planning stage.

Water cover can be employed in the rehabilitation of tailings impoundments that have sealed dam and basal structures (see chapters 8.3.2.2 and 8.3.2.3). The oxidation of iron sulphides and subsequent leaching of harmful substances from waste rock is most effectively prevented or slowed down by backfilling waste rock into the pit/

Figure 36. Luikonlahti former mining area before (upper) and after rehabilitation (lower). (Photographs: M. L. Räisänen)

underground mine and covering the backfill with a sufficiently thick layer of water (more information from Tremblay & Hogan 2001, EC 2009, INAP 2009, Eriksson 2001). The effectiveness of water cover is based on the gradual dissolving and travel (diffusion) of oxygen in the water compared to the air. Water and wet cover methods are described in more detail in Table 49, Chapter 8.4.1.1.

6.3.2
Water emissions from mined out spaces

As a result of the cessation of dewatering pumping and subsequent flooding of the pit/underground excavations following the decommissioning of activities, the excavated spaces can cause water discharges along rock cracks or permeable soil layers into the surrounding groundwater or as overflow to the surface water in the area. Emissions to groundwater can be prevented by good blocking of fractures and cracks that conduct water, or by constructing hydraulic barriers for the underground mine (e.g. in drifts or adits) prior to filling the mine with water. The barriers can direct flows of water in such a way that the acidic, metal-bearing water originating from the sulphide rich parts of the mine is separated from the cleaner water, while at the same time controlling the discharge of water into the environment. At underground mines, the water discharge channels may also be redirected by blocking flow routes or openings in the mine to which the discharge of overflow is to be avoided. Barriers can be made, for instance from concrete. These barriers can also promote and speed up the filling of the mined out spaces with water (INAP 2009). The blocking of the natural flow routes for water can lead to wall collapses with the increase in water pressure or by the water seeking new flow routes. The prevention of collapse requires the reinforcement of pit walls following closure.

Following the decommissioning of activities, the formation of water discharge caused by the oxidation of sulphide minerals is prevented by allowing the pit/underground mine to fill with water. In this way, water cover forms in the excavations, which prevents continuation of the weathering of sulphide minerals (see chapters 6.3.2 and 8.4). Filling with water can be speeded up by, for instance, pumping water into the excavated spaces or by blocking hydraulic channels using the aforementioned barriers (INAP 2009). During the operational stage and prior to the filling of the mined out spaces, oxidation products of sulphide minerals will have accumulated on the walls of the pit/underground mine, which will dissolve as the water level rises, thereby deteriorating the quality of mine water. The roads and floors of tunnels also have finely ground ore that could also leach harmful substances into the aquatic environment.

In order to mitigate loading on the waterway, the treatment of mine water is either performed *in situ* or by treating the mine overflow water. *In situ* means treatment of the water in the mined out spaces. The most conventional *in situ* methods are chemical or biological treatments. The most common chemical method is alkaline treatment where the acidity of the mine water is reduced by adding alkaline substance (e.g. limestone, lye), in order for the leached metals contained by the mine water to precipitate as hydroxides (INAP 2009). The best known biological method is the utilisation of sulphate reduction. In this method, bacteria, organic carbon and nutrition are introduced in the pit by adding an active sulphate reduction bacterial strain, the reaction of which is the reduction of sulphate as sulphide and leached metals precipitated as sulphides. At the same time, the reaction raises the alkalinity of the water (e.g. Vestola & Mroueh 2008). Other possible biological methods used include e.g. nitrogen removal for pit water containing minimal quantities of metals.

Similar active and passive methods are suitable for the treatment of mine overflow water, which are used during the operational stage and subsequently for the treatment of drainage and seepage in other parts of the mining area (see chapters 6.2.2.1 and 8.4.2). One other alternative for the treatment of mine water is the "pump and treat" method, where mine water is pumped for treatment into an independent treatment facility. In this way, attempts can also be made to recover valuable metals alongside treatment (e.g. Lottermoser 2007).

If the mined out spaces are only partly covered by water, water emissions can be caused by the oxidation of sulphides occurring on the walls of the excavated spaces lying above the water level. In a case such as this, efforts should be made to promote the filling of the mine by blocking all gaps that prevent the mine workings from filling and then pumping water into the mine (INAP 2009).

Preventative measures employed already during the operational stage to prevent the oxidation of sulphide material on the walls of the mined out spaces will reduce the treatment requirement following the decommissioning of operations. For instance, a wall passivation method has been developed over the past few years where the reactive rock surface is chemically covered with a permanent and protective surfacing, e.g. permanganate. The method works more effectively if the rock surface is fresh when it is covered. However, this is a new method, which means no long-term experience has been gained from its functioning (INAP 2009).

If mining waste is ultimately deposited in the pit/mine workings, assurances need to be made that the waste does not cause extra strain on the bodies of water. In order to prevent loading, mining waste can, for example, be covered in soil that is more permeable than the waste material, which means that the flow of water is directed into the clean soil instead of the waste material and the water will not wash harmful substances from the waste (e.g. Lottermoser 2007). The covering of waste using water in the pit needs to be sufficiently thick in order to avoid oxygen from accessing the mining waste, or the mixing of pit water due to wind or full circulation from causing the mixing of waste material or sedimentation to the water bed. Oxygen accessing the backfill can be reduced by covering the waste using e.g. till, which is then covered with water. This is especially recommended if the water cover remains shallow (MEND 1995).

For the mitigation of water emissions, all machinery, devices, structures and waste material (other than ultimately deposited mining waste) that may cause contamination of the water shall be removed from the mine once operations have been decommissioned.

6.4 Mitigation of social impacts during the planning and implementation of mining operations

Particularly with the planning of large mining projects, contrasting and conflicting understandings of mining activities and the desirable impacts of such from the perspective of regional development are often apparent. On the one hand, mining is thought to be a sensible industrial activity for the exploitation of natural resources that provides jobs and facilitates the viability of the region for the future. On the other hand, some may feel that retaining the current state of nature is the better option, in particular concerning the wildernesses of the eastern and northern parts of the country, including the development of related natural economies and tourism. These opposing stances produces very different experienced social impacts for the same mining project; something not even expert data can affect.

The social impacts of mining projects comprise the stakeholders' personal and collective, often conflicting attitudes, which are based on e.g. the experiences the locals have received from the ore prospecting stage or on other preconceived notions and beliefs. With communications and open dialogue, attitudes or the escalation of such can be affected on the local level; the general attitudes can be improved and at best can even help with the progression of the project. It is essential to fill the information gap using expert data before it is preceded by information from elsewhere. Public discussion in the media often incites attitudes and increases unnecessary fears.

One of the responsibilities of the mining company may be considered as taking care of the living conditions and contentment of its employees and their families also outside working hours. According to social sustainable development, social responsibility benefitting wider target groups may be regarded as the company's natural task. The need for developing society's services is high in many potential mining areas, which means that it is justified for forms of compensation to be focused on strengthening the public service structure.

The most central point of departure for the mitigation of harm and issuing compensation is the perception of the entire perspective and the combining of various interests (Table 39). The different and often conflicting goals of various interest groups need to simultaneously be approved and taken into consideration. Solutions need to be found in such a way that no interested party feels that they have been omitted from having the opportunity to influence. Working examples need to be sought from elsewhere, such as the possibilities for compensation in the form of a variety of social and health sector programmes, supporting the school sector or recreational activities via public or private service providers. Compensation is often a question of the willingness to take part in open discussion; locally functioning means for implementing compensation can be found using interactive planning.

The compensation of detriments and the benefits achieved should be long-term in nature, otherwise benefits will only be experienced by precisely the current participants, and in the worst case, the harm will remain the burden of future generations without compensation.

Negotiations about harmful impacts and the compensation for such should be held as early as possible, as later on during the project the compensation can easily

Table 39. Means presented for the compensation of detrimental impacts in the Sokli mining project. (See Anttonen 2010)

Compensation	Compensatory measures
Ecological compensation	The phosphorus content in the Kemijoki River is on the increase, which means that planting in the upper section of the Kemijoki River needs to be increased
	Fish ladders and bypass channels for every hydropower plant and dam
	It is important to retain the Nuorttijoki River as much as possible in its natural state
Landscape compensation	Selection of road alignments for wilderness tourism can be significant when travelling to the Nuorttijoki River
	Landscaping and taking into account the current landscape
	By aligning the mining infrastructure to the same opening in the backwoods of the villages where housing noise and landscape impact are easier to dampen as one of the characteristics of the area
Economic compensation	Annual monetary full compensation for reindeer herding cooperatives
	Reindeer economy compensation by building structures
	By supporting tourism development in the other parts of Savukoski, e.g. rivers Kairijoki and Kemijoki
	The project will introduce significant benefits, which are already part of the compensation
	Investments into the redesign and marketing of wilderness tourism
	Reindeer economy compensation, supplementary feeding and helicopter flight assistance
Social compensation	The plans are examined with entrepreneurs in an effort to find implementation solutions that least harm the practising of the business in question
	Technical mitigation measures in areas that experience disturbance of reindeer routes
	Compensation of reindeer economy in respect to increased need for fencing, sufficiently functioning ramp bridges to cross the pipeline
	Open discussion about the handling of radioactive matter in mining operations
Political compensation	By distributing appropriate information about the mining operations
	Investments into the infrastructure

concentrate merely on concrete compensation, and will no longer recognise, for instance the negative social impacts observed in the EIA. For instance, it is essential already during the planning stages of the mining project to consider the habitability and activity possibilities following mine closure particularly from the perspective of the neighbouring inhabitants. In particular, the potential alteration and feasibility of permanent housing for the new forms of use need to be assured. Inhabitants have often hoped the post-closure mining area could be used for other business activities, e.g. tourism (cf. Table 39).

All compensation should be voluntary and based on the company's own willingness. It is very likely that there are more advantages than the extra costs incurred, meaning this approach is feasible. For instance, the mining company can reserve a percentage of their budget or similar funds for compensation of social impacts. The area also needs operators with sufficient entitlements from the mining company to make resolutions in cooperation with the local inhabitants.

In line with social sustainable development, the social impact assessment implemented in connection with the EIA produces information pertaining to the various impacts of the mining project during different stages on human health, living conditions and contentment. On the other hand, one central task for the assessment is to institutionalise a functioning process of interactive flow of information and discussion. In accordance with this, the mining activity parties, the mining company and stakeholders are motivated and committed to cooperate in seeking new ways of strengthening the positive impacts of mining operations, as well as mitigating and compensating the negative impacts related to activities.

Regular dialogue between the mining company and local inhabitants shall continue throughout the entire lifecycle of the mine. In this way, relations of trust will be maintained, information about apparent needs and desires will be received, and essential avoidance of the emergence of fears and misunderstandings based on deficient information can be avoided.

7 Monitoring of activities and reporting

The monitoring of mine operations is based on the premise that the mining company must have sufficient knowledge of their activities' environmental impact and risks and ways to reduce harmful effects (Environmental Protection Act, Section 5). The monitoring of mines is divided into construction stage monitoring, monitoring of mining processes during the operational stage, emissions monitoring, monitoring of environmental impacts, and the inspection of emissions and impacts following the decommissioning of activities. Post-closure monitoring is described in the Mine Closure Handbook (Heikkinen *et al*. 2005).

Table 40. An example of monitoring obligations for a mine. (Mondo Minerals Oy 2008)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Monitoring during the construction stage													
Quality of receiving waterway													
Emissions monitoring													
Process water from the plant and seepage of waste rock area													
Toxicity of waste water													
Airborne emissions													
Noise													
Waste													
Environmental impact monitoring													
Physical-chemical quality of surface water													
Phytoplankton species and biomass													
Phytoplankton algae production potential													
Benthic invertebrates													
Metal content in fish													
Bookkeeping of fishing													
Fishing enquiry													
Electrofishing													
Sediment quality	monitoring agreed separately												
Groundwater quality and level													
Metal concentrations of *Lactarius rufus*, *Formica rufa* and till													
Suspended particles													
Noise													
Vibration													

The mining company shall formulate a monitoring plan in line with the requirements of the environmental permit, which is approved by the supervisory authority using a written decision. In addition to the monitoring obligation, the monitoring plan also includes procedures to be followed in cases of emergency. Table 40 shows an example of monitoring obligations for a mine. If necessary, alterations can be made to the monitoring plan in ways approved by the supervisory authority.

In addition to the monitoring obligation of the environmental permit regulations, the mining company usually conducts its own monitoring. The purpose of the mining company's own monitoring is the management of the processes of operations, e.g. precipitation of metals and monitoring the functioning of cleaning devices. In some cases, the content of this independent monitoring can affect, for instance, the internal practices of foreign holding companies that can sometimes demand a very detailed monitoring programme.

7.1
Monitoring during the construction stage

The monitoring plan also has its own monitoring obligations set for emissions generated during the construction stage. Monitoring includes the monitoring of construction work, waterway monitoring during the construction stage and the service inspections of various operations. An up-to-date logbook will be kept on the monitoring of construction work, the entries of which are agreed together with the supervisory authority. The logbook is kept at the mine, and the contact details for person responsible for maintaining such will be informed to the appropriate supervisory authority.

Monitoring during the construction stage:

- daily reports on the progress of construction tasks
- the working methods employed
- precise excavation times and places for trenches and channels
- timing and means of implementing the dewatering of water areas
- completion of water protection structures, surveillance of condition, observations related to functioning, as well as everything that is exceptional, even temporary differences in the water protection plan
- construction and emptying of ditch slurry basins and depressions
- timing and places for water sampling
- periodic inspections
- precipitation, temperature and wind direction
- all other possible events that are estimated to have an effect on the quality of water released from the worksites or loading of the waterway.

Substantial earth and water construction projects are usually performed during the construction stage that can have impacts on the waterways. The inspection samples are normally used for specifying e.g. suspended solids, ignition residue of solids, pH and metal concentrations depending on the natural composition of the soil. During the construction stage, visual observations are of special importance in order for any possible turbidity to be observed in good time, and extra monitoring and investigative work for resolving problems can be started as early as possible.

7.2

Monitoring of mining processes

The operational monitoring is directly associated with emissions monitoring. Depending on the nature of the process, operational monitoring can include very specific special sites. During the production stage of operations at mines, the mining company conducts its own very wide-ranging operational monitoring based on visual inspections, manual sampling and measurements, as well as measurement data obtained from automated devices. The majority of this monitoring is voluntary and related to the requirements of the mine, but some parts may also be obligatory monitoring stipulated in the environmental permit regulations. Operational monitoring also covers the operational construction stage. Monitoring includes the following:

- mine and concentration plant production (excavated rock, backfill rock, rock fed to the concentration plant or disposed of, concentrate and tailings)
- consumption of chemicals, fuels and energy
- excavation progress
- use of fresh and domestic water, use of recycled water
- quantity of dewatering water, process waste water and sanitation water to be discharged into the waterway
- traffic numbers
- operation of the treatment process for waste water, process water and seepage; usage times, operational failures
- functioning of overland flow areas and wetlands
- operating times and faults of dust removal devices
- produced waste; amount, quality and disposal of such
- dust and noise observations
- fill capacity and scope of waste rock area
- rehabilitation measures; scope, method of implementation, monitoring of functioning of applied methods
- maintenance of the areas; water management facilities, road network, grounds
- emergency situations, environmental damage and accidents
- sampling dates and places
- periodic inspections
- all other possible events that may affect emissions or the impacts of such.

Entries are made in the ways agreed with the supervisory authority. The logbook is kept at the mine, and the contact details for person responsible for maintaining such will be informed to the appropriate supervisory authority. The logbook shall be kept as long as operations continue. An annual summary of the entries shall be made, which shall be presented to the authorities when requested and appended to the documents for the revision application for the permit regulations.

Commissioning and inspection of dams

The commissioning of mine dams refers to the initiation of the first raising stage of the impounded material. In connection with commissioning, the implementation plan for the dam is approved, including e.g. future raising. The dam safety authority shall be given the opportunity to participate in commissioning the raises. Periodic inspections are conducted at least every five years. Periodic inspections shall be performed by the dam proprietor, but the dam safety authority and rescue authorities shall be given the opportunity to participate in the inspections.

The dam proprietor shall inspect the condition and safety of class 1 and 2 dams at least once a year (so-called annual inspection). The dam proprietor shall submit a written report on the annual inspection of a class 1 dam for the information of the dam safety authorities. In addition to the annual and periodic inspections, the dam proprietor shall arrange an inspection according to the approved inspection programme for the classed dam. Seasonal inspections usually entail the visual inspection of the dam ridge, slopes, covering and structures associated with the dams, such as the condition of pipelines and wells. Furthermore, observations are made for e.g. seepage quantity and possible quality, the water level of the basin, and the discharging of tailings into the dam. Further measurements and rectifying measures shall be performed when necessary.

7.3 Inspection of emissions

The inspection of emissions is part of the operational monitoring, but the official inspection of emissions stipulated by the environmental permit is performed by a consultant commissioned by the mining company, who is responsible for taking and analysing samples and forwarding the information on the findings to e.g. the representatives of the mining company, supervisory authority, local environmental protection authority and the local health and safety authority. The inspection of emissions includes the inspection of water, airborne, noise and vibration emissions, as well as the inspection of waste quantity and quality.

The inspection of water emissions includes the plant process water, dewatering water of the excavated spaces, seepage from the tailings areas, and sanitation sewage. Process and dewatering water is recycled via the settling ponds back into the process and/or is conducted into the receiving waterway following treatment. In addition, the seepage of the waste rock area often requires treatment to ensure it conforms to the emissions limits provided by the environmental permit. The environmental permit issues certain parameters for individual emissions limits. However, the annual total loading quantity can be restricted in respect to metals by specifying the annual total loading of all discharge points. In general, according to the ore deposit, principle metal concentrations, pH and possibly also sulphate content are measured from the waste water emissions. Almost without exception, the nitrogen emissions originating from blasting agents are also monitored. Furthermore, the obligatory inspection programme often incorporates the other metals contained within the ore deposit, mainly in respect to the more harmful metals from the environmental impact perspective, such as Hg, Pb and Cd. A variety of tests are used for testing the toxicity of waste water that determine the toxicity of the waste water for the organisms on the various levels of the food chain. Commonly used toxicity tests are the luminescent bacteria test (SFS-EN ISO 11348), green algae test (SFS-EN ISO 8692) and cladocera test (SFS-EN ISO 6341).

The domestic waste water formed is treated according to the permit regulations of the environmental permit. Each working day, the operating staff of the treatment facility conduct a service inspection of the functioning of the treatment facility in order to determine the quantity of waste water, possible bypass conducting, failures, chemical consumption, etc. A logbook is kept on the operational monitoring. The efficiency of the facility and inspection of loading are conducted with sufficient frequency. Temperature, oxygen, pH, electrical conductivity, COD_{Cr}, BOD_7, total P, total N, NH_4-N, suspended solids and faecal coliform bacteria are measured from the samples. In addition, the slurry content, sedimentation of the slurry of the aeration basin of the treatment facility and visual depth of the settling pond are measured on each inspection. Loading and the efficiency of the treatment facility are calculated as annual averages on the basis of flow rate and water quality. The slurry produced by the treatment facility is usually transported as aqueous slurry to the sewage treatment plant of the local authority.

The waste fractions generated in the mining activities shall be classed in accordance with the terms used in Ministry of the Environment Decree 1129/2001. The waste fraction properties are described in accordance with annexes 1 and 3 of the Mining Waste Decree 717/2009 (see Appendix 6). It is important to specify the acid-forming and neutralising potential, as well as the concentrations of potentially harmful substances and to estimate the short and long term solubility of these in disposal. The total concentrations of principle metals and sulphur (broad chemical element analysis, ICP-MS) and solubilities are generally analysed twice a year from the composite samples. Corresponding analyses are conducted on the neutralisation sludge of seepage. Composition data for waste rock is also updated during excavations if it can be assumed that the acid-forming characteristics or harmful substance concentrations of the waste rock change.

In the mining area, sources that cause airborne emissions are point sourced or channelled emissions sources and diffuse emissions sources. The inspections of emissions include the monitoring of the process during operations for the minimisation of emissions generation, as well as the specification of emissions from the emissions sources. Point source emissions sources include, e.g. crushing and agglomeration stations, as well as steam and oil boilers. Diffuse emissions sources cause, for instance the pit area as well as road, loading, storage and waste areas.

With respect to airborne emissions, the obligation is generally for either continuously operating or repeated re-suspended dust particulate measurements to specify total particle content and possibly certain particle size classes (e.g. PM10) in the environment, as well as regular particle concentration measurements of point source sites (e.g. exhaust fan of the dust removal system). In some cases the obligation can also include the concentration measurements of exhaust gases, if the process releases gases.

The European Parliament and Council resolution (EC) No. 166/2006 for the monitoring of emissions concerning the EU's emissions register E-PRTR (European Pollutant Release and Transfer Register) obligates the mining company to monitor and annually report to the supervisory authority the airborne emissions, emissions to water and soil of the pollutants listed in the pollutants list of the resolution, if these exceed the threshold value specified in the list. The authority is obliged to further report national emissions to the EU authorities for maintaining the joint European emissions register. This monitoring obligation as intended by the E-PRTR regulation is usually covered in the monitoring programme conducted in accordance with the environmental permit.

7.4 Monitoring of environmental impacts

The purpose of monitoring of environmental impacts is to establish in what ways the mining operations affect their environments. The inspection of emissions includes surface water, groundwater, air quality, noise and vibration. In addition to regular inspections, studies of a project nature will be performed on, for example, the impacts of operations on soil, aquatic fauna or vegetation, either voluntarily or as stipulated by the authorities. The purpose of the studies is often to monitor the trends in the neighbouring areas of the mine. Studies related to the environment are discussed in more detail in Chapter 5.

The obligation for monitoring surface water includes the monitoring of the physico-chemical condition, biological monitoring of surface water (phytoplankton species and biomass, phytoplankton algae production potential, benthic invertebrates and the metal concentrations of fishes), monitoring of fish populations and fishing (bookkeeping of fishing, fishing survey and electrofishing), and the monitoring of (aquatic) sediment composition.

The guidelines provided by the water and environmental administration can be followed in sampling procedures (Mäkelä *et al.* 1992) or other standardised methods or sampling methods that have been developed and tested in mining environment studies (e.g. sampling methods of GTK). With sampling it is important that the sampling method itself does not distort the composition of the sample (contamination avoidance) and the sample is preserved and/or kept in storage in the appropriate manner in the field for the purpose of taking to the laboratory. The specifications to be done on the samples are agreed in the monitoring programme. Most important is to measure these parameters to be used for the implementation of restrictions concerning the permit regulation emissions and that describe the potential environmental impacts caused by operations. For instance, with respect to water emissions of metal sulphide mines and the water monitoring sites downstream from the water releases it is recommended to measure temperature, oxygen, degree of oxygen saturation, pH, redox (reduction-oxidation potential) and electrical conductivity either on a continuous basis (some sites) or at regular intervals using multi-sensor instruments. Corresponding measurements can also be made in the laboratory using standard methods, where comparison can illustrate the changes in the sample associated with oxidation. Alkalinity can also be measured in the field in connection with sampling, or in the laboratory. The number of other parameters shall be appropriately selected to correspond to the objectives of the permit regulations, monitoring programme and monitoring sites (specific to mining activity and to mine site). In general the quantities of suspended solids, organic matter, nitrogen and phosphorous compounds, chemical residues (e.g. SO_4, Ca, Mg, Na, Cl, thiosulphate, cyanide), metals and metalloids, as well as other substances and compounds originating from the metal deposits (e.g. SO_4, Cl) are specified for the waste water and the surface and groundwater of the catchment area. In addition, the lake water is often subjected to tests for the specification of overall hardness, oxygen consumption (COD_{Mn}, COD_{Cr}), turbidity, colour and a-chlorophyll.

Biological quality factors are monitored according to the guidelines issued by the Environmental Administration (Meissner *et al.* 2010). Biological monitoring specifies the phytoplankton species and biomass as well as the algae generating potential of the phytoplankton, i.e. the primary production capacity of phytoplankton. Benthic invertebrate communities are monitored in the depressions of the lakes, in littoral areas and in the rapid water sections of fluvial waters. The monitoring of impacts also monitors the metal concentrations in fishes used for nutrition (e.g. vendace, pike-perch, pike and perch). Fish populations and fishing are also monitored using a fishing log, survey, electrofishing and experimental net fishing. The impact of operations on the quality of (aquatic) sediment and the thickness of sediment layers are monitored in the areas of the receiving waterways.

The groundwater impacts of the mine are monitored from the groundwater monitoring wells in the mining area, which are used for measuring the groundwater level and for conducting qualitative analyses (see specifications shown above). The wells and springs of the neighbouring areas can also be used as groundwater monitoring points.

Biological monitoring conducted in the land areas can include, for instance the specifications of metal concentrations in *Lactarius rufus* and *Formica rufa*. Other monitoring sites can include e.g. observations of the habitats and nesting conditions of flying squirrels or bats.

The measurement of inhalable particulate matter (PM10) in ambient air is conducted according to the EN 12341:1998 standard. Particle samples are collected from measurements of suspended particles, which are used to analyse the metals in such a way, that such may be compared to the target values of the Government decree for airborne arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons (Government decree 164/2007). Findings are compared to valid threshold values for respirable particle contents (Government decree 711/2001) and the reference value for respirable particle content (Government decision 480/1996).

A comprehensive environmental noise survey shall be conducted already in connection with the environmental impact assessment that either measures or models the general noise situation of the site. The noise areas are illustrated using maps. Environmental noise is usually measured with direct measurement from selected sites, e.g. the grounds of permanent or holiday homes in the daytime and night time (7 a.m. – 10 p.m. and 10 p.m. – 7 a.m.). The guidelines (Ministry of the Environment 1995) of Finland's Environmental Administration and the ISO and Nordtest standards (SFS-ISO 1996-1, SFS-ISO 1996-2, SFS-ISO 1996-3, Nordtest 2002) are used as measurement guidelines. (Mondo Minerals 2008)

Vibration dispersed into the environment is generated by e.g. rock excavation and traffic. The magnitude of vibration primarily depends on the quantity of blasting agents used in a single instance. The magnitude of vibration caused by traffic depends on e.g. the gross weight of the vehicle, speed and road conditions. The magnitude of vibration generated from excavation (blasting work) and the permitted magnitude of vibration as a function of distance to various buildings can be estimated on the basis of e.g. the formulae and coefficients published by Suomen maarakentajien keskusliitto (*Central Association of Earthmoving Contractors in Finland; today INFRA ry*) (Vuolio 1991).

Vibration is dispersed into the surroundings via bedrock and subsoil. The vibration dispersed via the subsoil usually dampens exponentially as the distance increases. Vibration travelling via bedrock dampens slower than vibration travelling via the subsoil. Vibration generated by excavations is usually of a shorter duration than vibration caused by traffic. Detrimentally intense vibration normally occurs in areas with soft and thick stratifications of clay and silt when the vibration impact region has buildings built on the ground. Harmful levels of vibration may also be experienced by buildings built on the bedrock, so-called frame noise on rail and road traffic, as well as vibration peaks in excavations of a brief duration. (Kuhmo Metals Oy 2008)

Provisions for the monitoring of impacts during operations subject to permitting and following decommissioning are stipulated in the Environmental Protection Act. The purpose of planning post-monitoring of surface and groundwater is to avoid harmful substances accessing the environment from the mining area and to ensure potential emissions are noticed as early as possible. The Kotalahti Mine of Outokumpu Mining Oy was closed in 1987. The impacts of the mine continue to be monitored by monitoring the condition of surface water and the receiving waterway. The water conducted into Oravilahti and the water quality of wetlands is monitored four times a year. A mine has permit conditions for iron, nickel, suspended solids and pH. In addition to these, the temperature, electrical conductivity, sulphate, manganese and copper are specified from the samples. Mine water is monitored in two shafts and from the mine overflow water. The condition of discharged water is monitored according to two joint monitoring programmes.

7.5

Reporting and quality assurance

Reporting on the monitoring findings is usually specified in the monitoring programme. The monitoring findings are submitted for the information of the supervisory authorities. An annual summary of activities and the emissions caused by such, the handling of waste (itemised by waste code) and the consumption of energy is usually entered into the VAHTI system online (www.ymparisto.fi) for approval by the supervisory authority. A written report is also made on the annual summary that summarises the entire annual activities of the mine, including exceptional circumstances and breakdowns. The environmental permit often regulates other reporting related to the protection of the environment, which can include, for instance, reporting on accidents associated with environmental protection and the reporting of other exceptional circumstances, reporting of construction and maintenance plans associated with environmental protection, reporting of exceptional emissions, and reporting of development projects.

In addition to the permit regulations, the reporting practice is also affected by the possible internal and external reporting practices set by the company that is the proprietor of the mine. The reporting practices can also be influenced by the standardised environmental and quality systems in place at the mine.

Monitoring findings are usually reported to the authorities during the monitoring term, e.g. monthly or quarterly, and an annual report is produced on monitoring. The general principle for the quality assurance of monitoring is that sampling and analyses employ standardised methods that are normally specified in the monitoring programme. A plan is drawn up for one-off studies, which is sent in advance to the authorities for approval. In the reporting of findings, the methods used and related uncertainty factors and statistical error assessments are presented. It is recommended that certified sample-takers and accredited expert laboratories for analyses be used for obligatory monitoring procedures.

8 Best environmental practices for metal ore mining

Mining activities complying with sustainable development entails responsible use of natural resources by ensuring the sufficiency of raw materials, recycling and availability now and in the future (Finland's Mineral Strategy, see Chapter 8.3.1). This requires the comprehensive and balanced utilisation of critical natural resources, the protection of critical natural values as well as a balanced and responsible way of working that considers the short and long term environmental, social, economic and administrative perspectives.

The best environmental practice (BEP) for mining activities is a way of working or method that assist in making sure the operations and the emissions they cause remain at a level that is acceptable for the local regional community. When defining the acceptable level (based on legislation) the potential impacts on the inhabitants of the surroundings, vitality and diversity of nature, and the landscape are taken into consideration. It is important to formulate environmental objectives for mining activities and to commit to implementing these in line with the planned schedule. The attainment of these set objectives requires the selection of best practices, where central focus is put on expert planning, reliable assessment that is based on research and investigations with regard to emissions and the assessment of impacts throughout the life of the mine.

The chapter on best environmental practices includes guideline recommendations and information about the best practices and methods. This chapter comprises four sections; the first (8.1) of which handles best practices for the planning of a mining project and administrative procedures. Chapter 8.2 describes the best environmental practices for the ore prospecting stage, Chapter 8.3 describes the BEP for the planning, construction and production stages of the mine, and Chapter 8.4 for the closure and rehabilitation stages of the mine. The best environmental practices are also associated with the eco-efficient use of materials and the reduction of mining waste quantities by developing techniques that can be used to e.g.

- prevent the generation of emissions (low-emission/emission-free practices, devices and ore processing methods, chapters 8.3.2 and 8.3.3).
- increase the proportion of by-products in relation to the mining waste intended for long-term disposal (see chapters 8.3.2 and 8.3.3.1).
- reduce the use of chemicals by optimising dimensioning and/or by recovering the chemicals for recycling (Chapter 8.3.3).
- reduce the raw water intake and increase the internal cycling of water (Chapter 8.3.3).

8.1

Best practices for planning mining projects and administrative procedures

The planning and implementation of a mining project with its numerous associated permits and related administrative processes forms a wide-ranging entirety. The fluent, quick and lawful progression of these benefits all parties, the mining company (cf. Chapter 8.1.1), permitting and supervisory authorities, as well as stakeholders and other interested parties (Figure 18, Chapter 3.2.5). The planning of a mining project, speeding up of various procedures and management of different issues is decisively aided when the mining company:

- internalises that the planning and implementation of the mining project, including the numerous associated permits and other related administrative processes will require plenty of resources, a lot of time, wide-ranging expertise, and close cooperation with various experts.
- implements the project's environmental impact assessment and plans for the prevention of detrimental impacts as integral parts of the planning processes for the mining project.
- is ready to invest the sufficient number of its own experts, resources and time into the project, with particular focus on planning the prevention and/or mitigation of the detrimental environmental impacts caused by the project, and also on conducting the environmental impact assessment procedure, making the necessary detailed plans, preparations for the permit application, and other administrative processes.
- is aware of the content requirements of the most important documents (e.g. EIA programme and report), various permit applications and plans (e.g. waste management plan for mining waste), the status of the numerous administrative processes associated with the project and the resources these demand, the legal requirements, as well as the prerequisites for granting permits.
- uses experts and consultants to assist in the planning of the project, the assessment of its environmental impacts and the making of permit applications, who have sufficient expertise, experience and resources for handling the matter in question. In other words, the mining company shall make a careful selection of its experts and consultants.
- ensures that the appointed experts and consultants have fully understood the assignment and handle the given tasks as agreed.
- takes special care in coordinating the planning and implementation of the project, including related administrative processes, and actively communicates the information pertaining to such to the different parties.
- during various stages of the project, is actively in contact with the most important authorities and discusses e.g. the necessary reports and plans.
- undertakes to enter into open and equal interaction with the various parties and engages in active sharing of information.
- conducts the environmental impact assessment and permit applications based on reliable and comprehensive data pertaining to the quality and quantity of emissions as well as to the changes caused by the construction of the infrastructure required for operations and other changes to the site.
- is aware that it carries any risk caused by uncertainty with the impact assessments and other studies, and that emissions substantially greater than forecast (described in the permit application) along with more detrimental environmental impacts can lead to some very significant extra costs and even lead to the permit being revoked.

Legislation directs the obligations and administrative procedures to be followed by the authorities, and the best practices for such. Following is a list of some practices employed by the authorities in relation to the EIA and permitting process:

- documents are published / announced in written and possibly electronic form,
- a sufficiently long period is allowed for issuing remarks and complaints (cf. 486/1994),
- the various authorities engage in fluent and flexible dialogue,
- the schedule for requesting statements is flexible,
- advice is provided on legal matters, if necessary (e.g. questions concerning the contents of the EIA reports and permit application),
- advice is given on nature protection issues (e.g. Natura and nature conservation sites, nature types, protected species),
- fluent dialogue takes place between the regional administrative authorities and the local authorities (nature protection issues, EIA, permits).

The best practices in supervisory tasks include e.g.:

- consultative liaison with the mining company,
- making of clear and comprehensive inspection reports,
- dialogue concerning the monitoring programmes,
- dialogue concerning the selection of best environmental practices,
- communication and dialogue with the municipal authorities of the area,
- communication with inhabitants.

8.1.1

Supervision and monitoring – responsibilities and obligations of the mining company

The monitoring of mine operations is based on the premise that the mining company must have sufficient knowledge of their activities' environmental impacts and risks and ways to reduce harmful effects (EPA, Section 5). Monitoring of mining operations emissions and environmental impacts assists with:

- ensuring that operations and emissions, including the impacts of such are in line with the permits granted for the operations,
- identifying hazardous situations, process failures or faults with the cleaning of emissions, thereby preventing environmental accidents and emissions into the environment produced during breakdowns as well as the detrimental impacts of such,
- continuously developing operations in line with the principles of sustainable development,
- developing plans and techniques to reduce emissions (noise, vibration, airborne and water emissions),
- developing activities towards reducing detrimental environmental and social impacts (restoration during operational stage),
- reducing the quantity and harmful properties of mining waste, as well as developing the safe handling of mining waste, including the rehabilitation of waste areas and the entire mining area (basic information for planning mine closure),
- developing rehabilitation measures for the mining waste areas (basic information for planning mine closure),
- improving social relations with the communities in the environment.

The monitoring of mines as specified in the environmental permit, is divided into construction stage monitoring, monitoring during the operational stage, emissions monitoring, monitoring of environmental impacts, and the inspection of emissions and impacts following the decommissioning of activities (cf. Chapter 7). In addition, the mining company can conduct its own independent monitoring that serves the environmental protection development of activities by, for instance, improving techniques for mitigating emissions and the environmental impacts of such. The intention of independent monitoring can also be the management of the various processes related to environmental protection and the development of such (e.g. precipitation of metals from waste water, monitoring the operation of cleaning devices, etc.). The best environmental practice is open communication of the monitoring and supervision findings in cooperation with the supervisory authority and mining company. This is integrated with the hearing of the surrounding communities (interaction).

8.1.1.1 Monitoring of airborne emissions, noise and vibration

The monitoring of airborne emissions includes the selection of monitoring sites by emissions source in the mining area and within the emissions dispersion area. The central objective of monitoring emissions is to assist with the development of reducing emissions. The best methods for monitoring airborne emissions are

- continuously operating and repeated measurements of airborne particles,
- regular measurements of point source emissions,
- video filming of blasting for the optimisation of charges, extent of the blasting field and use of chemicals.

The best practice for monitoring noise is repeated measurements of altered situations. The best practice for monitoring vibration is continuous measurement conducted at the closest sites of disturbance. It is also important to survey the damages potentially caused by vibration prior to commencing activities and at regular intervals during operations.

8.1.1.2 Monitoring of waste water discharge

The monitoring of waste water discharges includes the selection of monitoring sites outside the mining area by emissions source. The monitoring of the treatment efficiency of water and the monitoring of the quantity and quality of water in the surroundings of the mining area are central issues in the management of environmental impacts from discharged water (see Chapter 7). Monitoring shall assist

- monitoring the treatment efficiency (permit decisions and monitoring goals),
- receipt of sufficient data about various water fractions and emissions discharged into the water bodies, as well as the impacts of these on the downstream waterways (chemical, biochemical and physical, fauna),
- identification of possible faults (process failure, treatment failure, leaks in the water collection system/waste areas).

8.1.2 Design of mine dams, permitting and dam break hazard analysis

When making the construction or rectification plan, it is recommended for the proprietor of the dam to contact the dam safety authority in good time (Figure 37). It is recommended for project and master plan stage solutions to be given to the dam safety authority in order for the authority to make preliminary judgements on e.g. the class of dam and possibly also technical solutions. Contact made during the planning stage can ensure the correct direction from the outset, and that for instance, no large unexpected circumstances arise that may lengthen the processing of the permit. In the permit application, the plans are presented on the master plan level. During the permit processing stage, the Regional Administrative Authority will request a statement from the dam safety authority on the plan (Figure 37, see also Chapter 3.2.5).

It is recommended to present the drafts to the dam safety authority during the construction design stage, prior to the completion of the final designs. This practice is used to ensure that construction can be initiated as soon as possible following the completion of the designs and that no matters delaying the construction become apparent during the completion.

The scope of the dam break hazard analysis depends on the class of dam. The dam break hazard analysis is compulsory for class 1 dams, but the dam safety authority

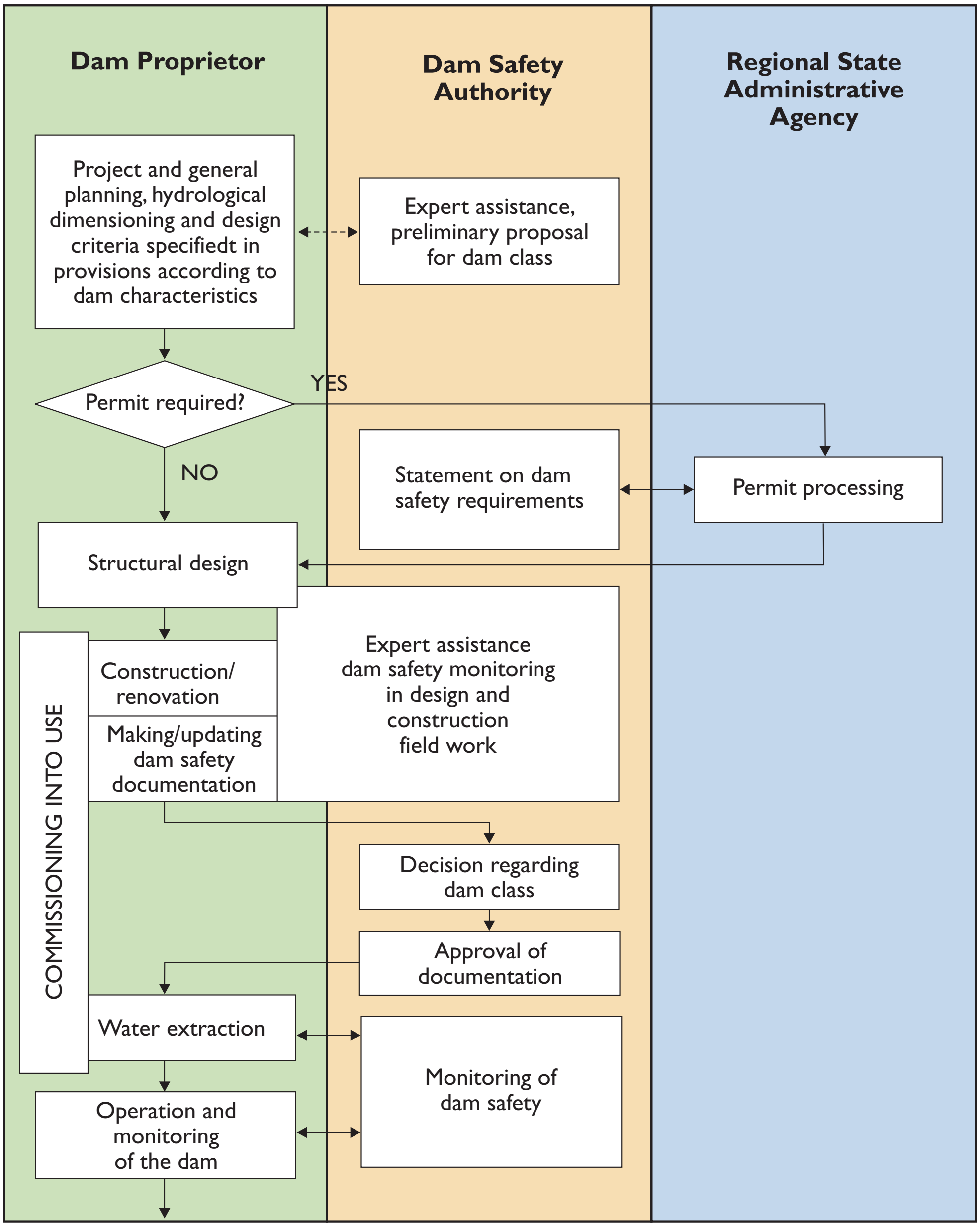


Figure 37. Construction and renovation of dams.

can require analyses also for other dams if necessary. In practice, some dam break hazard analysis is always conducted on mine dams irrespective of dam class (Dam Safety Act 494/2009, see Chapter 3.2.5.3). A safety plan is also conducted for class 1 dams. The safety plan presents the measures to be taken by the dam proprietor in cases of failure for the prevention of accidents and restricting damage, including measures for protecting humans, property and the environment, as well as measures to be taken for notifying of the accidents. In addition, the plan needs to present the materials and equipment reserved for the prevention of accidents, as well as the staff intended for this purpose. The safety plan for the waste dam also states the quality of the impounded material as well as the characteristics causing hazard, quantities and concentrations of the dammed material and dispersion and other special characteristics of the dam. If no safety plan is made for class 2 or class 3 dams, it is recommended for the dam break hazard analysis to be appended with instructions on measures to be taken in case of near-miss and accident situations, as well as plans for the extraction of blast rock and till required for the rectification of possible leaks, as well as plans for the resources that need to be available in case of accident.

8.1.2.1
Commissioning of mine dams, monitoring and decommissioning

A commissioning inspection is made on the dam, the dam class is resolved, and the seasonal inspection programme is approved (dam safety authority) prior to commissioning. A dam break hazard analysis and safety plan shall also be issued for approval in case of class 1 dams. The dam safety authority usually participates in the commissioning inspection.

Dam safety is regulated on the basis of the Dam Safety Act. The dam proprietor inspects the dam during operation in accordance with the approved monitoring programme. Each year, the proprietor of the dam shall conduct an annual inspection according to the monitoring programme for class 1 and 2 dams. The annual inspection report for class 1 dams shall be delivered to the dam safety authority. Similarly, it is recommended that a report of the annual inspection for class 2 dams is delivered to the dam safety authority. In practice, mine dams are monitored at least once a day. The dam proprietor shall perform a periodic inspection at least every five years. The dam safety and rescue authorities shall participate in the periodic inspections. For the purpose of the periodic inspection, it is recommended that the dam proprietor issues a summary of the monitoring data for the dam covering the previous five years, as well as a preliminary assessment of the condition of the dam issued by an expert. Factors affecting the changes in the condition of the dam and its safety are investigated during the periodic inspection with consideration for changes in land use, weather and water conditions. The dam proprietor shall conduct a comprehensive assessment of the condition of the dam or a section of the dam if the periodic inspection does not provide sufficient assurances that the dam adheres to the dam safety requirements set for the dam.

The dam can be decommissioned when the basin or similar structure no longer holds impounded material/substances and the basin is no longer used. The cessation in the use of the dam shall be verified in a separate inspection once all other legal obligations related to the dismantling or decommissioning of the dam have been fulfilled.

8.2

Ore prospecting

During ore prospecting, it is important to conduct prospecting activities in such a way that these cause as little as possible harm to the environment. Measures based on best environmental practice also includes openly informing the local population about the prospecting and prospecting measures, which will mitigate any preconceived notions about prospecting work.

Prospecting shall concentrate on at least the following, e.g.

- The making of a baseline/environmental study prior to engaging in large-scale prospecting measures
- Clarification of values/sites associated with nature protection prior to entering the area, and avoidance of these areas
  - Collaboration with the corresponding environmental authorities already prior to commencement of prospecting
- Communicating with landowners prior to prospecting, application for possible research permits, agreement on compensation procedures related to e.g. possible tree stand damage and applying for permits to traverse the area
  - The Cross-country Traffic Act (1710/1995) states that permission from the landowner must be sought when using a motor vehicle off-road.
  - Attention to other regulations that restrict/concern traversing the area, measures and areas (Murtovaara 2007)
- Taking into consideration the rules and instructions of Finavia with airborne measurements (e.g. guidelines pertaining to important bird nesting areas, fur farms and reindeer calving times)
- Informing the local residents of ore prospecting and prospecting measures
- The making of a plan for the management of environmental impacts during and after the operational stage (larger prospecting projects in particular)
- Planning of drilling and percussion drilling in such a way that the measures cause as little as possible damage, harm or disturbance
- Taking into consideration the season, access routes, size of machinery and waterway conditions in planning and implementation
- The making of a plan in case of possible accidents
- The recovery of rinse water containing suspended solids into precipitation tanks or infiltration into the ground prior to releasing into the natural waterway
- The blocking of sampling holes following sampling in order to prevent pressurised discharge of groundwater and waterlogging of the area, especially in areas that have natural spring discharges
- Possible monitoring during and after prospecting
- Rectification of prospecting traces and collection of waste/rehabilitation of the area once prospecting has reached completion
  - Among others, covering of prospecting trenches following observations and sampling, blocking of bore holes
  - Burying of drilling sludge underground
  - Agreement of case-specific measures with the holder of the area, if operations are conducted within a protected area (Idman & Kahra 2007).

More information about the best environmental practices for ore prospecting are available e.g. from the E3Plus guidelines made by the Prospectors & Developers Association of Canada (PDAC 2011), the guidelines published by the Saskatchewan Mineral Exploration and Government Advisory Committee (SMEGAC 2010), and the Code of Environmental Practice produced by the Association of Mining and Exploration Companies in Australia (AMEC 2010).

8.3
Establishing the mine and the production stage

8.3.1
Sustainable development and mining operations

Mining activities in line with sustainable development improve the standard of living, thereby ensuring balanced living conditions for its inhabitants now and in the future (MMSD 2002). This requires balanced and responsible mining activities that takes into consideration both short-term and long-term environmental, social, economic and administrative perspectives (Table 41). Despite the best environmental practices being used, mining activities will always have some impacts on the environment. The implementation of operations must be within the limits of tolerance for the environment, which facilitates the restoration of nature to a publically acceptable level following decommissioning. Operations such as this require e.g.

- responsible use of natural resources by also safeguarding the sufficiency of raw material resources for future generations (material use efficiency),
- protection of critical natural resources and values,
- development of techniques that reduce the emissions generated by excavation and processing ore,
- reduction of the quantity and harmful impact of waste intended for long-term disposal,

Table 41. The main principles of sustainable development for mining activities. (MMSD 2002)

Economic Sphere	Social Sphere
• Maximize human well-being.	• Ensure a fair distribution of the costs and benefits of development for all those alive today.
• Ensure efficient use of all resources.	• Respect and reinforce the fundamental rights of human beings including civil and political liberties, cultural autonomy, social and economic freedoms, and personal security.
• Seek to identify and internalize environmental and social costs.	• Seek to sustain improvements over time; ensure that depletion of natural resources will not deprive future generations.
• Maintain and enhance the conditions for viable enterprise.	
Environmental Sphere	**Governance Sphere**
• Promote responsible stewardship of natural resources and the environment, including remediation of past damage.	• Support representative democracy, including participatory decision-making of the individual in matters concerning the living environment.
• Minimize waste and environmental damage along the whole of the supply chain.	• Encourage free enterprise and competitiveness within a system of clear and fair rules.
• Prevent potential environmental impacts (precautionary principle).	• Ensure transparency through providing all stakeholders with access to relevant and accurate information.
• Operate within ecological limits and protect critical natural capital.	• Ensure accountability for decisions and actions, which are based on comprehensive and reliable analysis.
	• Encourage cooperation in order to build trust and shared goals and values.
	• Ensure that decisions are made at the appropriate level, adhering to the principle of subsidiarity where possible.

- prevention of short and long-term environmental impacts,
- responsible management of environmental issues,
- transparency, accuracy and appropriateness of the communication of information,
- trustworthy support of cooperation according to general objectives and values (MMSD 2002).

8.3.2
Planning and construction stage for mining operations

The point of departure for planning mining operations is the selection of methods that are controllable in respect to emissions and environmental impacts and that consider environmental protection values. The best environmental management system favours methods that reduce emissions and prevent and/or mitigate environmental impacts (Table 42):

- Methods favoured in the utilisation of ore are those which increase the versatile use of the excavated rock material (by-product development) and reduce the quantities of mining waste intended for long-term disposal above ground (e.g. eco-efficient use of materials, shifting to underground mining, and underground backfilling of mining waste).
- Methods favoured for planning the excavation of ore, blasting, and transportation of ore are those which reduce dust, noise and vibration emissions, as well as reducing blasting chemical residue in the drainage within the mining area.
- Appliances and methods selected for the planning of excavations and concentration are those which can minimise energy consumption.
- Methods favoured for the processing of ore are those which reduce the quantity of fresh water use and favour the recycling of service water. Additionally, process chemicals are favoured that
  - break down into a harmless form in the pumping of tailings or waste slurry and/or in the disposal areas of such prior to the final treatment of the waste water, or
  - are broken down into a harmless form in the process prior to disposing the waste slurry, or
  - can be recycled.

The basis for land use planning of a mining area is the conciliation of the operational area and the land use interests of the environment, as well as open dialogue with the local community (inhabitants, tourism, forestry and fishery enterprises), the local environmental protection authorities and the nature conservation associations. The taking into consideration of the livelihoods and interests of the local inhabitants as well as nature protection are central issues in the planning of mining operation structures, such as haulage routes (and possibly rail track) for ore and waste rock, pipeline routes (waste slurry, waste water, raw water), surface water flow directions and waste areas (Table 42). This is also associated with the management of incidents (accident, leakage) and planning of precautionary measures. The construction of a mining area breaks up large land areas, which increases the risk of soil erosion. The management of erosion and related dust formation requires leaving the tree stands as protection zones for the waste areas and road network and/or the vegetation of the protection zones (barriers) or maintaining of vegetation. The action plan shall also include the making of a monitoring programme in case of possible detrimental impacts caused by erosion.

Table 42. Factors to be taken into account when making BEP plans for mining operations. (Environment Canada 2009)

Designing the processing of ore	Assessment of waste water quality (process water, dewatering water, drainage from waste areas)
• Methods are selected that increase the use of recycled water and reduce the use of fresh water; energy-efficient methods are recommended (e.g. appliance planning)	• Physical and chemical properties, particularly acid-forming potential and potential leaching of harmful chemical elements (geology and geochemistry of the deposit)
• Assess the harm on the environment caused by process chemicals (inspection of chemical alternatives); precautionary measures for the breakdown of potentially harmful chemicals in the process water prior to further processing (e.g. cyanide destruction, neutralisation of thio compounds and/or sulphuric acid)	• Potentially harmful compounds: process chemicals/chemical residues (e.g. thio compounds, cyanide), blasting agent residues (nitrogen compounds), chemicals used in the water treatment
• Adjustment of chemical use to reduce consumption; precautionary measures in case of chemical leaks (transportation, storage, use); training employees	• Quantity and quality of suspended solids
• Assessment of dust and gas emissions; selection of process for reducing emissions, selection of possible emissions cleaning techniques	• Assessment of short and long-term fluctuations in quality
• Quantity and quality of waste fractions (tailings, mineral precipitate sludge) produced in the processing of precious materials, and an analysis of chemical stability; assessment of possibilities for recycling waste fractions	• Identification of indicators for changes in the quality of waste water (e.g. process fault in ore processing, failure in water treatment) for monitoring purposes, training for monitoring water quality
• Assessment of quantity, quality and long-term chemical alteration; assessment of recycling possibilities	
Designing of other structures	**Planning of control for soil erosion and washing of suspended solids**
• Exit road network (+ possible adjoining track); planning of alignment needs to consider risks of environmental catastrophe, routes of water flow and proximity of waterways (impact on fish populations), proximity of housing, nature protection perspectives, cultural perspectives, local planning, power lines and other infrastructure	• Examination of the erosion risk sites and potential environmental risks (e.g. dust dispersion, washing of solids into the waterway) associated with removal of vegetation and soil from areas for construction
• In selecting the alignment for the conveyor belt and pipelines for water and waste slurry one must take into account the environmental risks focused on the aquatic nature and dry land (leakage incident, prevention of dust emissions), servicing appliances and measurement points for failures or breakdowns	• Planning of a sufficiently large planted protection zone around exposed/constructed areas or the tree stands are left as protection zones around exposed/constructed areas and/or reshaping of topography of the terrain to curb erosion and the washing of suspended solids (sediment trap)
• Disposal of snow, possible conducting of thaw water for treatment	• Maintaining the persistence of vegetation in the protection zones during the operational stage
• Management, storage, transportation and/or possible handling on-site of other waste	• Planning a sufficiently expansive (at least 100 metres) buffer zone to protect the protection zones and the waterway or aquifers
• Underground placement of the crushing plant, construction of noise barriers to reduce emissions	• Designing an erosion management monitoring system (dust measurements, monitoring measurements of suspended solids travelling in water)

8.3.2.1
BEP planning for waste areas

General principles for management and disposal of mining waste

The point of departure for the management and disposal of mining waste is to develop the processing of the ore in such a way, that the quantity of waste fractions intended for long-term disposal is reduced and the quantity of operational-period by-products and potential by-products is increased. The environmental compatibility and/or recycling of mining waste in, for example, earth constructions, can be improved using e.g. the following measures (more information from e.g. EC 2009, INAP 2009):

- reducing the proportion of iron sulphides, thereby lessening the acid-generation potential of the waste
  - the separated iron sulphide-concentrated tailings form a potential by-product (Fe, S)
- enhancing the neutralising capacity of the waste (addition of lime/carbonate-containing mineral powder)
- breaking down harmful chemicals prior to disposal of tailings and/or reducing the quantity of soluble chemical residues in the waste intended for disposal (e.g. destruction of cyanide in the process)
- promote the binding of potentially harmful trace elements as weakly soluble into the waste intended for disposal (addition of chemicals)
- the potential by-products are separated in either excavations and/or the processing of ore and placed apart from the waste fractions intended for long-term disposal
- investigate the occurrence of various precious minerals and metals, such as high-tech elements (e.g. Ree, Ga, In, Nb, Li), which can promote the utilisation of the waste fraction in the future.

The planning of disposal for mining waste and the selection of placement site generally covers the entire life of the disposal area from construction through to closure (Figure 38, see also Chapter 5.4.3). The selection and planning of the placement site are guided by:

- the physical, chemical and geotechnical characteristics of the waste intended for disposal or by-products, and the potential interactions with the disposal environment
  - specifying the basal and dam structures for the disposal area
  - influencing the selection of water management systems and rehabilitation methods
- data pertaining to the condition of the environment, soil and bedrock characteristics, special hydrological and hydrogeological features for alternative placement sites (see also Chapter 5.4.3)
- collection of seepage and drainage water for treatment, both during the operational stage and following decommissioning, which also ensures the functioning of rehabilitation
- land use requirement during the operational stage and following decommissioning (+ ownership rights and conflicts with the local inhabitants)
- possibility for backfilling mining waste into open pit/underground mine
- proximity of housing
- existing road network and transportation obstacles
- proximity of protected sites and the potential impacts focused on these
- current and future recreational, agricultural and forestry use of the operations area

- cost factors: transportation costs, costs for structures and maintenance, rehabilitation costs and costs for the monitoring of rehabilitation
- possible risks to health, the environment and safety following the decommissioning of activities (Heikkinen *et al.* 2005)
- extreme weather conditions (once in one hundred years).

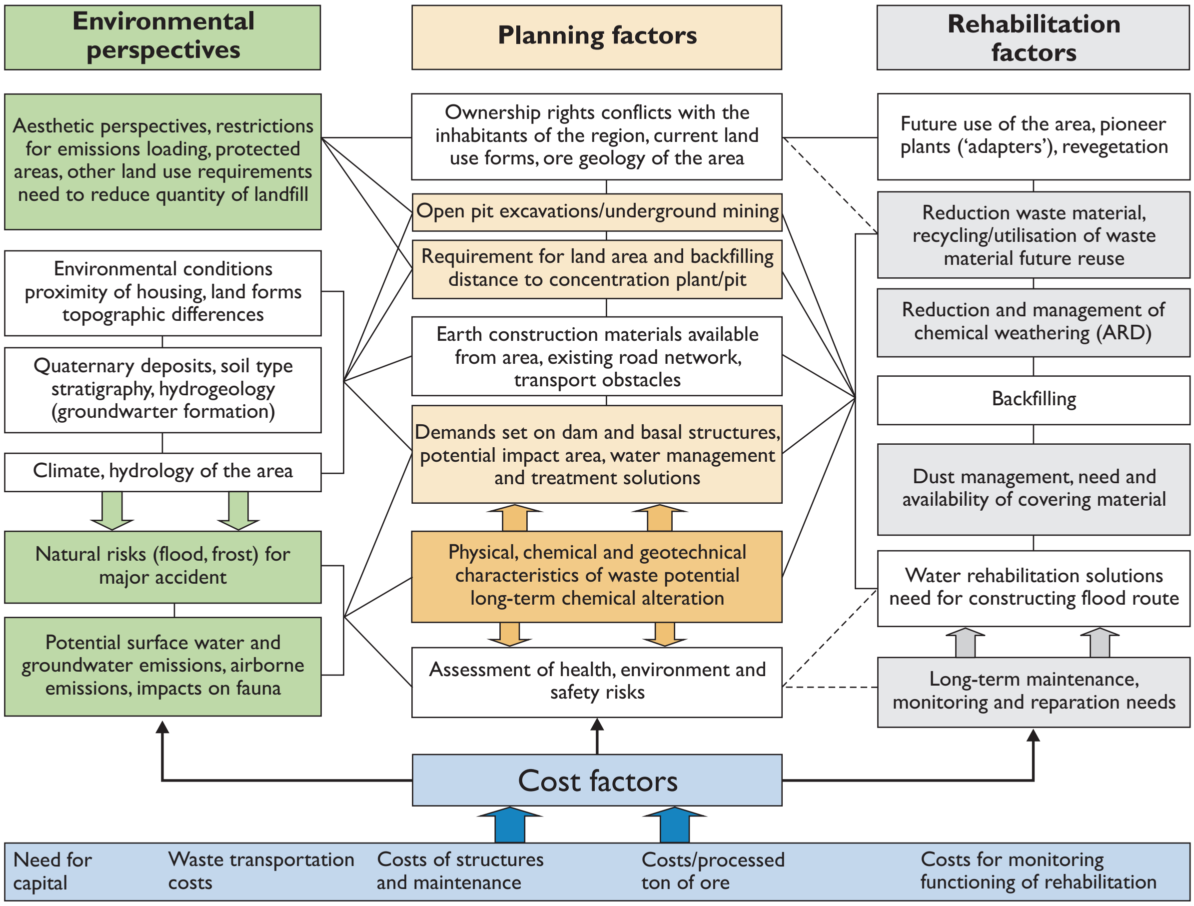


Figure 38. Factors guiding BEP planning and placement for mining waste areas (more information from EC 2009). The solid line between sections indicates a direct link and the broken line represents an indirect link between various factors.

Prevention of acid generation in the disposal of mining waste

The planning of mining waste disposal and selection of disposal method are centrally directed by the acid-forming and neutralising properties of the waste, as well as the potential leaching of harmful substances (Figure 38). Planning and the selection of disposal method also consider the environmental impacts of the different disposal and rehabilitation solutions and assess the risk of acid generation (Figure 35, Chapter 6.2.3). Disposal techniques suitable for preventing the acid generation of waste rock and tailings (+ waste mineral precipitate sludge) are:

- sorting, where rocks suitable for utilisation/recycling and rocks with poor environmental compatibility (acid-forming and slightly acid-forming and/or containing harmful substances) are separated into separate disposal and storage areas,
- containment, where the acid-forming waste rock is contained within rock material with neutralising capacity (above, below and on the sides) or with other material capable of increasing alkalinity (limestone powder, alkaline waste material),

- layering (layer cake structure, Figure 40), with alternating layers of waste rock material with different neutralising and acid-forming characteristics. Some layers can also comprise fine-grained, alkaline waste material or rock powder (paste layer), which retains water well and thereby slows/prevents the travel of oxygen into acid-forming waste rock layers,
- blending of waste rock and tailings, which may be implemented for instance, as backfilling of an open pit in such a way that carbonate-containing tailings with neutralising capacity are mixed with the acid-forming waste rock (Figure 40) (more information from INAP 2009, BC AMD 1989, Tremblay & Hogan 2001, Miller *et al.* 2006).

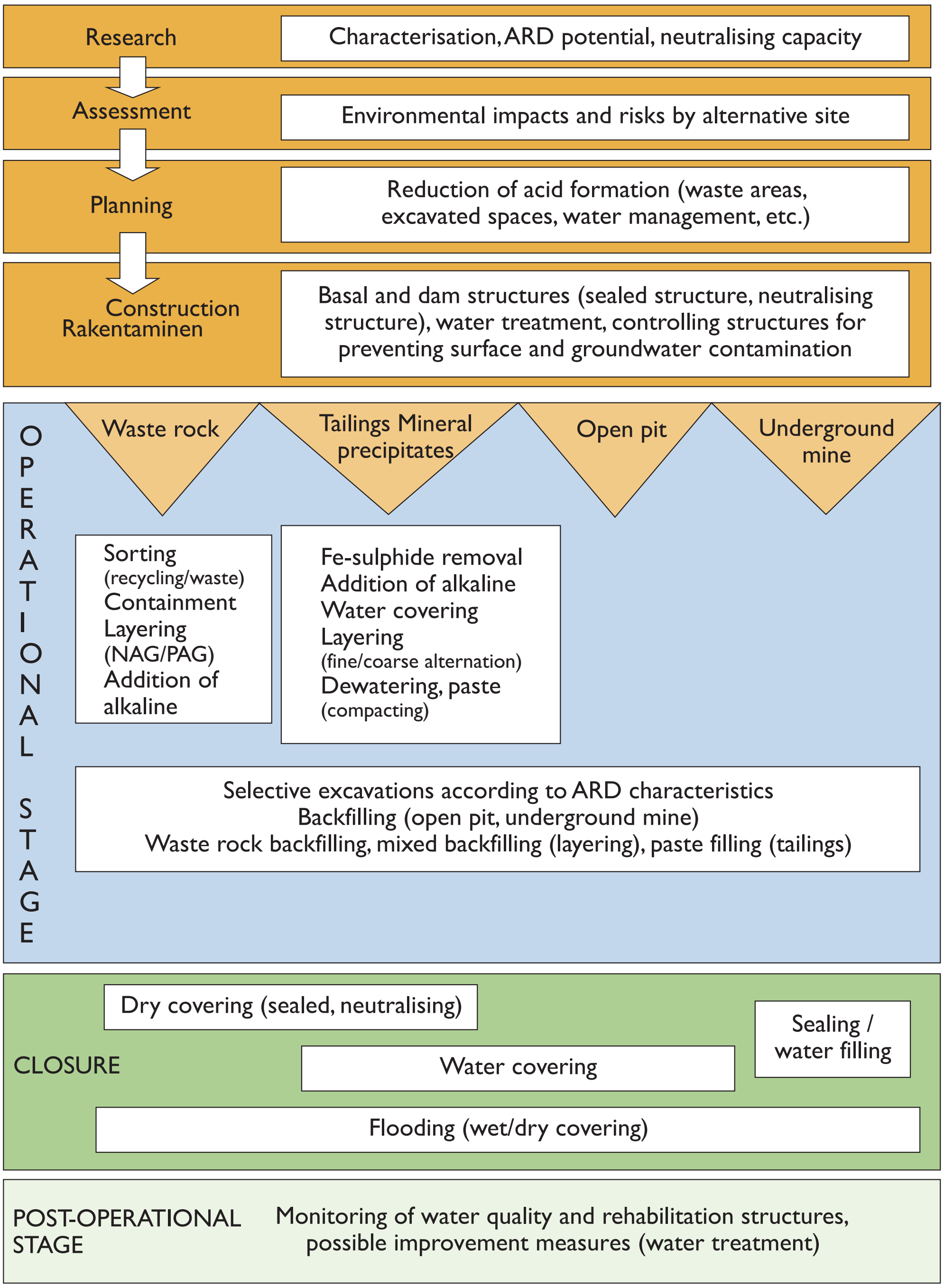


Figure 39. Prevention of acid formation (ARD) during the planning, construction, operational and post-operational stages of the mining activities (more information from INAP 2009).

Techniques suitable for the prevention of acid formation in tailings are:

- removal of iron sulphides from the tailings intended for long-term disposal,
- improvement of the neutralising capacity of tailings by adding lime or other alkaline material,
- increased adding of fines in tailings in-between layers (fine-coarse-fine alternation); carbonate-containing tailings with concentration of fines and minor concentrations of iron sulphides or other alkaline waste material is also suitable for use as the cover structure for an impoundment holding acid-forming tailings (water or wet cover, Figure 41),
- reducing the quantity of water and compaction of tailings by increasing the proportion of fines in waste filling (paste, thickening) (more information from INAP 2009, BC AMD 1989, Tremblay & Hogan 2001, Miller *et al.* 2006).

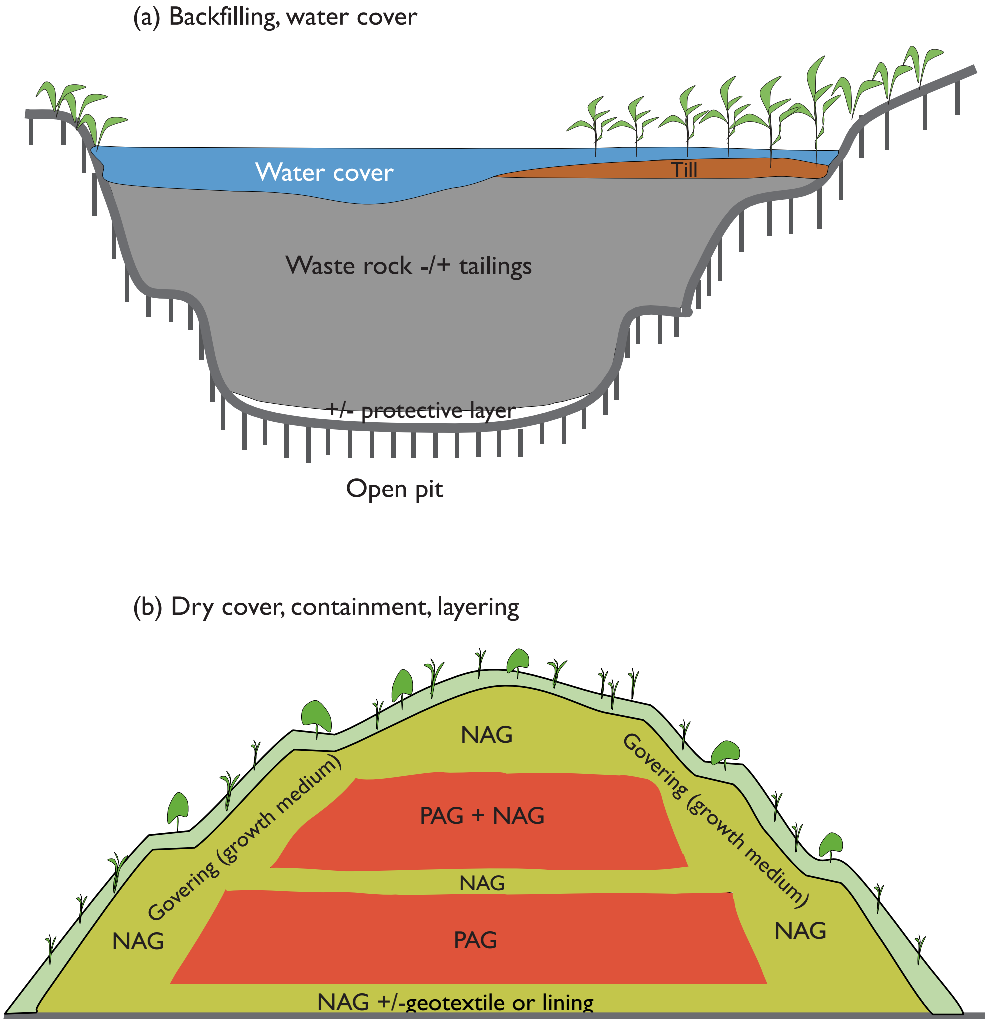


Figure 40. Disposal and rehabilitation methods suitable for the prevention of the acid formation of mining waste: (a) backfilling of waste rock and/or tailings (blended piling) into the open pit, including water cover and till cover of shallow water areas, (b) containment of waste rock and stratification, as well as dry cover (single-layer cover = growth medium). Key to abbreviations: NAG = non-acid generating, PAG = potentially acid generating. The surface of the backfill base can be made with non-acid generating aggregate. Backfilling can be done by blending tailings that increase neutralising capacity in with the waste rock that generates acid. (More information available from EC 2009, INAP 2009, Lottermoser 2007)

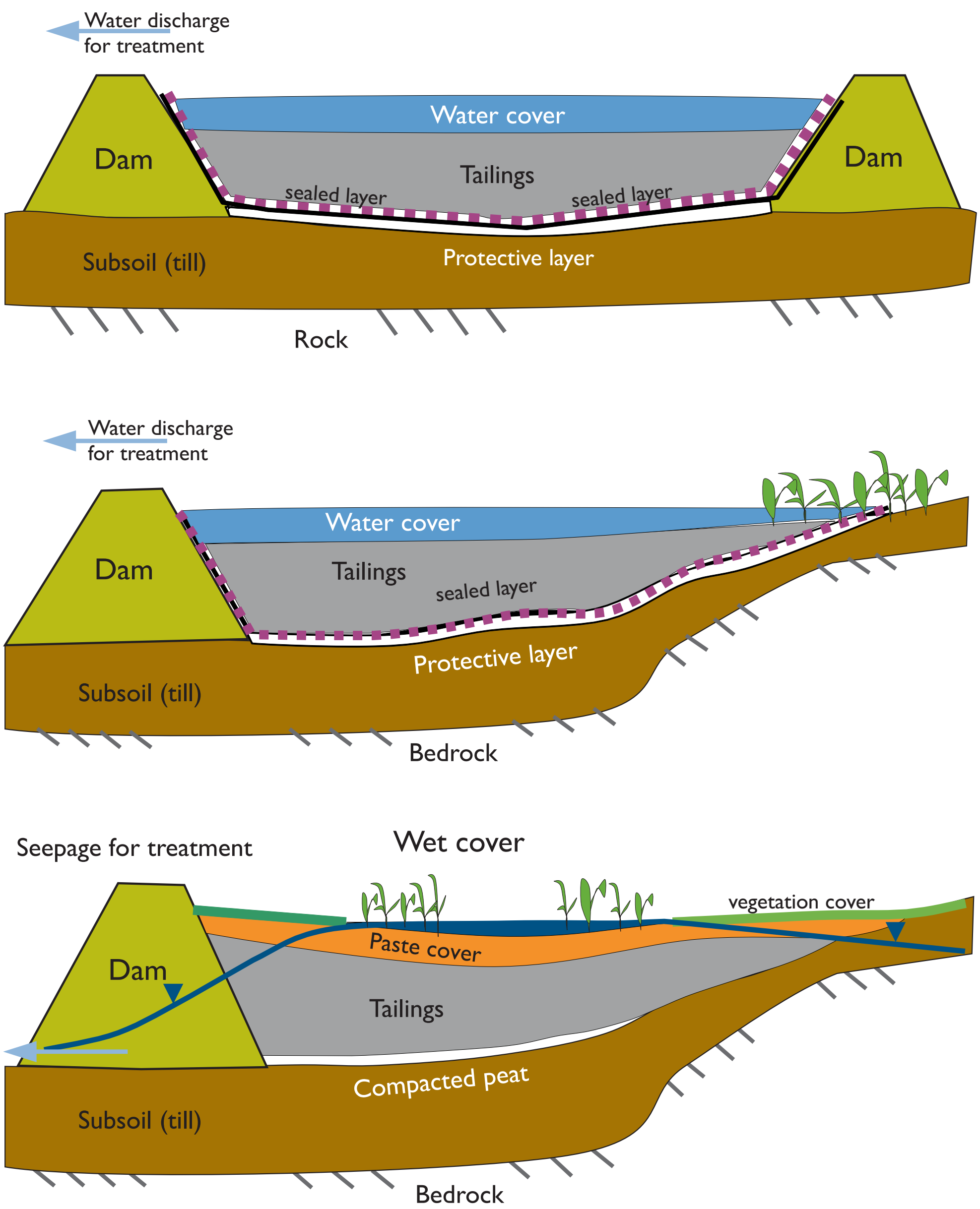


Figure 41. Rehabilitation methods for acid-generating tailings: water cover (compacted base and dam structure) and wet cover, where the water-retaining cover structure is fine-grained carbonate-containing tailings (few sulphides) or other alkaline waste material (paste cover). In wet cover, a wetland basin is formed in the centre of the impoundment for the collection of rain water and the dam is permeable, whereas the dam structure in water cover is sealed on the upstream side and the water level of the impoundment is adjusted by using either a set of dams or through the overflow facility (and/or foot drains) installed in the dam. (More information from INAP 2009, Tremblay & Hogan 2001, Lottermoser 2007, Räisänen & Juntunen 2004, Heikkinen *et al.* 2009)

Table 43. The best basal structure techniques according to the environmental compatibility properties of mining waste. (Finland's Environmental Administration 2010a [environmental permits for 2007–2009, Räisänen 2003, EC 2009])

Waste properties	Sealed lining for the base or reactive structure	Other structures, subsoil base[1)]	Permeability, layer thickness	Placement site, terrain form
Non-acid-forming, no potentially soluble harmful substances and/or chemical residues	no	till or bedrock as limiting and bearing stratum	till permeability 10^{-5} – 10^{-6} m/s	flat/valley/hilltop/ gentle slope, till or rocky soil
Non-acid-forming, metal/metalloid concentrations and solubility of these at background levels, no harmful chemical residues, ± blasting agent residues	no	till as limiting and bearing stratum	till permeability 10^{-7} – 10^{-8} m/s, thickness ≥1 metre	flat/valley/gentle slope, till soil
Non-acid-forming, metal/metalloid concentrations and solubility of these > background level, no harmful chemical residues, ± blasting agent residues	single layer structure: compacting peat[1)] and/or compacted peat	± compacting gyttja (protective layer)	permeability of sealing layer ≥10^{-10} m/s, thickness when compacted ≥0.3 metres	bog; flat/valley/gentle slope, till soil
		till (± bedrock) as bearing stratum	till layer (10^{-8} – 10^{-9} m/s) thickness ≥5 metres	
	blast rock with neutralising capacity/rock aggregate concentrated with fines[2)]	fine-grained till/compacting fine silt ± clay	till/silt layer (10^{-8} – 10^{-10} m/s) thickness ≥5 metres	valley, till soil/silt-clay soil
Non-acid-forming, metal/metalloid concentrations and solubility of these > background level, no harmful chemical residues, ± blasting agent residues	single layer structure: bituminous geomembrane liner	levelling and compacting of subsoil base ± protective layer[3)] on top of the bearing stratum	impermeable (10^{-9} – 10^{-14} m/s), thickness 3.63 mm or 4.04 mm	flat/valley/gentle slope, till soil
	single layer structure: HDPE lining	protective layer[3)], levelled and compacted (poor permeability) bearing stratum	impermeable (10^{-9} – 10^{-15} m/s), thickness 1.5 mm or 2 mm	flat/valley, till soil
Slightly acid-forming, metal/metalloid concentrations and solubility of these > background level, no harmful chemical residues, ± blasting agent residues	blast rock with neutralising capacity/rock aggregate concentrated with fines[2)]	fine-grained till/fine silt ± clayey sediment	till/silt-clay layer (10^{-8} – 10^{-10} m/s) thickness ≥5 metres	valley, till soil/silt-clay soil
	natural soil layers[2)]: compacting peat (highest) fine silt/clay (lowest)	bearing fine-grained till beneath compacted layers	impermeable (10^{-10} – 10^{-12} m/s), thickness ≥0.5 metres, fine-grained till (10^{-9} m/s) thickness ≥5 m	flat/valley, till soil
	single/double layer structure: HDPE lining or bituminous geomembrane ± bentonite liner	protective layer[3)], levelled and compacted (poor permeability) bearing stratum	impermeable (10^{-9} – 10^{-15} m/s), HDPE lining thickness 1 mm or 1.5 mm, bituminous geomembrane lining thickness 3.63 mm or 4.04 mm	flat/valley, till soil
Acid-forming, metal/metalloid concentrations and solubility of these > background level, no harmful chemical residues, ± blasting agent residues	double layer structure: plastic-lining (highest) bentonite lining (lowest) or double plastic lining[4)]	protective layer[3)], levelled bearing stratum	impermeable; plastic lining 10^{-9} – 10^{-15} m/s and bentonite lining ≥10^{-8} m/s, thickness 1.5 mm and/or 2 mm	flat/valley (gradient max. 3%), till soil or excavated bedrock bed

[1)] Tree stand removed
[2)] Suitable for waste rock piles; compacting subsoil base and disposal method employed is layering/containment, if some of the rock is concentrated with metals/metalloids and/or acid-generating
[3)] Protective layer between the rocky/boulder subsoil base and bituminous geomembrane liner to avoid point loading.
Protective layer for waste rock/rock aggregate area (particle size<liner thickness) is constructed above and below the sealing layer.
In the tailings or mineral precipitate sludge disposal area, a protective layer will only be installed below, if there is no point loading.
The thickness of the protective layer is defined by the weight (height) of the disposed mass and according to the hydrogeological nature of the subsoil base.
[4)] A protective layer/drainage layer for monitoring pipes is fitted between the plastic liners.

8.3.2.2
BAT basal structures of the waste areas

The selection of basal structures for mining waste areas are guided by the chemical and physical characteristics of the waste (waste class), as well as the hydrogeological characteristics and topography of the soil at the placement site. Table 43 shows the basal structures and placement sites according to the characteristics of the waste. The basal structure alternatives are collated in the table according to acid-forming characteristics and presence of harmful substances. If the mining waste intended for long-term disposal is acid generating and/or it contains potentially soluble harmful substances, then the basal structure should:

- promote the stability of waste disposal as well as prevent/mitigate the environmental impacts of the disposal (on the groundwater, underlying soil),
- slow down the chemical alteration of the waste, especially in the base section of the disposal site,
- prevent oxygen-rich groundwater from accessing the waste (see also dam structures),
- guide the selection of rehabilitation method for the waste area.

8.3.2.3
BAT structures of the mine dams

The dam structures of the tailings areas are designed as stable to be able to endure the filling of the impoundment during the operational stage. The dams shall remain stable also after completion of filling, in such a way that during the rehabilitation stage there is no longer the need for reshaping or enhancing stability.

The sealing structure of the tailings impoundment dam is selected according to the waste to be impounded and the characteristics of the seepage to be discharged from the impoundment. The selection of dam structure is directed by the sealing requirements for the basal structure of the impoundment and the quality of seepage. If the basal structure is completely waterproof, the dam should also be fitted with a sealing structure impermeable to liquid. If the quality of seepage of the waste to be impounded is harmless for the environment and the seepage can be discharged into the natural bodies of water, the structure of the dam can be permeable. In this case, the base dam shall be either constructed as a homogenous earth dam, rockfill dam or zone dam (Tables 44 & 45). Non-acid forming and harmful substance-free tailings can be used in the raising of the dam. If the waste comprises potentially harmful seepage, the dam shall be constructed as impermeable (sealed). In this case, the base dam and elevations will be made as either rockfill or zone dams. The sealed structure in mine dams is usually constructed on the upstream side of the dam, both for permeable and completely sealed dams. The sealed dam core, located in the centre of the dam, is rare in mine dams. The sealed structure comprises sulphide-free till and plastic lining or bituminous geomembrane lining. Bentonite lining can be installed between the plastic or bituminous geomembrane lining and till.

Table 44. The suitability of dam type on the basis of permeability.

Dam structure type	Sealing structure	Seepage can access the environment	Seepage cannot access the environment
Homogenous till dam	till, silt, clay	x	
Zone dam	till, silt, clay	x	
	geosynthetic		x
Rockfill dam	till, silt, clay	x	
	geosynthetic		x
Tailings raising	fine-grained tailings	x	

Table 45. Comparison of dam types.

Dam structure type	Dam safety	Environment	Finance
Homogenous till dam	++	+(+)	+(+)
Zone dam	+++	++(+)	+(+)
Rockfill dam	+++	++(+)	++(+)
Tailings raising	+	++(+)	+++

The paragraphs below compare the strengths (+) and weaknesses (–) of different dam types (Table 45):

Homogenous till dam

+ simple to construct, one material
+ reasonably inexpensive, if the overburden of the mining area can be used
– a lot of natural material is required, if the mine overburden masses cannot be utilised
– waterlogging risk of the downstream slope → possible stability problems
– needs a larger area than the blast rock structure.

Zone dam

+ management of seepage is easier than with homogenous earth dams → better stability
+ total masses are smaller than for homogenous earth dams
+ the blast rock frame can be built during the wintertime
+ space requirement is smaller, steeper slopes made from rockfill compared to till
– more complicated to build
– need for different materials, some of which (filter) will have to be crushed or acquired from elsewhere
– the need for natural materials is large, if the waste rock and overburden of the mine cannot be utilised.

Rockfill dam

+ management of seepage is easier than with homogenous earth dams → better stability
+ total mass is smaller than for other dams
+ the blast rock frame can be built during the wintertime
+ space requirement is smaller, steeper slopes made from blast rock compared to till
+ easier to build than a zone dam
+ well endures very rapid fall in water level, especially when geo-synthetically sealed
– the need for natural materials is large, if the waste rock and overburden of the mine cannot be utilised.

Tailings dam

+ cheap to construct, as the material is ready at the site; minimal use for natural materials
– the base dam must be constructed from natural materials (till)
– due to dam safety requirements, large raising cannot be conducted at the same instance
– susceptible to erosion, slopes must be covered with till or riprap
– free standing water cannot lie directly against the dam → dry shore, or so-called beach section must be sufficiently long
– the weathering of tailings can weaken stability in the long term.

8.3.2.4

Water management and treatment methods

The point of departure for the management of mine water will be the separation of natural water (so-called clean water) accessing the mining area that comes from the environment from the waste water of the mining operations, and from the drainage water formed in the mining area that potentially contains harmful substances. The best practice for water management is to reduce the amount of fresh water needed and increase the internal recycling of water. The planning of water treatment and selection of treatment method shall be based on the following studies and assessments (more information from INAP 2009, EC 2009):

- The chemical and physical characteristics of the water intended for treatment needs to be clarified, and on the basis of the water quality, the water treatment method will be selected, structures for the treatment facility will be designed and goals set for the quality of treated water.
- The probability and quantity of the formation of ARD and/or neutral metal concentrated water, fluctuation in acidity at the various collection system sites, and the seasonal and medium-term fluctuation in acidity are assessed.
- The occurrence and quantities of chemical residues from the process water and blasting agent residues from the dewatering water are established and the fluctuations in the quantities of such are monitored. On the basis of research, an assessment of the separate treatment of chemicals at the concentration plant or process plant (e.g. cyanide) is conducted, and in respect to blasting agents in the excavated spaces prior to discharging the water to the outdoor treatment basin.
- A flexible water management, treatment and monitoring system shall be made that takes into account not only the short-term alterations in operations, but also the medium-term alterations and the post-mining operational phase rehabilitation solutions. This is also associated with the planning of precautionary measures in order to prevent the harm caused by unpredictable emissions (restoration measures).
- Assessment of the functioning of the water management system and dimensioning of treatment objectives for mitigating environmental risks (inhabitants of the surroundings and nature).
- Assessment of the impact of climatic factors on the long-term fluctuation in the quantity of water for treatment and the sufficiency of the treatment capacity. Contingency plans are made for extreme weather conditions (flooding, storms, drought).
- The quantity of slurry produced in the treatment process is assessed, along with the composition and chemical state of the slurry (stability-solubility of precipitate compounds in different conditions), and the rehabilitation of the treatment basins are designed on the basis of these. At this stage, the chemical elements that have become concentrated in the slurry and the possibilities for recycling the compounds should be taken into consideration.

Active methods for treating waste water are (more information from INAP 2009, also Table 34, Chapter 6.2.2.1):

- alkaline treatment (lime, lye, limestone powder) for the neutralisation of waste water and the precipitation of metals as hydroxides, sulphate and carbonate salts,
- aeration (addition of oxygen) for the oxidation and precipitation of iron and manganese,
- addition of oxidant, e.g. ferric sulphate for removal of arsenic,
- microbiological removal of nitrogen (nitrification, denitrification),
- chemical precipitation of sulphate (barium sulphate, ettringite),
- microbiological reduction of sulphate, microbiological precipitation of metal sulphides (addition of electron and carbon source),

- membrane filtration (reverse osmosis/nanofilter membrane), probably preceded by water evaporation treatment,
- ion-exchange resin filtering (zeolite),
- chemical precipitation of metal sulphides (addition of Na2S/NaHS/FeS/CaS).

Passive methods for waste water treatment are (more information from INAP 2009, PIRAMID Consortium 2003, also Table 34, Chapter 6.2.2.1):
- aerobic wetland treatment (shallow water basin, aeration, slow flow, settling of suspended solids, growth of algae),
- anaerobic wetlands (deep water basin ≥1.5 metres, reduction of sulphate, dissolution of basal structure limestone, rotting organic matter),
- wetland treatment increasing reduction and alkaline properties (reduction of iron and sulphate, raising alkalinity),
- anoxic limestone drain treatment (raising alkalinity),
- aerobic (open) limestone channel treatment (aeration, raising of alkalinity).

In situ treatment methods include e.g. (more information from INAP 2009):
- the covering of mining waste or soil contaminated by mining operations with an alkaline material,
- treatment of mine shaft or open pit water using additions of chemicals or bacteria (promotes the precipitation of metals/metalloids as metallic/metalloid sulphides or retaining in iron and other hydroxide precipitates),
- the covering of the mining area and/or mining waste using organic soil, which may reduce the dust formation in the area and thereby also the contamination of surface water; can also improve the quality of the drainage water of sites for restoration.
- the construction of reactive walls at sites that are the sources of contaminating water that spread into the groundwater and/or surface water of the surroundings.
- injection of alkaline suspension slurry into the acid-generating waste material or contaminated soil.

Table 46 shows a comparison of the qualitative applicability of active and passive treatment methods. Active treatment methods are best suited for the treatment of process water, which can include a number of treatment stages (cf. Figure 42, Chapter 8.3.3.2). Both active and passive methods can be applicable for the treatment of dewatering water (e.g. overland flow area) in accordance with the chemical quality of the water intended for treatment. The use of chemical methods in the treatment of dewatering water usually requires the settling of suspended solids prior to actual chemical treatment. Passive treatment methods are usually best employed for the treatment of small waste water quantities (≤1,000 m^3/day), such as for the treatment of seepage from rehabilitated waste areas (INAP 2009).

8.3.3
Production stage of mining operations

The best environmental practice for the production stage is to monitor the realisation of operational objectives in line with plans and to develop the production process to mitigate emissions and environmental impacts. As the foundation for the development of activities, an environmental management system is made, that specifies:
- environmental policies in line with sustainable development,
- environmental objectives and the scheduled commitment to these, and
- long-term development goals for operations and the schedule for implementation (see also Table 41, Chapter 8.3.1).

Table 46. Qualitative comparison of methods for the treatment of the waste water generated by mining operations. (More information from EC 2009, INAP 2009):

Description of operation and characteristic	**Active treatment**	**Passive treatment**	***In-situ* treatment**
Operational stage of the mine	Best suited for the pilot excavation and production stage, as the treatment requires active control of functions, maintenance and monitoring	Best recommended for the closure stage of the mining area and the rehabilitation stage of the waste areas, as the treatment requires only occasional monitoring and supervision of functioning.	Best suited for the exploration and production stage, as the treatment requires active control of functions, maintenance and monitoring
Operational requirements	Active and continuous operation of treatment appliances; requires staff for maintenance, operation and/or supervision	Does not require permanent staffing or appliances, but the regular monitoring of the proper functioning of the treatment process is important	Requires active and full-time operating staff, but is not permanently bound to the operations site
Labour and material requirements	Requires chemicals, operating and maintenance staff, electrical energy, continuous monitoring and/or periodic monitoring	Self-adjustment; may require seasonal monitoring, occasional reparation or constructed expansion (increase/exchange of structural materials)	Requires chemicals, operating staff, occasional service maintenance, electrical energy, seasonal monitoring
Energy input	Electrical and mechanical sources of energy	Natural sources of energy: gravitation, solar radiation, biochemical energy	Electrical and mechanical sources of energy
Management and monitoring requirements	Requires continuous commitment to operation; permanent operating and monitoring staff	Seasonal commitment to monitoring functioning; does not require permanent operating staff	Requires continuous monitoring staff, but not permanently bound to the operations site
Limits to applicability flow rate and water quantity, materials for treatment	Suitable for all flow rates and water quantities (particularly suitable for treatment of large volumes of water) and for the removal of any compound or chemical element	Suitable for slow-flowing waters, for the removal of acidity, metals and sulphate	Suitable for all flow rates and water quantities; mainly for the removal of acidity and metals
Treatment level (water quality objectives)	The treatment process can be designed to adhere to the objectives defined for the water quality	The quality of treated water can fluctuate and may occasionally be poor, depending on the choice of treatment system	The quality of treated water can fluctuate and may occasionally be poorer quality than what can be achieved using active treatment
Treatment of sludge and salt precipitates	Consists of finely-grained sludge and various highly soluble salt precipitates (carbonate, sulphate, hydroxide, chloride, etc.); requires rehabilitation of the disposal site	Does not consist of highly soluble salt precipitates, but permanent sulphide precipitates, requires restrictions as to the use of wetland areas (no drainage)	Consists of fine-grained sludge, which shall be placed in the waste area or rehabilitated at the treatment site
Need for capital (investment)	Major investment costs and occasional requirement for acquiring extra capital	Moderate investment costs including possible restoration /improvement constructions	Minor investment costs based on short-term treatment requirement
Operating and maintenance costs	Major operating and maintenance costs including the costs of recycling water, possible processing costs of the separation of by-products (metals) from the waste water	Low operating and maintenance costs	Moderate operating costs, but may have high chemical consumption costs as a result of treatment inefficiencies

Development goals include e.g.

- monitoring and operational programmes for different types of emissions
- objectives for the mitigation of emissions and the schedule for the mitigating measures,
- Plans for the eco-efficient use of materials (e.g. recycling, sorting of waste and utilisation),
- improvement of eco-efficiency, and
- strategy for communications (e.g. emissions and failures).

In addition, the environmental management system includes operational guidelines/ documents (more information from EC 2009, Environment Canada 2009), such as

- documentation of emissions monitoring findings,
- updates to the waste management plan,
- documentation of alterations to the operational methods (e.g. processing of ore, water management and treatment, neutralisation and cleaning of flue gases),
- service and restoration programme and the measures performed,
- responsible persons for various operations (+ description of competence) and tasks, training programme and training implemented,
- guidelines for internal and external communications,
- instructions for precautionary measures for preventing incidents, documentation of implemented measures,
- environmental damage and measures for rectification,
- rescue plan for hazardous situations (staff, environment),
- work accidents,
- rescue drills and training,
- auditing,
- authority inspections and inspection minutes.

Table 47 shows the studies and measures associated with the mitigation of emissions. The point of departure is the surveying of actual emissions sources and emissions monitoring findings during the operational stage, as well as an assessment made on the basis of these of other potential emissions sources if operations are expanded and/ or processes are altered. The selection and development of mitigation techniques is also associated with the cost comparison of applications in relation to the emissions reduction achieved, and thereby the reduction in the environmental impacts. The mitigation measures by emission are described in Chapter 6.2. The paragraphs below list the mitigation measures and techniques for dust, gas and water emissions.

Mitigation of dust dispersion from the mining area further into the environment is achieved with:

- tree stand zone around the mining area and especially the mining waste areas,
- topographic obstacles (barriers/natural hills),
- covering and vegetation of closed waste areas,
- sprinkling of dried waste areas using e.g. water, lime milk or bitumen emulsion, or subaqueous disposal of the fine-grained waste products (water cover),
- irrigation of blasting fields, correct dimensioning of blast charges, staging of blasting (dust removal systems in underground mines),
- suction and treatment of drill dust,
- irrigation of haulage routes for ore and waste rock, washing vehicle tyres,
- use of dust-binding agents along the haulage routes,
- covering of loads intended for long-distance transportation,
- containment/underground placement of crushing plant and screening facility,

- dust removal system for the crushing plant (suction, electrical deposition, containment, washing/sprinkling, filtering) and the regular servicing of appliances,
- temperature adjustment for drying ore concentrates, filtering system and containment,
- surveying of fugitive emissions and the implementation of measures related to the mitigation of these in accordance with the plans and schedules made.

Gas emissions can be mitigated with:
- blasting charges being dimensioned correctly and staged,
- use of low-emissions blasting chemicals,
- ventilation of an underground mine and cleaning of exhaust air,
- selection of low-emission machinery and the regular servicing of vehicles,
- continuous operational monitoring of process and cleaning devices, servicing of appliances sufficiently frequently,
- enhancement of recovery and cleaning of gas emissions (neutralisation, oxidation/reduction) produced in the concentration of ore. Most crucial is the correct selection and dosage of chemicals.

Mitigation means for water discharges include e.g.
- Increased recycling of process water and/or dewatering water and reduction in the raw water intake requirement. Constantly monitoring water flows and balance.
- Conducting only dirty water for water treatment and separate the clean natural runoff to bypass the mining area.
- Developing ore processing techniques to reduce the necessities for process water.
- Monitoring the consumption of process chemicals, chemical concentrations of discharged water and the residues of such. Enhancement of the water treatment process if necessary.
- Reducing fugitive loading of the mining area, using the following measures, e.g.
  - constructing sealed basal and dam structures for the mining waste areas and waste water ponds,
  - collection of the drainage water and seepage from waste area surroundings for treatment,
  - construction of a sealed basal structure and a covering for the ore storage facility and loading area,
  - collection of contaminated ditch water along ore and waste rock haulage routes for treatment,
  - regular inspection and servicing of pipelines.

Noise and vibration can be mitigated by:
- choosing quiet technologies and techniques,
- containment of noise sources,
- constructing noise barriers,
- placement of crushing and screening below ground,
- staging the charges of blasting procedures and by dimensioning the dosage of blasting chemicals in order to reduce vibration,
- timing operations that generate noise and vibrations for publicly acceptable times,
- taking noise prevention into account in all activities.

Table 47. Management of emissions during the operational stage of the mine, and studies and measures associated with the mitigation of emissions. (More information from Environment Canada 2009, EC 2009)

Management of noise and vibration	**Management of air quality factors**
• Identifying actual and potential emissions sources; taking noise prevention into account in all activities	• Surveying of emissions sources and site-specific studies of air quality
• Dampening of noise and vibration sources by choosing quiet technologies and techniques, containing sources of noise, using noise barriers, timing activities that generate noise and vibration at socially acceptable times (e.g. haulage restricted to daytime)	– greenhouse gases – other flue gases and odours (SO_2, NO_2, H_2S) – traffic emissions – quantity and possibly quality of small particles (10 µm)
• Taking into consideration the impacts of noise and vibration on the fauna of the surrounding forest environment and fish populations of the waterway by building protection zones (noise barriers, topographic modifications)	• Surveying the factors that affect the magnitude and quality of emissions and assessment of the health and ecological risks of emissions
• The making of a long-term mitigation plan for the mitigation of the noise and vibration level and monitoring the progress of the plan	• The making of an emissions monitoring programme and on the basis of the measurements a plan will be drawn up for the mitigation of emissions in the short and long term (cf. Chapter 6.2.1) and the implementation of the mitigation plan will be monitored
• Employee training	• Enhancing the cleaning of emissions or developing more effective cleaning methods if the measurement findings exceed the permitted emissions norms • Training of employees responsible for operating the appliances and measuring emissions
Management of discharged water	**Management of mining waste**
• Surveying of actual and potential emissions sources (fugitive loading sites) for contaminated water and the making of a monitoring programme by emissions source and updating of the precautionary measures for extreme weather conditions that was made during the planning stages	• Updating of the data pertaining to the chemical and physical characteristics of the mining waste during the operational stage (changes in the geology of the ore deposit or processing of ore)
• In accordance with the monitoring findings, the water from different emissions sources is conducted for treatment at either the same facility or according to water quality into further treatment or directly into the waterway, if the water meets the natural water criteria	• Monitoring of the chemical alteration of mining waste in the waste areas and the quality of seepage; according to the findings, the collection and treatment of seepage will be enhanced, restoration measures will be employed for maintaining the chemical stability of the waste (prevention of acid formation/dissolution of chemical elements)
• According to the monitoring findings, the water treatment will be enhanced if necessary (water treatment methods, figures 42 & 43, Chapter 8.3.3.2); reporting of changes and improvements made	• Initiation of rehabilitation tasks for the filled waste areas; placement of waste rock and/or as blended tailings backfill into decommissioned open pits/open pit sections and/or underground cavities
• Making of a long-term mitigation plan for water emissions (internal recycling of water, enhancing use of water) and monitoring the implementation of the plan (tables 33 & 34, Chapter 6.2.2)	• Training of supervisory staff for the waste areas
• Regular inspection and reparation of water pipes, water pressure of the pipes and condition of open drains (backfilling of suspended solids, collapse of channel walls) in accordance with inspection findings; training of supervisory staff	• Monitoring of the dust formation of waste areas; implementation of dust prevention according to plans
• Servicing and maintenance of equipment in a covered facility fitted with an oil separation facility	• Monitoring the condition of the dam and basal structures of the waste area; necessary restoration done according to findings
• Concentration of fuel distribution to distribution stations specifically built for this purpose; sufficient protection and safety pond capacities in the chemical storage areas and processes	• Monitoring the impacts of the waste areas on the groundwater of the environment, downstream surface water, nature and nearby housing
• Continuous measurements of emissions sources and the utilisation of findings in the running of the process and development measures	• Reporting of all monitoring data and observations as well as the reparations implemented

Examples of measures that reduce or mitigate social impacts are the following:

- The course of interactive data and maintaining dialogue between the mining company and local inhabitants (regular information exchange, maintaining good relations). Furthermore, it is essential to fill the information gap using expert data before it is preceded by information from elsewhere.
- The mining company shall also take care of the living conditions and contentment of its employees and their families outside of work hours.
- The mining company actively (voluntarily) participates in the development of society's services, e.g. the compensation of possible detriments using a variety of social and health sector programmes or by supporting school sector and/or recreational activities via public or private service providers. Compensation is often a question of the willingness to take part in open discussion; locally functioning means for implementing compensation can be found using interactive planning.
- During the planning stages of mining operations, the negative social impacts brought up during the EIA stage are taken into consideration, in particular from the perspective of the inhabitants of the neighbouring regions. It is essential to assist with the preservation of the region's viability and operational possibilities following the decommissioning of mining operations. In particular, the potential alteration and feasibility of permanent housing for the new forms of use need to be assured. Inhabitants have often hoped the post-closure mining area could be used for other business activities, e.g. tourism.

8.3.3.1

Management and reduction of mining waste and emissions of the waste areas

The management of mining waste is centrally directed by the chemical and physical characteristics of the waste (see Table 47). These characteristics shall be updated during the operational stage, if the ore type and consequently the quality of waste rock or ore separation process changes during the operational stage. The point of departure for the management of waste is the classification of waste fractions according to characteristics as utilisable (by-products) and non-utilisable requiring long-term disposal (see Chapter 8.3.2.1). The waste fractions intended for potential use in the future can be included in the latter group, which needs to be taken into account with the disposal of these. The best environmental practice for the reduction of mining waste quantities is:

- increasing the quantity of by-products and reducing the quantity of waste fractions for long-term disposal by developing the processing of ore,
- placement of waste rock and tailings into underground mine cavities and/or as open pit backfilling following the completion of excavations.

The environmental impacts of the waste areas are reduced by:

- impermeable basal and dam structures (e.g. reducing acid formation and contamination of groundwater).
- the dry and water cover of waste areas as far as such is possible (dusting and/or seepage quality reduction and improvement of quality).
- collection of seepage from the waste areas for treatment (reduction in fugitive loading).
- covering of dam embankments using blast rock or synthetic material and aggregate, or by covering the surfaces with a growth medium and by planting grass (dusting).
- removal of process chemicals prior to the disposal of tailings or sediment slurry in the waste areas (e.g. destruction of cyanide).

- regular condition inspections and reparation of drainage ditches surrounding the waste areas, e.g. removal of suspended solids, blocking of collapses and deepening of channel.

Continuous restoration of the waste areas can (benefits):
- reduce the dusting of waste material, erosion of embankments and the dispersion of suspended solids into the environment (sedimentation),
- reduce the costs for restoration and rehabilitation of the area following the decommissioning of operations,
- selectively repair sites that are noticed as causing exceptional dispersion of emissions into the environment,
- monitor the functioning of reparation/rehabilitation methods and replacement with better rehabilitation method if necessary, if the reduction in emissions is not in accordance with set goals.

8.3.3.2
Water management and treatment methods

During the operational stage, the majority of waste water intended for treatment is produced in the processing of ore and the dewatering water of the open pit and/or underground mine, and from the drainage of the waste areas (see chapters 6.2.2 and 6.2.3). The quantity of drainage is usually significantly smaller than the quantity of process or dewatering water. Water for treatment can also be generated at other sites in the mining area, such as on ore haulage routes and on the storage areas for ore and ore products. The drainage from these areas also needs to be collected and conducted for treatment, if the concentrations of chemical elements deemed harmful exceed the natural concentration levels for the surroundings.

It is crucial in the development of water management (Table 47, Chapter 8.3.3) to:
- survey actual and potential sources of water discharge,
- measure or assess by emissions source the chemical quality of water (monitoring); develop and implement continuously functioning measurement of water quality, water flows and water balance, especially at principle water discharge sites,
- make a plan of measures for possible exceptional discharges of water and for communicating failure situations (employees, local inhabitants),
- according to monitoring findings, direct dirty water either concentrated to the same treatment unit or by emissions to the different treatment units,
- update the surveying of water emissions sources as the operations expand or change, e.g. if there are changes in the ore deposit type and the processing of ore,
- make precautions for extreme weather conditions (e.g. safety ponds in case of flooding, water collection basins in case of dry season).

The best environmental practices for the management and treatment of waste water generated in mining operations shall adhere to the following criteria:
- Achieving a treatment level that facilitates as much as possible recycling of treated water for using according to water requirement at different operations sites.
- The collection of waste water and use (and storage) of treatment chemicals is arranged in such a way that it poses no risk for human health in the mining area and its neighbouring surroundings.
- The quality of discharged water released into the environment will not cause significant contamination in the downstream waterway (physical and chemical quality of the water and/or the biodiversity of fauna in the short and long term).

- The precipitation sludge generated in the treatment of water is stored according to degree of harmfulness, in either basins with a sealed structure or basins with a partly sealed structure (see Chapter 8.3.2.2).
- The central quality criteria for the treated water are sufficiently low:
  - concentrations of harmful substances (metals and/or metalloids, chemicals and/or chemical residues),
  - concentrations of chemical elements that increase eutrophication or disturb nutrient balance (N, P, C, S, Ca, Mg, K, Na),
  - concentrations of chemical elements and or compounds with potential acid generating qualities (e.g. Fe, Mn, Al, SO_4, thio- compounds) or
  - concentrations of compounds that increase alkalinity (e.g. lime, lye), and
  - suspended solid concentrations.

The water treatment methods and operating principles are listed in Figure 42 (see Table 34, Chapter 6.2.2.1). The top boxes of Figure 42 show the main operating principle of the treatment process, below which is a list of methods on which neutralisation or precipitation of the chemical element and/or salt compound into solid matter is based. Some of the methods shown in the figure are also briefly described in Chapter 8.3.2.4 (more information from INAP 2009). Figure 43 shows a flowchart describing the industrial-scale treatment facility based on the neutralisation and aeration of waste water, which is suitable for the precipitation of iron and other metals as well as the removal of suspended solids.

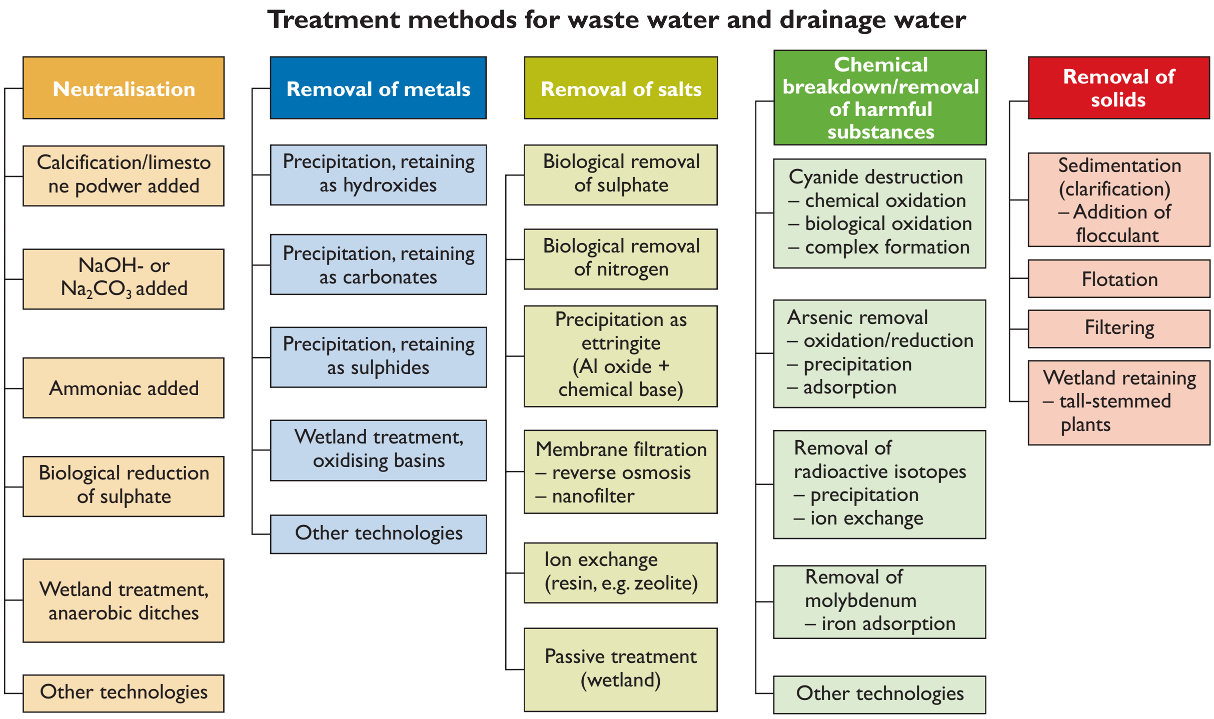


Figure 42. Treatment methods for waste water (more information from INAP 2009, EC 2009). The uppermost boxes show the main principle for the treatment of waste water, with a list below of the treatment methods on which neutralisation or precipitation of the chemical element and/or salt compound is based.

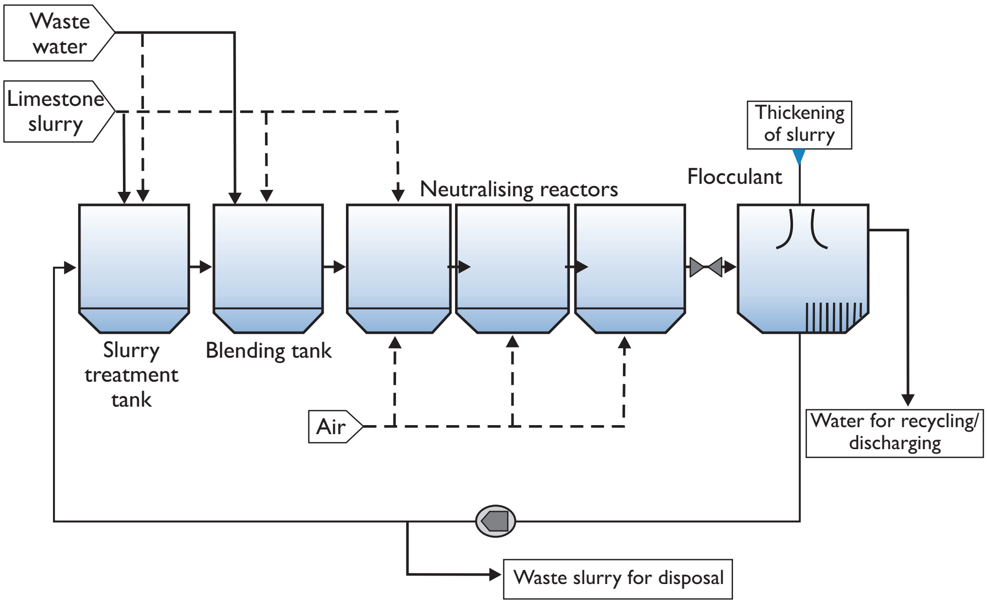


Figure 43. A flowchart of industrial-scale waste water treatment based on neutralisation reactions (metal precipitation, removal of suspended solids, more information from INAP 2009).

8.3.3.3
Raising of dams

The dams of mine waste areas are raised every few years to increase storage capacity. The best environmental technique is to conduct dam raising using either blast rock and/or till (see Chapter 8.3.2.3). Raising can also make use of tailings, if on the basis of geotechnical and environmental compatibility characteristics the tailings are suitable for such. It is not recommended to use tailings in the construction of the dam structure if it contains harmful quantities of e.g. iron sulphides that produce acid and/or chemical elements and/or compounds regarded as harmful. The tailings used for the raising is excavated from the inside of the impoundment, where the material normally is more coarse-grained, then it is lifted on top of the dam to "dry" before compacting and evening into the dam. Coarser tailings will percolate to become sufficiently dry for use in the construction of a durable dam. The recommended raising technique for mine dams is downstream filling (cf. Chapter 5.4.4).

The best environmental practices for the monitoring of dam safety and making precautions for emergency situations are described in Chapter 8.1.

8.4
Mine closure and rehabilitation

When the mining operations are decommissioned, the mining area is rehabilitated and closed. The objective of closure is to restore the area into a condition that is safe for humans and the environment, as well as making the area blend in with its environment and surrounding landscape as well as possible.

The best environmental practices with respect to closure are:

- The taking into account of closure, as well as setting the objectives of closure and the planning of closure measures, needs to be done as early as possible during the life of the mine, including consideration for the special characteristics of the site
  - The making of detailed plans at mines with an operational period that is expected to be brief, as soon as possible
  - The detailed plan should be based on risk assessment

- The updating of the closure plan during the operational stage to correspond to alterations occurring in operations
- Economic preparations in place during the operational stage for the closure of the mine
- Optimising the land use of the area: assessment of the possibilities for future use of the area, planning and implementation – and/or modification of the area into a biologically diverse habitat
- Demolition and/or removal of all unnecessary structures and appliances from the area (without endangering possible future mining activity in the area if ore of a commercial grade remains in the deposit)
- Utilisation and/or recycling of demolished materials
- Adhering to the best environmental practices in the closure of mining waste areas and mined out spaces (cf. chapters 8.4.1 and 8.4.2), in the treatment of water and the restoration of contaminated soils
  - Ensuring the physical and chemical stability of structures remaining at the site
  - Removal of structures that cause safety risks or making of such hazard-free
  - Removal or management of emissions sources (e.g. water treatment)
- Ensuring the functioning of rehabilitation measures using monitoring (e.g. water treatment, cover structures for waste areas and dams) and engaging in sufficient rectification measures should the need arise
- The minimisation of the negative socio-economic impacts of closure and taking into consideration the needs of the local community (e.g. restrictions to recreational use)
- Open communication regarding the closure and rehabilitation of the area.

Technical solutions related to the closure of a mine are described in more detail in the Mine Closure Handbook (Heikkinen *et al.* 2005). The following paragraphs discuss the closure and rehabilitation of mining waste areas and mined out spaces that remain in the mining area after decommissioning activities in more detail.

8.4.1

Closure and rehabilitation of waste areas

Planning the closure of waste areas and the selection of rehabilitation measure are directed by:

- physical and chemical characteristics of waste,
- disposal site,
- implemented disposal technique,
- basal and dam structures of waste area, and
- environmental impacts verified during mining operations and possible post-rehabilitation environmental impacts and the likelihood of their occurrence (long-term environmental risks).

The objective of rehabilitation is to restore the area into an environmentally safe condition and minimise long-term environmental impacts and especially to prevent the occurrence of detrimental impacts. The closure of the stockpiling areas always requires the updating of the current state study (see Chapter 5.2.4), which includes:

- monitoring findings for the waste area during the operational stage,
- information about the chemical alteration situation of the waste area,
- information about the water balance of the waste area,
- estimates and/or measurements of the condition of basal and dam structures (identified leakages or dripping, potential leakage points, risk assessment for collapse), and

- reports on the reparations performed and the functioning of cover structures for waste areas and an assessment of the impacts of these on the quality and quantity of emissions (dust, water discharges).

8.4.1.1
Landscaping of waste areas, cover structures and water management and treatment

Landscaping is essentially associated with the closure and rehabilitation tasks for the waste areas. The planning for rehabilitation tasks is initiated during the master plan stage for the mine. This also helps with the consideration for rehabilitation and landscaping as well as the quantity of soil masses and the space required for such. The planning and implementation of landscaping work is associated with the following, e.g.

- Wherever possible, the scheduling of mining operations shall be planned in such a way, that landscaping of the waste areas can be conducted simultaneously with the removal of overburden, thereby avoiding intermediate stockpiling of masses and the haulage costs for hauling the masses.
- Landscaping planning is conducted by professionals in the field (landscape architect, etc.).
- Landscaping is performed as part of daily mining operations and the planning of such, not merely during the final stages of operations or following decommissioning.
- The availability of masses required for landscaping is investigated and the placement sites for these are reserved.
- The vegetation of cover structures and dam slopes will be initiated as quickly as possible following the spreading of the covering layer, in order to avoid the erosion of covering material and dusting. This measure speeds up the landscaping of the closed area into the surroundings.
- Reduce the formation of ponds on top of the cover structure and preventing the erosion of the cover structure (effect of flowing water) using conducting of rain and thaw water and by constructing erosion shields along the route of water flow, using for instance edge sloping (dam zone).
- Speeding up the forming of vegetation on top of the cover structure by planting grasses. Following this, the successful growth of trees to be planted in the area or other naturally spreading vegetation will be improved.
- Consideration of the properties of the cover structure when choosing the plant species to be planted or sown, and the local climatic and growing conditions.
  - Choice of plants with short roots if the cover structure is to remain impermeable and to reduce water and oxygen from accessing the waste material. The growth in the length of roots can damage the cover structure and weaken its functioning.
  - Damage to the sealing layer can also be reduced using a sufficiently thick growth medium and by preventing the spreading of trees with long roots.
- Using landscaping implemented during operations and the covering of waste areas, the environmental impacts of the waste areas can be reduced, and consequently the ultimate costs of rehabilitation will also be reduced.

The method for covering the waste areas is selected on the basis of long-term behaviour of the waste. Depending on the quality of the waste, the purpose of the cover can be the prevention of dust formation and/or chemical and physical weathering of the waste (cf. Chapter 6.3.1). Covering solutions in accordance with best practices are dry cover or wet cover. Below is a description of the properties of these cover structures and Table 48 shows the compatibility of different covering solutions for different types of waste.

Table 48. Rehabilitation methods for the waste areas, the suitability for various waste types and water management. (More information available from EC 2009, Lottermoser 2007, INAP 2009)

Rehabilitation method for waste areas	Principle of the method and suitability for different waste types	Collection and treatment of water
Dry cover		
Single-layer cover	The stockpiling area is covered with mineral soil/till containing organic matter and a growth medium (layer thickness 0.5 – 1 metre), which enables vegetation of the area (grass + tree stand). This method is suitable for the landscaping of a non-acid-generating waste area (waste rock, tailings) and for waste areas where the long-term solubility of potentially harmful substances is minimal or manageable by conducting the water for treatment.	Clean surface water is separated from possible deteriorated seepage from the waste area. Deteriorated water is conducted for treatment (infiltration field/ constructed wetlands).
Double-layer cover		
Multi-layered cover including a layer that prevents the travel of oxygen and retains water	The dry cover is made as a multi-layered cover used to reduce the travel of oxygen into the pile. This method is suitable for the rehabilitation of waste rock that is non-acid-generating or poorly acid-generating (including harmful metals/metalloids).	Clean surface water is conducted separate from the drainage and exit seepage of the pile. Seepage is treated using either active or passive treatment methods.
Multi-layered cover including a layer that slows down the travel of oxygen and increases the consumption of oxygen	The cover is made as a multi-layered cover used to prevent the travel of oxygen into the pile. The cover has a layer containing organic matter that consumes oxygen, which prevents oxygen from accessing waste containing sulphides. The oxygen-consuming layer can be a basin-shaped wetland depression, where the decomposition reactions of plants consume oxygen. This method is suitable for the rehabilitation of acid-forming tailings (includes harmful metals/metalloids).	
Cover with carbonate-containing tailings/ fine-grained waste that increases neutralisation and slows down the travel of oxygen (paste cover)	The waste area is covered with carbonate-containing, fine-grained tailings, or rock or mineral powder (Mg and/ Ca silicate ± carbonate), that retains rainwater and that has alkaline gravitational water[1]. Cover structure [paste cover ≥ (1.5–2) m] decelerates oxygen diffusion and enhances the neutralising capacity of the waste. Suitable for the rehabilitation of acid-forming tailings.	Rain water is allowed to infiltrate into the pile. The water seeping from the pile is conducted for treatment; either active or passive treatment.
Impermeable cover (includes synthetic materials)	The cover structure includes a cover layer that prevents water from percolating (HDPE lining + /– bentonite lining). A synthetic cover structure requires an upper (sunlight protection, growth medium) and a lower protective layer (prevention of point loading, prevents interaction) and careful sealing. The waterproof layer prevents oxygen from accessing the pile. This cover structure is suitable for the rehabilitation of acid-forming tailings areas and mineral precipitate sludge ponds. The suitability for using bentonite lining requires that the structure will not dry (desiccation cracks) and no cation exchange reactions occur[2].	The clean surface water is directed away from the stockpiling area using channels; spreading of tree stand prevented. Deteriorated seepage from edge slopes and dams are conducted for treatment. Active and/or passive treatment.

[1] Räisänen & Juntunen 2004, Räisänen 2005
[2] INAP 2009, htpp://www.gardguide.com

Dry cover

The dry cover can comprise a single soil layer or a layered structure of numerous soils and/or synthetic materials. The properties and thicknesses of the layered structure as well as the water management of waste areas are described by waste type in Table 48. The property requirements for the cover structure are specified according to the objectives set for rehabilitation. The dry cover shall:

- retain water for use by plants (growth medium for plants),
- conduct water well for collection of surface water (covered drains on surface section),
- reduce the quantity of water accessing the waste (impermeable layer),

- limit the travel of oxygen through the cover and into the waste material,
  - cover structure that consumes oxygen (e.g. wetland),
  - cover structure made from water retaining fines, which slows down the travel of oxygen downwards (paste cover),
- increase the alkalinity of water seeping through the cover; the alkaline layer can also act as a chemical protective layer that weakens the interaction reactions of waste material and cover material,
- prevent the capillary rising in saline waste water and consequent precipitation to top cover structures (coarse cover structure, lowest) (Lottermoser 2007).

The use of synthetic material in the cover structure can significantly reduce the transport of water and oxygen into the waste. The synthetic material can comprise:
- polyethylene lining (PE, HDPE, LLDPE, CPE, DuPont™ HYPALON®, PVC), and/or
- geosynthetic clay lining (GCLs), and/or
- bituminous geomembrane lining.

The following matters shall be taken into account in the construction of synthetic lining structures and supervision during operation:
- The linings are sensitive to change under sunlight (cracking/disintegration) and should therefore be covered with soil to a sufficient thickness.
- In order to avoid the linings from breaking, the joining of the sections should be conducted with special care (impacted by weather conditions) and professionalism.
- Below the lining, and also above in the case of waste rock piling, a sufficiently thick protective layer needs to be built that will prevent point loading and the breaking of the lining e.g. by sharp rocks or sand particles. The particle size of the soil of the protective layer should be less than the thickness of the lining.
- In the selection of upper and lower protective layers, consideration must also be given to the pile traffic during the rehabilitation stage.
- The placement of a lining structure on the sloped embankments requires investigation of the stability and thereby the reduction in slope gradient.
- The selection and designing of lining structures must take into consideration the possible gases and/or heat reactions (heat expansion) produced in the long-term alteration of the waste.

Water cover or partial water cover (wet cover)

According to current knowledge, the subaqueous disposal of mining waste or covering using an adequately thick layer of water is the best rehabilitation method for preventing or decelerating the oxidation of iron sulphides and the subsequent leaching of harmful substances (Tremblay & Hogan 2001, EC 2009, INAP 2009, Eriksson *et al.* 2001). This is based on the slower dissolution and travel of oxygen (diffusion) in water than in air. The thickness of the required water layer depends on the extent of the area to be covered, as well as the windiness in the area and the depth of the vertical blending of water caused by wind. In Finland, the blending of water (full circulation) occurs during the spring and the time when ice cover thaws, and in the autumn during autumn storms when the surface layers of water mix with the lower water layers. The blending of water can be prevented, e.g. using underwater till-covered ridges. In waste areas where the water depth is insufficient for preventing the travel of oxygen, the waste material is covered by sulphide-free till or other fine-grained rock material 0.5–1 m layer).

Table 49 describes the suitability of water cover for different ways used for the disposal of waste and the water management for the waste area. Water cover is suitable for the rehabilitation of a tailings impoundment, if the impoundment has impermeable dam and basal structures (see chapters 8.3.2.2 and 8.3.2.3). If the basal structures are waterproof and the dam structures endure minimal fluctuation in water level (sufficient freeboard), the majority of the tailings can be saturated in water by forming the central section of the impoundment into a basin for collecting rain water (and thaw water from snow) (wet cover, Figure 41). Alternatively, the water level in the waste can be controlled by flooding, if the waste area is located in a depression (Alakangas 2006). Flooding can either be done by raising the groundwater level (no waterproof base) or by conducting surface water into an impoundment. Water cover is also used in the rehabilitation of pit backfilling, if the open pit is filling with a sufficiently thick layer of water (see Chapter 8.4.2).

Water management and treatment

In addition to covering the waste areas, the rehabilitation of the waste areas usually requires the collection and treatment of water seeping from the waste areas. In line with best practices, the treatment of water shall take the following into account:

- clean natural water is conducted to separate from the seepage and drainage of the waste areas, and the latter is recovered for treatment,
- the needs and solutions for the treatment of water is done on the basis of water quality and quantity; long-term estimates of quality and quantity are based on e.g. geochemical modelling,
- treatment uses similar active and passive methods as during the operational period (Figure 43, Chapter 8.3.3.2),
- following the decommissioning of activities, it is often appropriate to undertake to use passive methods that require less maintenance and servicing than active methods; it should be noted, however, that the passive methods are not suitable for all types of water, and the reliable functioning of these is often poorer than for active methods,
- sufficient space for the post-operational treatment of water is reserved already during the operational stage,
- with the treatment of water, assessments shall also be made as to whether the water to be treated or the mineral precipitates produced in the treatment can contain recoverable amounts of precious metals or other valuable substances (e.g. gypsum, carbonates), or is it possible to make use of the e.g. mineral precipitates as raw materials in another industry (e.g. pigment or nano-silicon production, sulphuric and magnesium salts); thereby reducing the quantities of sludges requiring final disposal and reducing the quantity of harmful substances from these into the environment, as well as covering the costs incurred for treatment,
- the mineral precipitates produced in the treatment of water that is not suitable for beneficial utilisation will be ultimately disposed to appropriate landfills on the basis of the chemical, mineralogical and solubility characteristics,
- both active and passive water treatment solutions require continuous monitoring of water quality to ensure treatment functions flawlessly
- the treatment of water is continued as long as it takes for the quality to achieve the criteria set for water that can be discharged into the environment (cf. Chapter 8.3.3.2, see also INAP 2009).

Table 49 shows the water management and treatment methods suitable for different cover solutions for waste areas.

Table 49. Water cover, partial water cover and other possible (future) rehabilitation methods. (More information from EC 2009, INAP 2009)

Rehabilitation method for waste areas	**Principle of the method and suitability for different waste types**	**Collection and treatment of water**
Water cover or partial water cover		
Water cover Pit backfilling and water cover	The diffusion of oxygen in water is 30 times smaller than in air, which slows down the travel of oxygen into the waste. In shallow water cover (<2 metres) oxygen diffusion can be further prevented by covering the waste with fine-grained till[1]. This method is suitable for acid-forming tailings impoundments that have impermeable basal and dam structures or for backfilled acid-generating waste rock or the mixed backfilling of tailings with waste rock. In pit backfilling, the bedrock groundwater and surface water raining into the pit will form the water cover. Bedrock groundwater contamination can be mitigated by filling the gaps between rock walls and waste with fine-grained filter filling (rock powder/sulphide-free tailings). Pit backfilling is not suitable if oxidised groundwater accesses the pit via rock fractures.	The water level of the waste impoundment with water cover must be adjusted and an overflow channel or discharge pipe must be constructed for the discharging of water; possible deteriorated water must be conducted for treatment; active or passive treatment
Wet cover, partial wet cover (wetland cover)	The waste area is shaped in its centre to become basin-like for the collection of rain water and thaw water from snow. In the centre of the impoundment, the water level is close to the ground level and above. The water level of the waste area falls when moving closer to the edges. Suitable for poorly acid-generating, or used with paste cover for an acid-generating tailings impoundment that is located in a valley[2]. This method requires the reinforcement of edge slopes/dams in order to endure the annual fluctuations in water level and a waterproof or partially waterproof basal structure.	Rain water is allowed to infiltrate into the pile. The water seeping from the pile is conducted for treatment; either active or passive treatment.
Flooding of the waste area	Surface water or groundwater is conducted to the waste area, as a result of which the water level will rise to the surface of the waste. This assists with the waste remaining saturated in water. Suitable for waste areas with acid-forming tailings, where the groundwater/surface water can be conducted in a controlled manner via the boundary areas and base to the waste area[3].	The water level of the flooded waste impoundment must be adjusted and an overflow channel must be constructed for the discharging of water; possible deteriorated water must be conducted for treatment; active or passive treatment
Other rehabilitation methods (pilot study stage)		
Iron sulphide removal (depyritisation)	The waste is reprocessed and the iron sulphides are removed, which makes the waste become non-acid-forming. The reprocessing of the waste can also remove other usable minerals/chemical elements (sulphide flotation).	The reprocessing of waste can reduce the treatment need for water.
Chemical addition, passivation	Oxygen-consuming chemicals or agents are absorbed into the waste, which covers the iron sulphide grains and prevents contact with oxygen.	The improvement of the environmental compatibility of the waste affects the necessity for treatment the drainage from the waste area.

[1] Ljungberg *et al.* 1997, Eriksson *et al.* 2001
[2] Räisänen 2005, Heikkinen *et al.* 2009
[3] Alakangas *et al.* 2006

8.4.2
Rehabilitation of excavated spaces

The purpose of the rehabilitation of the pit areas and underground excavations shall be the assurance of physical safety, blending in with the surroundings wherever possible and the prevention of contamination caused by mine water accessing the bodies of water in the environment.

The physical safety of mine spaces and open pits can be assured by:

- making vertical drops or steep rock walls posing the risk of collapse at open pits into gentle slopes,
- by preventing collapses and depressions of mine spaces by filling and reinforcing areas susceptible to collapse,
- filling of open pits with either rock material or water in order to prevent collapse and restricting entry by outsiders,
- preventing outsiders from entering mine spaces by closing mine access tunnels and ventilation shafts and/or by closing mine access roads, and
- fencing and marking with warning signs the areas at risk of collapse or depression (requires regular inspections to ensure the functioning of signs and fences).

The mine spaces and open pit can be made to blend in with the surrounding landscape by shaping and planting the ground surface surrounding the pit. In open pits, the edges of the overburden removal areas can already be shaped following the completion of overburden removal, in order to facilitate landscaping following the completion of excavations.

The contamination caused by the mine water on the water of the environment depends on e.g.

- the mineralogical and chemical composition of the ore deposit, as well as hydraulic characteristics (fracturing),
- weathering of walls of the pit/mined out spaces,
- hydraulic characteristics of the surrounding bedrock and soil, and
- the mining waste materials to be backfilled and the composition of such.

The contamination of the environment caused by mine water can be prevented/reduced by:

- making fresh reactive mine walls passive with surfacing installed already during the operational stage,
- removing all unnecessary and contaminating infrastructure, appliances and materials/chemicals from the pit and excavated spaces,
- assessing and surveying the possibilities for mine water discharges (flow routes, flow rates, water quality):
  - blocking of flow routes (e.g. permeable cracks and fractures), construction of hydraulic barriers,
  - water collection and treatment if necessary,
- ensuring that the pit/mine spaces fill with water:
  - speeding up the filling with water by pumping water into the pit/mined out spaces,
- make technical assurances that the mining waste materials backfilled into the mine spaces will not cause the contamination of water:
  - containment of mining waste or covering with more permeable soils,
  - isolating the mining waste using a sufficiently thick water layer,

- treating the mine water either at the pit/in the excavated spaces or by treating the overflow water either actively or passively;
  - biological or chemical *in-situ* treatment (e.g. sulphate reducing bacteria, alkaline treatment),
  - the treatment of overflow water using similar active or passive methods as those used during the operational stage (cf. Chapter 8.3.3.2),
  - the pumping of mine water for treatment at the processing facility,
- using monitoring to ensure the selected water treatment is functional and sufficient.

References

Alakangas, L., Lundberg, A., Corrége, O. & Öhlander, B. 2006. Changes of groundwater quality in sulphide-bearing mine-tailings after remediation at Kristineberg, northern Sweden. Manuscript. Julk: L. Alakangas. Sulphide oxidation, oxygen diffusion and metal mobility in sulphide-bearing mine tailings in northern Sweden. Doctoral Thesis 2006:27. Luleå University of Technology, Department of Chemical Engineering and Geosciences, Division of Applied Geology. ISSN: 1402-1544 ISRN: LTU-Dt—06/27—SE.

AMEC 2010. Code of Environmental Practice for Mineral Exploration in Western Australia. Association of Mining and Exploration Companies (AMC) & the Chamber of Minerals and Energy of Western Australia. Full version – October 2010. 15 s. http://www.cmewa.com/UserDir/CMEPublications/Code%20of%20Environmental%20Practice%20for%20Mineral%20Exploration%20in%20Western%20Australia%20%20Full%20Version%20FINAL213.pdf

Anttonen, M., Heikkinen M., Karjalainen, T.P. & Reinikainen K. 2010. Soklin kaivoshankkeen sosioekonomisten vaikutusten arviointi. Yara Suomi Oy.

Arizona Chemical 2008. Sylvapine™421. Safety data sheet. http://www.arizonachemical.com/Global/MSDS/EU_MSDS/SYLVAPINE%e2%84%a2%20421_English.pdf. Luettu 26.5.2010.

BC AMD 1989. Draft Acid Rock Drainage Technical Guide. British Columbia Acid Mine Drainage Task Force (BC AMD). BiTech Publishers Ltd., Vancouver, BC.

Bertills, U., Björklund, I., Borg, H. & Hörnström, E. 1986. Biological effects of xanthates. Report no 3112 from the National Swedish Environment Protection Board. Solna, Sweden.

Blowes, D. W. & Ptacek, C. J. 1994. Acid-neutralization Mechanisms in Inactive Mine Tailings. Julk: J. L. Jambor & D. W. Blowes (Eds.). The Environmental Geochemistry of Sulfide Mine-wastes. Mineralogical Association of Canada. Short Course Handbook, Volume 22: 271-292.

Carlson, L., Hänninen, P. & Vanhala, H. 2002. Ylöjärven Paroistenjärven kaivosalueen nykytilan selvitys. Geologian tutkimuskeskus, arkistoraportti. S/41/0000/3/2002. 54 s.

CICAD 2003. Hydrogen sulphide: Human health aspects. Concise International Chemical Assessment Document (CICAD) 53. WHO. http://www.who.int/ipcs/publications/cicad/en/cicad53.pdf

Cravotta, C. A. III, Brady, K. B. C., Rose, A. W. & Douds, J. B. 1999. Frequency Distribution of the pH of Coal-Mine Drainage in Pennsylvania. Julk: D. W. Morganwalp & H. Buxton (Eds). United State Geological Survey Toxic Substances Hydrology Program. Proceedings of the Technical Meeting, Charleston South Carolina, March 8-12, 1999, Volume 1 of 3. Contamination from Hard-Rock Mining. U.S. Geological Survey Water-Resources Investigation Report 99-4018A: 313-324.

EBRC 2008. HERAG. Health Risk Assesment Guidance for Metals. http://www.ebrc.de/ebrc/ebrc-projects.php

EC 2001. Assessment of plans and projects significantly affecting Natura 2000 sites. Methodological guidance on the provisions of Article 6(3) and (4) of the Habitats Directive 92/43/EEC. European Commission (EC), Environment DG. European Communities 2002. http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/natura_2000_assess_en.pdf. Luettu 19.3.2010.

EC 2009. Reference document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities. January 2009. European Commission (EC). 511 s. ftp://ftp.jrc.es/pub/eippcb/doc/mmr_adopted_0109.pdf. Luettu 7.9. 2010.

Elinkeino-, liikenne- ja ympäristökeskus 2011. Ympäristövaikutusten arviointi YVA ja SOVA. http://www.ely-keskus.fi/fi/Ymparisto/Ymparistonsuojelu/yva/Sivut/default.aspx. Luettu 5.9. 2011.

Environment Canada 2009. Environmental Code of Practice for Metal Mines. 1/MM/17, Mining Section, Mining and Processing Division, Public and Resources Sectors Directorate, Environmental Stewardship Branch, Environment Canada. http://www.ec.gc.ca/lcpe-cepa/documents/codes/mm/mm-eng.pdf

Eriksson, N., Lindvall, M. & Sandberg, M. 2001. A quantitative evaluation of effectiveness of the water cover at the Stekenjokk tailings pond in northern Sweden: Eight years of follow-up. Securing the Future, International Conference on Mining and the Environment, Skellefteå June 25 – July 1, 2001. Proceedings, Volume 1: 216-227.

Fuerstenan, M. C., Jameson, G. J. & Yoon, R. H. 2007. Froth Flotation: A Century of Innovation. Society for Mining, Metallurgy, and Exploration, Inc. (SME). Littleton, CO. 891 p.

Grönholm, S. 1994. Influence of mineral composition and microstructures on the mechanical properties of host rocks of the Kemi (Elijärvi) chromite deposit, Finland. Geologian tutkimuskeskus, Tutkimusraportti 126. 36 s.

GTK 2006. GTK:n malminetsintätyöryhmän raportti. Julkaisematon raportti 27.9.2006 / Dnro E/482/032/2006.

Hakapää, A. & Lappalainen, P. (toim.). 2009. Kaivos- ja louhintatekniikka. Kaivannaisteollisuusyhdistys ry, opetushallitus. Vammalan kirjapaino Oy. 383 s.

Heikkinen, P. 2000. Haitta-aineiden sitoutuminen ja kulkeutuminen maaperässä. Geologian tutkimuskeskus, tutkimusraportti 150. 74 s.

Heikkinen, P. M. 2009. Active sulphide mine tailings impoundments as sources of contaminated drainage: controlling factors, methods of characterization and geochemical constraints for mitigation. Geological Survey of Finland, Espoo. 38 s. 7 figures and 2 tables. Original articles I-IV. ISBN-952-217-085-9.

Heikkinen, P. M., Korkka-Niemi, K., Lahti, M. & Salonen, V.-P. 2002. Groundwater and surface water contamination in the area of the Hitura nickel mine, western Finland. Environmental Geology 42 (4): 313-329.

Heikkinen, P. M., Noras, P., Mroueh, U.-M., Vahanne, P., Wahlström, M., Kaartinen, T., Juvankoski, M., Vestola, E., Mäkelä, E., Leino, T., Kosonen, M., Hatakka, T., Jarva, J., Kauppila, T., Leveinen, J., Lintinen, P., Suomela, P., Pöyry, H., Vallius, P., Tolla, P. & Komppa, V. 2005. Kaivoksen sulkemisen käsikirja. Kaivostoiminnan ympäristötekniikka. Outokumpu Oyj, Tieliikelaitos, Maa ja Vesi Oy, GTK ja VTT. Vammalan kirjapaino, Vammala. 165 s. ISBN 951-690-941-8.

Heikkinen, P. M., Räisänen, M. L. & Johnson, R. H. 2009. Geochemical characterization of seepage and drainage water quality from two sulphide mine tailings impoundments: Acid mine drainage vs. neutral mine drainage. Mine Water and the Environment 28, 30-49.

Hernesniemi, H., Berg-Andersson, B., Rantala, O. & Suni, P. 2011. Kalliosta kullaksi, kummusta klusteriksi. Suomen mineraaliklusterin vaikuttavuusselvitys. Elinkeinoelämän Tutkimuslaitos ETLA. Taloustieto Oy. Unigrafia, Oy Helsinki. ETLA B252. ISBN 978-951-628-526-2. ISBN 978-951-628-527-9 (PDF). http://www.etla.fi/files/2668_kalliosta_kullaksi_kummusta_klusteriksi.pdf.

Holm J. & Leskelä A., 1979. Padot. Julk: S. Mustonen (toim.). Vesirakenteiden suunnittelu, Suomen rakennusinsinöörien liitto RIL 123. s. 53–112.

Hukki, R. T. 1964. Mineraalien hienonnus ja rikastus. Helsinki, Otava. 656 s.

ICMM 2007. MERAG. Metals Environmental Risk Assessment Guidance. http://www.icmm.com/page/1185/metals-environmental-risk-assessment-guidance-merag

Idman, H. & Kahra, A. (toim.). 2007. Malminetsintä ja kaivostoiminta suojelualueilla sekä saamelaisten kotiseutualueella ja poronhoitoalueella: opas. KTM julkaisuja 28/2007. 86 s.

INAP 2009. The GARDGuide. The Global Acid Rock Drainage Guide. The International Network for Acid Prevention (INAP). http://www.gardguide.com/ Luettu 10.11.2010.

Itä-Suomen ympäristölupavirasto 2007. Tulikivi Oyj. Huutojoen uoman siirtäminen Vaaralammen kaivospiirin alueella ja töiden aloittamislupa, Juuka. Itä-Suomen ympäristölupavirasto. Päätös Nro 76/07/2, Dnro ISY-2005-Y-324. 9.7.2007.

Jokimäki, J. & Hamari, S. 2007. Kevitsan kaivoshankkeen Natura-arviointi. Lapin vesitutkimus Oy, helmikuu 2007. http://www.environment.fi/download.asp?contentid=64736&lan=fi. Luettu 12.3.2010.

Juslén, J. 1995. Sosiaalisten vaikutusten arviointi (SVA) - monipuolisempaan suunnitteluun. Stakes Raportteja 180.

Kauppinen, T. & Tähtinen, V. 2003. Ihmisiin kohdistuvien vaikutusten arviointi -käsikirja. Stakes, Aiheita 8/2003. http://info.stakes.fi/NR/rdonlyres/911022A6-5F87-4FA2-A21B-6DFD56A58AA3/0/Aiheita82003.pdf. Luettu 12.3.2010.

Koljonen, T., Gustavsson, N., Noras, P. & Tanskanen, H. 1992. Alkuainekuvaukset ja geokemialliset kartat. Julk: Koljonen, T. (toim.). Suomen geokemian atlas, osa: moreeni. Geologian tutkimuskeskus, Espoo. s. 143-217.

KT ry 2006. Sullivanin kaivosonnettomuus. Turvallisuushälytys. Kaivannaisteollisuus ry.

Kuusisto, E. 1991. Metalli- ja rikkimalmikaivosten ja -louhosten jätealtaiden ja jätekasojen vaikutusta ympäristöön tutkivaan hankkeeseen liittyvä esiselvitys. Geologian tutkimuskeskus. Arkistoraportti S/42/0000/1/1991. 88 s.

Kuhmo Metals Oy 2008. Suomussalmen nikkeliprojektit. Ympäristövaikutusten arviointiselustus 15.12.2008.

Lapin ympäristökeskus 2007. Kevitsan kaivoshankkeen Natura-arviointi, helmikuu 2007. Luonnonsuojelulain 65 §:n mukainen lausunto Kevitsan kaivoshankkeen Natura-arvioinnista. Lapin ympäristökeskus, lausunto 18.6.2007, LAP-2004-R-12-531. http://www.environment.fi/download.asp?contentid=70206&lan=fi. Luettu 12.3.2010.

Lapin ympäristökeskus 2009. Soklin kaivoshankkeen Natura-arviointi, päivätty 26.6.2009. Luonnonsuojelulain 65 §:n mukainen lausunto Soklin kaivoshankkeen Natura –arvioinnista. Lapin ympäristökeskus, lausunto 21.8.2009. LAP-2008R-1-531. http://www.ymparisto.fi/download.asp?contentid=107610&lan=fi. Luettu 12.3.2010.

Lappalainen, P. 2009. Maanalaiset louhintamenetelmät. Julk: Hakapää, A. & Lappalainen, P. (toim.). Kaivos- ja louhintatekniikka. Kaivannaisteollisuusyhdistys ry, opetushallitus. Vammalan kirjapaino Oy. S. 99-122. ISBN 978-952-13-3488-7.

Laurila, J. & Hakala, I. 2010. Paras käyttökelpoinen tekniikka (BAT) – Ympäristöasioiden hallinta kiviaineshuollossa. Suomen ympäristökeskus, Ympäristönsuojelu. Suomen ympäristö 25 / 2010. 87 s. ISBN 978-952-11-3809-6.

Leskelä, A. 1992. Maapatojen kunnon arviointi. Imatran voima Oy. Tutkimusraportti IVO-A-06/92. Helsinki.

Leskelä, A. 2005. Maapatojen suunnittelun ja rakentamisen perusteet, Patoturvallisuuden täydennyskoulutusohjelma 2004-2005, luentomateriaali 14.6.2005 pidetty luento.

Leskelä, A. 2009. Maapatojen suunnittelu. Lähtökohdat, käyttökohteet, maapatotyypit. Savonia-ammattikorkeakoulu, Kaivannaisteollisuuden maapatojen sekä läjitysalueiden rakenteet ja turvallisuusnäkökohdat -koulutus, luentokalvot. http://portal.savonia.fi/amk/hankkeet/patoturvallisuus

Ljungberg, J., Lindvall, M., Holstrom, H. & Öhlander, B. 1997. Geochemical field study of flooded mine tailings in Stekenjokk, northern Sweden. Proceedings of 4th International Conference on Acid Rock drainage. Vancouver, B. C., Canada, 31 May – 6 June 1997: 1401-1417.

Lottermoser, B. G. 2007. Mine wastes. Characterization, Treatment, Environmental Impacts. Second Edition. Springer, Berlin. 304 s. ISBN-10 3-540-48629-1.

Lukkarinen, T. 1987. Mineraalitekniikka. Osa 2: Mineraalien rikastus. Helsinki: Insinööritieto, 1987. 442 s. ISBN: 951-795-147-7.

Luodes, H., Kauppila, P. M., Karlsson, T., Nikkarinen, M., Aatos, S., Tornivaara, A., Wahlström, M. & Kaartinen, T. 2011. Kaivannaisjätteen luokittelu pysyväksi. Louhinnassa muodostuvat sivukivet. Suomen ympäristö 21/2011, Ympäristönsuojelu. 35 s. Ympäristöministeriö. URN:ISBN:978-952-11-3919-2. ISBN 978-952-11-3919-2 (PDF).

Maijala, T. 2010. Patoturvallisuusopas. Luonnos 24.11.2010. Hämeen elinkeino-, liikenne- ja ympäristökeskuksen julkaisuja 4/2010. 99 s. http://www.ymparisto.fi/download.asp?contentid=123380&lan=fi

Mann, A. W., Birrell, R. D., Mann, A. T., Humphreys, D. B. & Perdrix, J. L. 1998. Application of the mobile metal ion technique to routine geochemical exploration. Journal of Geochemical Exploration 61 (1-3): 87-102.

Mattila, K., Zaitsev, G. & Langwaldt, J. 2007. Biological removal of nutrients from mine waters. Final report -loppuraportti. Finnish Forest Research Institute. Kaira-hanke. S. 99. ISBN 978-951-40-2060-5 (PDF). http://www.metla.fi/hanke/7207/index-en.htm.

MEND 1995. Review of in-pit disposal practices for the prevention of acid drainage – case studies. Environmental Neutral Drainage (MEND) Programme. Energy, Mines and Resources of Canada, CANMET. Mend Project Report 2.36.1.

Meissner, K., Aroviita, J., Hellsten, S., Järvinen, M., Karjalainen, S. M., Kuoppala, M., Mykrä, H. & Vuori. K.-M. 2010. Jokien ja järvien biologinen seuranta – näytteenotosta tiedon tallentamiseen. http://www.ymparisto.fi/download.asp?contentid=122681&lan=fi.

Miller, S., Rusdinar, Y., Smart, R., Andrina, J. & Richards, D. 2006. Design and Construction of Limestone Blended Waste Rock Dumps – Lessons Learned from a 10-Year Study at Grasberg. Julk: R. I. Barnhisel (Ed.). Proceedings of 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, St. Louis, MO. American Society of Mining and Reclamation. Lexington, KY.

MMSD (Mining, Minerals and Sustainable Development) 2002. Breaking New Ground. The Report of the Mining, Minerals and Sustainable Development Project. Earthscan Publications ltd. London. http://www.iied.org/mmsd/final report/index.html

Mondo Minerals Oy 2008. Sotkamon kaivoksen ja tehtaan tarkkailuohjelma. 30.5.2008. Pöyry 9M608033.

Murtovaara S. 2007. GTK:n maastotoiminnan käsikirja E 479/013/2007.

Mustonen, R., Ikäheimonen, T., Kurttio, P., Vesterbacka, P., Nikkarinen, M., Tenhola, M. & Äikäs, O. 2007. Uraanimalmin koelouhinnan ja rikastuksen ympäristövaikutukset (URAKKA). Säteilyturvakeskuksen ja Geologian tutkimuskeskuksen projektiryhmän loppuraportti ympäristöministeriölle. 24.1.2007. http://www.ymparisto.fi/download.asp?contentid=70241. Luettu 27.10.2010.

Mäkelä, A., Antikainen, S., Mäkinen, I., Kivinen, J. & Leppänen, T. 1992. Vesitutkimusten näytteenottomenetelmät. Vesi- ja ympäristöhallinnon julkaisuja, sarja B 10. 86 s.

Nelimarkka, K. & Kauppinen, T. 2007. Ihmisiin kohdistuvien vaikutusten arvioiminen. Stakes. Oppaita 68.

Niinivaara, I. 2009. Esiselvitys: kaivosteollisuuden BAT. Suomen ympäristökeskus, julkaisematon raportti. 49 s.

Nikkarinen, M. 2004. Tulikivi Oyj, Juuka. Selvitys Vaaralammen vuolukiviesiintymän louhinnan vaikutuksista suojeltavan kasvilajin esiintymisalueisiin. Natura-arviointi. Geologian tutkimuskeskus, julkaisematon tutkimusraportti. 14 s.

Nikkarinen, M., Kollanus, V., Ahtoniemi, P., Kauppila, T., Holma, A., Räisänen, M. L., Makkonen, S. & Tuomisto, J. T. (toim.). 2008. Metallien yhdennetty kohdekohtainen riskinarviointi. Abstract: Integrated site-specific risk assessment of metals. Kuopion yliopiston ympäristötieteen laitoksen monistesarja 3/2008. Kuopion yliopisto, Kuopio. 401 s. http://fi.opasnet.org/fi_wiki/images/c/c7/Finmerac-raportti.pdf

Nordstrom, D. K. & Alpers, C. N. 1999. Geochemistry of acid mine waters. Julk: G. S. Plumlee & M. J. Logsdon (Eds). the Environmental Geochemistry of Mineral Deposits. Part A, Processes, Techniques, and Health Issues. Reviews in Economic Geology, Volume 6A: 133-160.

Nordtest 2002. Nordtest method: NT ACOU 112. Acoustics: Prominence of impulsive sounds and for adjustment of L_{Aeq}. S. 5. http://www.nordicinnovation.net/nordtestfiler/acou112.pdf.

OECD 1999. Environmental activities in uranium mining and milling. A joint report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency. OECD Publications. 173 s.

Paalumäki, A. 2009. Avolouhinta. Julk: Hakapää, A. & Lappalainen, P. (toim.). Kaivos- ja louhintatekniikka. Kaivannaisteollisuusyhdistys ry, opetushallitus. Vammalan kirjapaino Oy. s. 91-98. ISBN 978-952-13-3488-7.

Papunen, H. 1986. Suomen metalliset malmiesiintymät. Julk: H. Papunen, I. Haapala & P. Rouhunkoski (toim.). Suomen malmigeologia. Metalliset malmiesiintymät. Suomen geologinen seura ry. Mäntän kirjapaino, Mänttä. s. 133-241.

Parekh, B. K. & Miller, J. D. 1999. Advances in flotation technology. Society for Mining, Metallurgy, and Exploration, Inc. (SME). Littleton, CO. 463 p.

Parviainen, A. 2009. Tailings mineralogy and geochemistry at the abandoned Haveri Au-Cu Mine, SW Finland. Mine Water and the Environment 28: 291-304.

PDAC 2011. E3Plus – A Framework for responsible exploration. Website: http://www.pdac.ca/e3plus/index.aspx

PIRAMID Consortium 2003. Engineering guidelines for the passive remediation of acidic and/or metalliferous mine drainage and similar wastewaters. European Commission 5th Framework RTD Project no. EVK1-CT-1999-000021 "Passive *in-situ* remediation of acidic mine / industrial drainage" (PIRAMID). University of Newcastle Upon Tyne. Newcastle Upon Tyne, UK. 166 s.
Plumlee, G. S. 1999. The Environmental Geology of Mineral Deposits. Julk: G. S. Plumlee & M. J. Logsdon (Eds). The Environmental Geochemistry of Mineral Deposits. Part A: Processes, Techniques, and Health Issues. Reviews in Economic Geology, Volume 6A:71-116.
Pohjois-Suomen ympäristölupavirasto 2007. Talvivaaran kaivoksen ympäristö- ja vesitalouslupa, Sotkamo ja Kajaani. Lupapäätös Nro 33/07/1, Dnro PSY-2006-Y-47. 29.3.2007.
Price W. A. 1997. Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia. Reclamation Section, Energy and Minerals Division; British Columbia Ministry of Employment and Investment. 159 s. http://www.mndm.gov.on.ca/mines/mg/leg/BC%201997%20Draft%20Guideline.pdf. Luettu 25.10.2008.
Puustinen, K. 2003. Suomen kaivosteollisuus ja mineraalisten raaka-aineiden tuotanto vuosina 1530-2001, historiallinen katsaus erityisesti tuotantolukujen valossa. Geologian tutkimuskeskus, arkistoraportti, M 10.1/2003/3. 578 s.
Rantamäki, M., Jääskeläinen, R. & Tammirinne, M. 1979. Geotekniikka. Otatieto 464. Oy Yliopistokustannus/Otatieto. Helsinki. 307 s.
Rasilainen, K. 2008. Rock Geochemical Database of Finland, version 1.1. Geologian tutkimuskeskus, Espoo. http://www.gtk.fi/geotieto/aineistot/uusimmat/metadata/rgdb.html
Raunio, A., Schulmlan, A., Kontula, T. (toim.) 2008. Suomen luontotyyppien uhanalaisuus. Suomen ympäristökeskus. Osa 1: Tulokset ja arvioinnin perusteet. S. 264. Osa 2: Luontotyyppien kuvaukset. s. 572. Suomen ympäristö 8.
Reinikainen, J. 2007. Maaperän kynnys- ja ohjearvojen määritysperusteet. Suomen ympäristökeskus. Suomen ympäristö 23. 90 s.
Reinikainen, K. & Karjalainen, T. P. 2009. Sosiaalisesti kestävä suunnittelu ja sen arviointi – esimerkkinä Soklin kaivoshanke. Julk: H.-L. Hentilä & E. Ihatsu (toim.). KaSuKat – Kasvun ja supistumisen ohjauskeinot ja elinympäristön laatu – tapauksena pohjoisen Suomen kaivoskunnat. Loppuraportti. Oulun yliopiston arkkitehtuurin osaston julkaisuja C 124. Oulu. S. 36-43. Elektroninen versio: ISBN 978-951-42-9134-0. ISSN 0358-030X. (http://herkules.oulu.fi/isbn9789514291340/). Painettu versio: ISBN 978-951-42-9137-1. ISSN 0358-030X.
Räisänen, M. L. 2003. Rehabilitation options for tailings impoundments – case studies of "wet" cover and wetland treatment. Julk: C. Hebestreit, J. Kudełko & J. Kulczycka (Eds). Mine Waste management Best Available Techniques. CBPM Cuprum, Wroclaw and MEERI PAS, Kraków. p. 141-150.
Räisänen, M. L. 2004. Luikonlahden vanhan kuparikaivoksen ympäristön nykytila ja suositukset sivukivien läjitysalueiden kunnostukseen. GTK, Kuopion yksikkö. Julkaisematon raportti, 17 s.
Räisänen, M. L. 2005. A sustainable use of magnesite tailings as a cover for acid generating wastes – A case study of an old copper mine. Julk. Securing the future – International Conference on Mining and the Environment Metals and Energy Recovery, June 27 – July 1 2005 Skellefteå. Proceedings, vol. 2: 826-636.
Räisänen, M. L. 2009. Capability of natural and constructed wetlands to mitigate acidic leakage from closed mine waste facilities – cases in Eastern Finland. In: Securing the future – Mining, metals and society in a sustainable society and 8th ICARD (International Conference on acid rock drainage) in Skellefteå, Sweden June 22 – June 26 2009. http://www.proceedings-stfandicard-2009.com
Räisänen, M. L. & Juntunen, P. 2004. Decommissioning of the old pyritic tailings facility previously used in talc operation, eastern Finland. Julk: A. P. Jarvis, B. A. Dudgeon & P. L. Younger (Eds). Proceedings of the Symposium Mine Water 2004 – Process, Policy and Progress vol. 1: 91-99.
Räisänen, M. L. & Korhonen, K. 2004. Vuonoksen talkkitehtaan rikastushiekka-altaan ja rikastamon ympäristön pohja- ja pintavesien kemiallinen nykytila ja arvio havaintoputkien käyttökelpoisuudesta ja määrästä pohjaveden tilan seurantaan. GTK, Kuopion yksikkö. Julkaisematon raportti, 28 s.
Räisänen, M. L., Lestinen, P. & Kuivasaari, T. 2001. The retention of metals and sulphur in a natural wetland – preliminary results from the old Otravaara pyrite mine, eastern Finland. Securing the Future – International Conference on Mining and the Environment, June 25 – July 1 2001, Skellefteå, Sweden. Proceedings, vol. 2: 662-670.
Räisänen, M. L., Niemelä, K. & Saarelainen, J. 2003. Rautasulfidipitoisen rikastushiekan läjitysalueen rakenne ja ympäristön pintavesien nykytila. Geologian tutkimuskeskus, arkistoraportti S/44/0000/1/2003. 27 s.
Saarela, J. 1990. Kaivosjätteiden geoteknisistä ominaisuuksista ja ympäristövaikutuksista. Helsinki: Vesi- ja ympäristöhallinnon julkaisuja, sarja A 64. 145 s.
Salminen, R. (ed.) 1995. Alueellinen geokemiallinen kartoitus Suomessa 1982-1994. Summary: Regional geochemical mapping in Finland in 1982-1994. Geologian tutkimuskeskus. Tutkimusraportti 130. Geologian tutkimuskeskus, Espoo. 47 s. 24 Appendix Maps.
Salminen, R., Heikkinen, P., Nikkarinen, M., Parkkinen, J., Sipilä, P., Suomela, P. & Wennerström, M. 2000. Ympäristövaikutusten arviointimenettelyn opas kaivoshankkeisiin. Kauppa- ja teollisuusministeriön tutkimuksia ja raportteja 20/1999. 82 s.

SFS-ISO 1996-1. Akustiikka. Ympäristömelun kuvaaminen ja mittaaminen. Perusteet ja menetelmät.
SFS-ISO 1996-2. Akustiikka. Ympäristömelun kuvaaminen ja mittaaminen. Maankäyttöä koskevien mittaustietojen hankinta.
SFS-ISO 1996-3. Akustiikka. Ympäristömelun kuvaaminen ja mittaaminen. Soveltaminen melurajoihin.
Siivola, J. 1986. Malmimineralogiaa. Julk. Papunen, H., Haapala, I., & Rouhunkoski, P. (toim.): Suomen malmigeologia. Metalliset malmiesiintymät. Suomen Geologinen Seura ry. Mäntän kirjapaino Oy. s. 13-32.
Sivonen, M & Frilander, R. 2001. Patoturvallisuuden toteutuminen Suomen jäte- ja kaivospadoilla. Suomen ympäristökeskus. Suomen ympäristö 462, ympäristönsuojelu. Helsinki. 123 s.
Slunga, E. 2004. Patojen rakentaminen ja tekniset ratkaisut erilaisilla pohjilla. Patoturvallisuuden täydennyskoulutusohjelma, luentomateriaali 19.-20.8.2004.
SMEGAC 2010. Mineral Exploration Guidelines For Saskatchewan. The Saskatchewan Mineral Exploration and Government Advisory Committee (SMEGAC). Website: http://www.saskmining.ca/uploads/news_files/16/mineral-exploration-guidelines-2010.pdf
ST 12.1. 2011. Säteilyturvallisuus luonnonsäteilylle altistavassa toiminnassa. Säteilyturvakeskus. http://www.edilex.fi/stuklex/fi/lainsaadanto/saannosto/ST12-1?toc=1
Sosiaali- ja terveysministeriö 1999. Ympäristövaikutusten arviointi. Ihmisiin kohdistuvat terveydelliset ja sosiaaliset vaikutukset. Sosiaali- ja terveysministeriön oppaita 1999:1. 51 s. http://www.stm.fi/c/document_library/get_file?folderId=122630&name=DLFE-8445.pdf. Luettu 12.3.2010.
Suomen mineraalistrategia 2010. http://www.mineraalistrategia.fi/etusivu/fi_FI/etusivu/_files/84308780946884010/default/SuomenMineraalistrategia.pdf
Suomen ympäristökeskus 2010a. Ympäristölupa-arkisto. Valtion ympäristöhallinto. http://www.ymparisto.fi/default.asp?node=1493&lan=FI. Päivitetty 26.8.2010.
Suomen ympäristökeskus 2010b. YVA-hankelista. Valtion ympäristöhallinto. http://www.ymparisto.fi/default.asp?contentid=100466&lan=fi. Päivitetty 8.1.2010. Luettu 12.3.2010.
Söderman, T. 2003. Luontoselvitykset ja luontovaikutusten arviointi – kaavoituksessa, YVA-menettelyssä ja Natura-arvioinnissa. Suomen ympäristökeskus. Ympäristöopas 109. 196 s.
TEM 2010. Suomen mineraalistrategia. Kirjapaino Keili Oy, Vantaa. 20 s. http://www.mineraalistrategia.fi/ Luettu 21.01.2010.
Tremblay, G. A. & Hogan, C. M. (Eds.). 2000. Treatment, Mine Environmental Neutral Drainage (MEND) Manual, vol. 5. MEND 5.4.2e. Energy, Mines, and Resources Canada.
Tremblay, G. A. & Hogan, C. M. 2001. Prevention and control. MEND Manual Volume 4. MEND 5.4.2d. 352 p.
Uudenmaan ELY & Ympäristöministeriö 2011. Meluntorjunnan tietojärjestelmä. Valtion ympäristöhallinto. http://www.ymparisto.fi/default.asp?contentid=269377&lan=fi&clan=fi. Luettu 15.5.2011.
Verta, M., Kauppila, T., Londesborough, S., Mannio, J., Porvari, P., Rask, M., Vuori, K.-M- & Vuorinen, P. J. 2010. Metallien taustapitoisuudet ja haitallisten aineiden seuranta Suomen pintavesissä – ehdotus laatudirektiivin toimeenpanosta. Suomen ympäristökeskuksen raportteja 12/2010. 45 s. ISBN 978-952-11-3779-2 (pdf), ISSN 1796-1726 (verkkoj.).
Vestola, E. & Mroueh, U.-M. 2008. Sulfaatinpelkistyksen hyödyntäminen happamien kaivosvesien käsittelyssä. Opas louhoskäsittelyn hallintaa. VTT tiedotteita 2422. 58 s.
Vuolio, R. 1991. Räjäytystyöt 1991. Suomen maarakentajien keskusliitto, Helsinki. 318 s.
Walton-Day, K. 2003. Passive and active treatment of mine drainage. Julk: J. L. Jambor, D. W. Blowes & A. I. M. Ritchie (Eds). Environmental aspects of mine wastes. Mineralogical Association of Canada, Short Course Series vol. 31: 335-359.
Ylitulkkila, S., Parviainen, J., Rantala, L., Tuomela, P., Kilpeläinen, E., Heikkinen, M.-L. & Sauvola, T. 2009. YARA Suomi Oy. Soklin kaivoshanke - Luonnonsuojelulain 65 §:n mukainen Natura-arviointi. Pöyry Environment Oy, Raportti 9M607220.COYL17, 26.6.2009. 79 s.
Ympäristöministeriö 1995. Ympäristömelun mittaaminen. Ympäristöministeriön ympäristönsuojeluosaston ohje 1/1995. 82 s. http://www.ymparisto.fi/download.asp?contentid=120513&lan=fi.

Appendix 1. Metal ore mines operating in Finland

1 Introduction

At the beginning of 2010 there were seven metal ore mines operating in Finland, of which four produced gold (Kittilä, Jokisivu, Orivesi, Pahtavaara) and the remaining three base metals (Kemi Mine: chrome; Talvivaara Mine: multimetal mine; Pyhäsalmi Mine: copper, zinc, pyrite). The nickel and copper mine at Hitura started up again at the end of 2010. Nickel is also produced as a side process of the Lahnaslampi talc mine. In addition to the mines currently operating, a number of new metal ore mines are being planned around the country, such as the Pampalo gold mine (operations begun 2011), the Laiva gold mine, the Kevitsa multimetal mine, the Kylylahti copper and cobalt mine and the Länttä lithium mine.

The sections that follow provide descriptions of the production at the metal ore mines that were operating in 2010, including descriptions of the relevant excavation and concentration methods being used and the ore reserves. The last section of the appendix gives a brief presentation of mining projects which were started up in 2010.

2 The Cr mine in Kemi

The Kemi chromium mine operated by Outokumpu Plc (Figure 1) is located in the municipality of Keminmaa, some 10 km from the city of Kemi. It is the only chromium mine in the European Union. The chrome ore deposit was discovered in 1959 and in 1964 Outokumpu made the decision to exploit it. Initially a pilot concentrating plant was built in conjunction with the mine to investigate concentrating methods; later a full-fledged plant was erected at the site and a ferrochrome plant was built in nearby Tornio. Production of ferrochrome was begun in 1968 from concentrate produced at the pilot concentrating plant and full-scale concentrating began in Kemi in 1969.

Figure 1. Chromium mine in Kemi. (Photo: Outokumpu Plc)

Excavation of the ore began using bench stoping in an open pit, with this accounting for the principal production of the mine until the end of 2005. Using bench stoping in the pit with a distance between levels of 12 metres, a total of 31 Mt of ore and 132 Mt of gangue were removed. The depth of the pit is 185 metres.

Construction of an underground mine began in 1999 and the mine began operation in 2003. Since the beginning of 2006 all production has come from the underground mine. The lowest level in the mine lies at a depth of 475 metres and the stope size is 25,000 tons. The excavation method is two-phase bench stoping with 25 metres between levels. The mined stopes are filled after excavation with waste rock from open pit mining and with the lump rock from the lump ore concentrating plant.

The extracted ore is transported to an ore chute and crushed with a large gyratory crusher to sizes less than 250 mm in size. After separation of iron, the crushed ore is moved into two silos dug into the bedrock. The ore is raised from the silos by skip hoisting to the preliminary crush silos on the surface and from there to the crushing plant. At the plant the ore is crushed to pieces 100 mm or smaller in size and screened.

Concentration of ore occurs in two stages using methods based on gravity separation. The stages are lump concentrating and fine concentrating. The coarser crushed ore (grain size of 10–100 mm) is concentrated at the lump concentrating plant operating in conjunction with the crushing plant and the finer ore (grain size <10 mm) is sent to the fine concentrating plant to be ground.

At the lump concentrating plant the ore is concentrated in a two-phase heavy-medium circuit in which the medium is a ferro-silicon/water mixture. The slurry density in the first phase is 3.2 kg/dm^3 and in the second 3.6 kg/dm^3. In the first stage lump rock is separated from the ore as a light product and this is returned to the mine for use as backfill. In the second stage, a lump concentrate is separated from the ore as a heavy product and placed in indoor storage facilities. The remainder (light/intermediate product) is crushed further into pieces smaller than 25 mm and moved on with the fine fraction (under 10 mm) to the fine concentrating plant. There the ore is ground using rod/ball grinding to a grain size of less than 0.7 mm.

The product of the grinding process is separated using cyclones into two grain sizes, with material under 80 microns going into the slurry circuit and that of 80–700 microns being concentrated using Reichert's cone and spiral separators whose operation is based on differences in specific gravity. The final fine concentrate is dried in a Topfeed drum filter to a moisture content of less than 4%, homogenised and stored in indoor storage facilities. The concentrate is then transported by truck to the ferrochrome plant in Tornio. The tailings slurry formed in the concentrating process is pumped into the tailings pond, with the solid matter allowed to settle and the water is conducted into settling ponds. Water that has been clarified in the settling ponds is pumped back to the concentration plant. The water in the plant is circulated in an entirely closed system.

Some 1.3 Mt of ore are mined annually and its average Cr_2O_3 content is 26.5%. The yearly production of lump concentrate is some 200,000 tons, the Cr_2O_3 content of which is 36% and of fine concentrate 400,000 tons, which has a Cr_2O_3 content of 45%. The present (2010) ore reserves of the Kemi mine are 37 Mt and mineral resources 87 Mt. Seismic studies have shown that the ore deposit extends to a depth of several kilometres, meaning that the mineral resources may prove to be much greater than originally assumed.

The mine employs 160 persons and approximately 100 other persons are employed by the contractors at the mine site. The Kemi mine is the first stage in the integrated production chain of Outokumpu Tornio Works, whose annual capacity is ca. 1.2 Mt of stainless steel.

Figure 2. Gold mine at Kittilä (Photo: Agnico-Eagle Mines Ltd.)

3
Kittilä Au mine

The Kittilä gold mine (Figure 2), owned by Agnico-Eagle Mines Ltd is located some 35 km northeast of the town of Kittilä. The first gold deposit was discovered in 1986 in the area known as Suurikuusikko, with more detailed investigations following in the period 1987-1997. The Kittilä gold mine received an environmental and water permit in 2002 and construction of the mine was begun in 2006. Excavation began at the Suurikuusikko open pit in spring 2008 and production of gold concentrate commenced in the autumn of that same year. The first doré bar was cast in January 2009.

Ore is mined along with waste rock at the open pit in Suurikuusikko in 7.5 metre benches by blasting in situ and the ore and waste rock are separated in the loading phase. The pit will eventually be 160 m deep. Some 3,000 tons of ore are fed to the concentrating plant daily. An underground mine is being prepared for production as open pit operations proceed and is scheduled to begin in 2010. The method used underground will be bench stoping. The stopes will be 25–40 metres high, and the average stope size 10,000 tons of ore. After loading, the mined out stopes will be filled with a hardening fill, making it possible to mine the adjacent ore effectively and safely.

Ore is transported from the mine to the concentrating plant and crushed with a jaw crusher. The crushed ore is moved by conveyor into an intermediate silo, from where it is taken further to be ground. The ore is ground in a semiautogenous grinder and the finely ground ore continues on to the flotation circuit, where flotation takes place in two stages. In the first stage organic carbon is removed from the slurry concentrate by flotation. In the second gold-bearing sulphide minerals are recovered. After flotation the slurry is oxidised in an autoclave at a temperature of 190°C under a pressure of 1900 kPa. Thereafter, the oxidised concentrate is processed in the gold leaching circuit. The concentrate spends 24 hours in six leaching tanks (CIL tank), in which the gold is separated. The dissolved gold is recovered using active carbon. The active carbon containing gold is stripped, that is, the gold is extracted back into a solution, from which it is precipitated by electrowinning. The precipitated gold is melted and cast into doré bars. The bars are then sent to an outside company for further refining, after which the gold content of the product is 99.99%.

The tailings produced in the concentrating process are stored in water-tight tailings ponds. In practice the amount of tailings is the same as the amount of ore delivered to the concentrating plant, since only gold is separated from the ore. The waste rock excavated along with the ore is piled at the mine site in the waste rock storage area.

The gold deposit at Suurikuusikko is located in the middle section of the Central Lapland greenstone belt and is the largest known gold deposit in northern Europe. The proven ore reserves are 21.4 Mt and the average gold content of the deposit is 4.7 g/t. Of the total gold, 75% is bound at the atomic level to the lattices of arsenopyrite and 23% to arsenic-bearing pyrite. Only 2% of total gold is free gold. The anticipated annual production of gold at the mine is 5000 kg.

4
Pyhäsalmi Mine Zn-Cu-S

The Pyhäsalmi Zn-Cu-S Mine (Figure 3) is located in Pyhäjärvi. The ore was discovered in 1958 and in the spring of 1959 Outokumpu Oy made the decision to open a mine. The mine began operations in 1962 and in 2002 was acquired by its present owner, Inmet Mining Corporation.

Ore was initially mined in an open pit. Underground mining began alongside open pit operations in 1967, and in 1975 mining took place exclusively underground. At this writing, excavation is proceeding in its entirety below the +1050 level, with the deepest production level being +1410. Ore is mined using sub-level and bench stoping. The height of the stopes is 25–50 m and width 15–25 m. Tunnels are reinforced using bolts and injected concrete and the stopes are cable bolted. Empty stopes are filled with waste rock and the fill is hardened with a mixture of tailings, slag, fly ash and concrete.

Figure 3. The Pyhäsalmi mine (Photo: Pyhäsalmi Mine Oy)

The loosened ore is crushed using a jaw crusher in a single stage in an underground crushing plant, from which the ore is hoisted through a mine tower to the surface and into a rock silo. The ore is screened in the tower into three grain sizes and transported on from the silo by conveyor to silos at the concentrating plant. At the plant the ore is ground using what is known as semiautogenous grinding, in which fine and coarse ore are ground together. The ore is concentrated by flotation to yield copper concentrate, zinc concentrate and pyrite concentrate in three stages. Excess water is removed from the concentrates by thickening and filtration, after which the concentrates are stored at the mine site for transportation. The copper and zinc concentrates are transported by rail to domestic smelters and the pyrite concentrate is sold on both domestic and international markets.

The coarsest material is separated from the tailings that form during concentration and used as mine fill, and finer material is pumped as a slurry into the tailings pond. In the tailings pond, the process water is neutralised and solids are allowed to settle out. The clarified water is conducted into the Pyhäjärvi watercourse.

The amount of ore mined at Pyhäsalmi yearly is some 1.4 Mt, with production being 13,400 t of copper, 31,300 t of zinc and 420,000 t of pyrite (2009). The ore deposit is a massive Zn-Cu-pyrite deposit that contains some 75% sulphide minerals. In December 2009 the ore reserves at the mine were 11.8 Mt, comprising 1.1% Cu, 2.2% Zn, 41% S, 0.4 g/t Au and 14 g/t Ag. With its present resources the mine is anticipated as operating until the year 2018. The mine provides work for a total of 218 employees and 53 contractors.

5 Talvivaara multimetal mine

The mine operated by Talvivaara Sotkamo Oy is located some 30 km southeast of the centre of the city of Kajaani and 25 km southwest of the centre of the municipality of Sotkamo. The ore deposits of Kuusilampi and Kolmisoppi as well as the metal recovery plant lie entirely within the municipality of Sotkamo. The western part of the mining concession is located within the city limits of the city of Kajaani.

Ore prospecting has been carried out in the southern Sotkamo area by various companies since the 1930s. Suomen Malmi Oy discovered the first nickel-bearing samples in the Talvivaara area in the early 1960s and the Geological Survey of Finland located the Kolmisoppi deposit in 1977 and the Kuusilampi deposit in 1978. Outokumpu conducted ore investigations between 1989 and 1992 and Talvivaara continued them starting in 2004. The Talvivaara mine received an environmental and water permit in March 2007 and construction of the mine began in April of that year. Excavation of ore from the open pit in Kuusilampi was begun in spring 2008 and piling of ore in the primary heap in summer 2008; the first precipitation of concentrate was carried out in autumn 2008.

Ore is mined using bench stoping with a distance between levels of 15 metres. It is anticipated that starting in 2011 24 Mt of ore and the same quantity of waste rock will be mined. The estimated width of the pit is 1,500 m, length 3,500 m and depth 500 m.

Mined ore is transported by truck to a coarse grinding plant, where the ore is ground to pieces less than 250 mm in size. The ore is then moved via the Kuusilampi conveyor to the intermediate ore storage facility, from where it goes on to the fine grinding plants and the screening plant. After fine grinding, the ore material is less than 8 mm in grain size. Thereafter the ore material is processed at the agglomeration station with a solution in order to fix the fine material to the surface of the grains before piling. The ore is piled on the primary heap field in four piles, each of which is 400 metres wide, 1,200 metres long and some 8 metres high (Figure 4).

Figure 4. Plant area of the Talvivaara mine and primary heap field for ore concentrating (Photo: Talvivaara Sotkamo Oy)

The ores is concentrated through bioheapleaching. Each primary heap is irrigated with a leach solution which circulates through the heap. The dissolution of metals is enhanced not only by irrigation but by aerating the pile through the base. When the metal content of the leach solution is sufficient, some of it is channelled to the metal recovery facility. In the recovery of metals, copper, zinc and nickel-cobalt are precipitated out of the solution as sulphides. The remaining leachate is purified and returned for irrigating the heap. The gypsum and iron precipitate that forms in purifying the leachate are piped into the gypsum waste pond.

The heaps in the primary field are irrigated for some 1.5 years, after which they are dismantled and the leached ore material is transported by conveyor to the secondary heap. There the final leaching of the ore is carried out, which lasts some 3.5 years. The secondary heap is also the final disposal site for the ore. The secondary heap will be 1,500 m wide, 2,500 m long and some 60–70 m high.

The ore material at the Talvivaara mine contains uranium in trace element concentrations. The concentration of uranium in the leachate is some 25 mg/l. Talvivaara is planning recovery of uranium from the leachate using an extraction method. The uranium recovery plant will operate as a permanent part of the production process. Uranium will be extracted from the process solution between the zinc sulphide and nickel-cobalt sulphide precipitation stages. The extraction process recovers more than 90% of the uranium in the feed solution. The final product is uranium peroxide, which is produced to yellow cake grade. The production of uranium peroxide will yield some 350–500 tons per year.

6
The gold mines of Dragon Mining Oy

Dragon Mining Oy (formerly Polar Mining Oy) mines gold at Jokisivu and Orivesi. Ores from both mines are transported to the company's concentration plant in Sastamala (i.e. Vammala production centre).

6.1
The Orivesi gold mine

The Orivesi gold mine is located in the municipality of Orivesi near the city of Tampere. A gold mineralisation was discovered in the area in 1982 and Outokumpu Oy mined gold ore during the period 1994–2003. The mine was acquired by Dragon Mining Oy in 2003 and mining of gold ore from the Kutemajärvi deposit was begun again in 2007, which is part of the Sarvisuo deposit, which was discovered outside the previously mined area. The ore deposit at Kutemajärvi consists of several vertical ore pipes which have been mined to a depth of 720 metres; some of the pipes extend to depths of over 1000 metres.

Ore is mined from an underground mine using bench stoping and all mined out spaces are filled with waste rock from the mine. Production is some 200,000 t/a. The ore is transported as boulders by trailer trucks to be crushed and concentrated at the Sastamala concentrating plant.

6.2
The Jokisivu gold mine

The Jokisivu mine is located in Jokisivu, some 8 km southwest of the centre of the town of Huittinen. The first indications of an ore deposit were found in 1964 and subsequent investigations carried out in several stages mining of ore were begun by Polar Mining Oy at the Kujankallio open pit in 2009. The application for an environmental permit was filed in 2003 and the final decision was obtained from the Supreme Administrative Court in the end of 2007.

Figure 5. Open pit at Kujankallio in Jokisivu (Photo: Dragon Mining Oy)

Some 100,000 tons of ore will be mined from the open pit at Kujankallio, after which it will be 45 metres deep, 400 metres long and 100 m wide. Ore is mined in 5 m benches (Figure 5) and transported as boulders by trailer-truck to the Sastamala concentrating plant to be crushed and concentrated. An underground mine has been planned for the area below the open pit and a deposit known as the Arpola deposit has been identified in the area, where plans call for opening a smaller open pit later. The environmental permit for Jokisivu requires that the Kujankallio and Arpola deposits be mined at different times.

The gold deposit at Jokisivu consists of narrow quartz veins surrounded by gneisses and vulcanites. The known ore reserves at the deposit are 1.3 Mt, with a gold content of 6 g/t on average. The gold occurs primarily as free gold in the quartz vein zones but some of it occurs also as arsenopyrite inclusions.

6.3
Crushing and concentrating of gold ores at the Sastamala concentrating plant

The gold ores mined at Jokisivu and Orivesi are crushed at the Sastamala concentrating plant in three stages using jaw, gyratory and cone crushers. The crushed ore is screened and 20 mm crush is transferred by conveyor to an intermediate silo, from which it is fed using drum feeders to be ground. Grinding is begun using a rod mill, after which the coarser grain size is separated from the Jokisivu ore using a cyclone classifier and the fines are conducted directly to flotation. The material heavier as to its specific weight is further separated from the coarser grain size using a Reichert cone into a separate gravity circuit and the remaining material is returned via ball mill grinding to flotation. The gravity circuit consists of the Reichert cone as well as spiral classifiers and a shaking table. The concentrate separated in flotation is clarified using a thickener and water is removed using a pressure filter. The concentration process uses few chemicals, as flotation takes place at the natural pH of the ore.

The gold content of the flotation concentrate is 200 g/t Au and clean concentrate from the shaking table is about 90% Au. Gravity concentrate cannot be produced from the ore at Orivesi, whereby the ore is concentrated using flotation only.

The precious metals recovered from the gold ore in concentrating represent some 5% of the ore fed into the concentration process. The residual material from concentrating, the tailings, is pumped as a slurry into the tailings area, in which water is separated from the slurry by settling. The clarified water is returned to the concentrating plant to be used in the process. Additional water is obtained as needed from the closed Storm nickel mine, to which excess water is also returned.

7
Ni production at the Lahnaslampi talc mine

The Lahnaslampi talc mine owned by Mondo Minerals (Figure 6) is located in the municipality of Sotkamo some 20 km from the town centre. The mine and adjacent concentrating plant and fine grinding facility comprise one of the world's largest talc production units. The deposit was known already in the early 1900s and work towards exploiting it began in the 1950s. Mining activities in the Lahnaslampi mining concession began in 1968 and production in 1969. Nickel has been concentrated as a by-product of talc at Lahnaslampi since 1974. Some 0.5 Mt of ore is mined annually.

The ore is mined in an open pit with the present distance between levels being 20 metres. Production at the Lahnaslampi mine will end in 2010 and will continue at the Punasuo open pit, which is located less than a kilometre south of Lahnaslampi and is part of the same formation. When mining ceases at Lahnaslampi, the open pit will be filled with tailings and waste rock from Punasuo. Somewhat less than 18 Mt

Figure 6. The Lahnaslampi talc mine and talc production unit in Sotkamo. (Photo: Mondo Minerals B.V. Branch Finland)

of ore and 32 Mt of waste rock will eventually be mined at Lahnaslampi. The depth of the pit is 180 metres.

The ore mined is brought to a primary crushing plant, where it is crushed to pieces smaller than 200 mm. Ore is then moved from the primary crushing plant by conveyors through a screen to an intermediate storage facility. The crushed ore is then moved from the intermediate storage facility on a conveyor to the secondary plant, where it is crushed further using a gyratory crusher to a grain size of less than 25 mm. The crushed ore is then ground to flotation fineness (grain size of less than 0.1 mm) in a water slurry using ball mills with steel grinding balls. The ground talc ore is separated for feeding into the flotation process with cyclones and the coarser underflow in the cyclones is returned to be ground again.

The ground ore is concentrated by flotation in several stages. In primary flotation the residue from the ground ore (magnesite sand and Ni sulphides) is pumped into nickel flotation and the separated rougher talc concentrate is pumped through cleaner flotations to a thickener. The end product of the process of concentrating talc ore (talc content 45–55%) is talc concentrate, the talc content of which is 96–98%. After thickening, the concentrate is filtered and dried and sent to the microtalc plant to be further refined.

The nickel concentrate is separated from the residue of the rougher flotation of the talc ore in multistage flotation. The nickel concentrate obtained is filtered using a disk filter and placed in storage. The concentration residue is pumped into the tailings ponds. The nickel concentrate is delivered to customers in the form of a wet concentrate. The nickel content of the concentrate is 8% on average, and the sulphur content 32%.

The tailings consist primarily of magnesite and are piled in tailings ponds on the eastern side of the plant area. The water clarified from the tailings ponds is piped back to the concentrating plant to be used as process water. Waste rock produced in mining is piled in a dedicated area. They consist for the most part of black schist, mica schist and poor-quality talc ore. The seepage from the waste rock storage area is collected and treated before being discharged further.

8 Pahtavaara Au mine

Lappland Goldminers AB began mining gold ore from the Pahtavaara deposit in Sodankylä at the end of 2008 (Figure 7). Continuous production at the Pahtavaara concentration plant was begun in April 2009 (Lappland Gold Miners AB 2010). The Pahtavaara gold deposit was discovered in 1985 and has been previously exploited by Terra Mining Oy (1996–2000) and Scan Mining Oy (2003–2007).

Ore is mined from an underground mine using bench stoping and is concentrated at the Pahtavaara concentration plant. The capacity of the plant is about 1,500 t of raw ore a day. For concentrating ore is crushed using a jaw crusher to pieces less than 200 mm in size and transported by conveyor via an intermediate storage facility to be ground. The ore is ground autogenously in a wet process to a grain size of 1.5 mm. The heavier fraction from grinding is conducted through a classification cyclone to gravity separation and the lighter fraction goes to flotation.

The gravity concentration circuit consists of a Reichert cone, a magnetic separator, spirals and a shaking table. Magnetic material is removed with magnetic separators from the heavier fraction separated using the Reichert cone, after which the non-magnetic material is divided with spirals into heavy and light fractions. The heavy fraction is moved on to the shaking table, where the GM (gravity middling) gold concentrate is separated from it by cleaner concentration. The lighter fraction is returned through a dewatering cyclone back to grinding and the gravity circuit again (Environmental Permit Authority of Northern Finland 2006, Lappland Goldminers AB 2010).

Figure 7. The Pahtavaara gold mine in Sodankylä (Photo: Lappland Goldminers AB)

The flotation circuit for the lighter fraction obtained from cyclone separation consists of primary flotation, scavenger flotation and washing of the concentrate. The washed concentrate slurry (flotation concentrate) is dried further using a thickener and a filter. The tailings formed in flotation are pumped as water slurry into the tailings pond (Environmental Permit Authority of Northern Finland 2006, Lappland Goldminers AB 2010).

Annual production at the Pahtavaara mine was some 600 kg of gold in 2009, and in 2010, when production was continuous, production had risen to 740 kg. At the beginning of 2011, the ore reserves at Pahtavaara were 577,000 t, with some 2.74 g/t of gold (Lappland Goldminers AB 2011).

9 Hitura nickel and copper mine

The Hitura nickel and copper mine is located in central Ostrobothnia some 130 kilometres south of Oulu and 12 kilometres southeast of the centre of the town of Nivala. The mine began working in 1969, operated by Outokumpu Oy. In 1990 the mining rights were transferred to Outokumpu Finnmines Oy, in 2007 to Hitura Mining Oy, and in 2008 to Finn Nickel Oy. The mine was closed from 2009 to 2010, when operation was resumed by Belvedere Mining Oy (Regional State Administrative Agency for Northern Finland 2010).

At the beginning of 2008, according to an internal estimate by the mine the ore reserves at Hitura were 2.35 Mt, with a nickel content of 0.62%. Potentially exploitable resources are 1.45 Mt with a nickel content of 0.69%.

At the Hitura mine, nickel-bearing sulphide ore is mined and concentrated. The mine is prepared to concentrate ore brought in from elsewhere. The production capacity of the mine is 620,000 t/a and plans call for raising this to 1 Mt a year in 2012 at the earliest. The ore yields nickel-copper concentrate amounting to some 4–8% of the processed ore. The residue is tailings, which are disposed of in the tailings area. Nickel-copper concentrate consists of pentlandite, chalcopyrite, pyrrhotite and silicates. The amount of concentrate produced is 30,000–35,000 t/a, with a nickel content of 2,200–3,000 t. The tailings produced total some 650,000 t/a (Regional State Administrative Agency for Northern Finland 2010).

Mining of the ore began as open-pit mining. In 1991, operations went underground. An access tunnel from the edge of the open pit, from the 40 m level, leads into the underground spaces and it is through this tunnel that mine traffic flows. The tunnel bifurcates into tunnels leading to the eastern and western parts of the ore deposit. The stages in mining the ore are drilling, loosening of rock by blasting, loading and removal of loosened rock, and support of the mined out spaces. Key aspects of the work are ventilation of underground spaces and removal of rain and groundwater flowing into the mine. Ore loosened by blasting, as well as waste rock, is placed onto trucks by loaders, brought to a crushing plant on the surface or stored temporarily on the field near the crushing plant. Waste rock is moved into different parts of the underground mine to be used as mine fill or brought to level +40 of the open pit, where it is dumped as fill for the pit (Regional State Administrative Agency for Northern Finland 2010).

The stages in ore concentration are crushing, grinding, flotation and dewatering, storage and loading. The concentration processes take place under normal pressure and temperature in numerous stages. The moisture content of the end product, the nickel-copper concentrate, is 10% and the concentrate is delivered to customers in trucks. Operations of the concentration plant include acquisition of process and raw water, as well as the manufacture and feeding of process chemicals (Regional State Administrative Agency for Northern Finland 2010).

10
Mining projects at the start-up stage

In 2010, in addition to the metal ore mines described above, Finland had two gold mines (Pampalo and Laiva), two multimetal mines (Kylylahti, Kevitsa) and one lithium mine (Länttä) that were starting operations. Below are brief descriptions of their activities. In addition, there were a number of mining projects at different stages of planning and implementation, for example the Hannukainen iron-copper-gold mine project of Northland Resources AB in Hannukainen, the Suhanko palladium, platinum project of Gold Fields Arctic Platinun Oy (Kilvenjärvi Mining concession), exploitation of the Hautalampi nickel-copper-cobalt deposit by Altona Mining Ltd, the vanadium mining project of Adriana Resources Inc. in Mustavaara and the silver mine project of Silver Resources Oy in Sotkamo.

Gold mines

The *Laivakangas* gold deposit was discovered near the city of Raahe in 1980. Nordic Mines AB has carried out targeted gold prospecting in the area since 2005. The feasibility study completed at the beginning of 2010 indicated that the ore reserves of the Laiva deposit totalled 11.7 Mt, making it one of the largest gold deposits in the Nordic countries. It is estimated that gold production will begin in the area in 2011 (Nordic Mines 2010). The mine will be implemented as an open pit mine, from which an estimated 2 Mt of ore will be mined annually. The gold content of the estimated ore reserves is 2.09–2.4 g/t. The amount of B-ore (ore whose gold content is some 0.6 g/t) to be mined annually is 750,000 t. The production process at the Laivakangas mine will comprise the following main stages: excavation, crushing using a jaw crusher, two-stage grinding, flotation, gravity separation, cyanide concentration and processing of tailings (Environmental Permit Authority of Northern Finland 2009).

The *Pampalo* gold deposit in Ilomantsi was discovered in 1990. The deposit has been in the possession of Endomines Ab since 2006 and the company received an environmental permit for mining activities in 2008. Production of gold began in full scale in spring 2011. The amount of ore to be mined from the underground mine is some 200,000 t/a. Processing of the ore will comprise crushing, grinding, and concentration using gravity separation (coarse fraction) and flotation (fine fraction) (Environmental Permit Authority of Eastern Finland 2008). The estimated ore reserves are 1.3 Mt; and their gold content 4.1–6.1 g/t (Endomines 2010).

Multimetal mines

The Ni-Cu ore deposit at *Kevitsa* in Sodankylä was discovered in 1985. It contains not only nickel and copper but also gold, cobalt and platinum group metals. The mine is owned by First Quantum Mineral Ltd, which made a decision in 2009 to open the mine. Construction of the mine began in spring 2010 and production will begin in 2012. Ore will be excavated at the open pit at the rate of some 5 Mt/a. It will be concentrated at the mine site after crushing and grinding using selective flotation, in which copper concentrate is separated first and nickel concentrate thereafter. The estimated production quantities are 85,000 t/a for nickel concentrate and 55,000 t/a for copper concentrate. The estimated mineral resources at the mine at the end of 2009 were some 165 Mt, with a nickel content of 0.30% and a copper content of 0.27%. The lifespan of the mine has been estimated at 20 years (FQML 2009).

The *Kylylahti* multimetal deposit of Altona Mining Ltd is located in Polvijärvi. It was discovered in 1984 and the mine will begin operations in the beginning of 2012. Mining will take place underground and the ore will be transported to the concentrating plant in Luikonlahti. The concentration method used will be flotation. The estimated ore reserves of the deposit are 8.4 Mt, containing 1.25% Cu, 0.24% Co, 0.20% Ni, 0.54% Zn and 0.68 g/t Au. Altona Mining Ltd. also has a mining concession in Outokumpu with the rights to the Hautalampi Ni-Cu-Co deposit, exploitation of which is at the permitting stage. In addition, Altona Mining Ltd is currently investigating the possibilities to exploit the nickel deposits (Valkeisenranta, Särkiniemi) in the Kotalahti area.

Lithium mine

Keliber Oy intends to start up the mining and production of lithium in the near future at the Länttä spodumene pegmatite deposit located in Ullava in Kokkola. The deposit was discovered in the beginning of the 1960s. The mining concession was acquired by Keliber Oy in 1999 (previously Keliber Resources Ltd Oy). An environmental permit for the activities was received in 2006 (Environmental Permit Authority of Western Finland 2006b). Mining will begin as open-pit mining, possibly proceeding to underground mining later. The annual amount excavated is estimated to be some 125,000-200,000 t. The ore will be transported as blasted rock, crushed at a primary crusher, or as crushed rock to be concentrated in Kaustinen, where lithium will be separated from spodumene using heating (altering the crystal structure) and pressure leaching and then precipitated into a carbonate (Environmental Permit Authority of Western Finland 2006a, 2006b, Keliber Oy 2010). In addition to lithium carbonate the Länttä deposit will produce niobium and tantalum concentrate, quartz feldspar concentrate, crushed rock and possibly also sodium zeolite (analcime). The estimated reserves at the Länttä deposit are some 3 Mt, containing 0.92% by weight Li_2O, 79 ppm Ta_2O_5 and 80.3% by weight quartz-feldspar mix (Keliber 0y 2010). Keliber Oy has a number of other lithium claims near the Länttä deposit, for example Emmes and Jänislampi, exploitation of which the company is presently investigating.

Sources

Endomines 2010. Pampalo. http://www.endomines.com/pampalo.php. Read 19.5.2010.

Environmental Permit Authority of Eastern Finland 2008. Pampalon kultakaivosta ja rikastamoa koskeva ympäristölupa ja Lietojanlammen padon vahvistaminen. Itä-Suomen ympäristölupavirasto. Päätös Nro 23/08/2, Dnro ISY-2004-Y-271. 21.2.2008.

Environmental Permit Authority of Northern Finland 2006. Pahtavaaran kultakaivoksen ympäristölupa sekä vesilain mukainen lupa, Sodankylä. Pohjois-Suomen ympäristölupavirasto. Lupapäätös Nro 68/06/1, Dnro PSY-2003-Y-194. 4.7.2006.

Environmental Permit Authority of Northern Finland 2009. Laivakankaan kaivoksen ympäristö- ja vesitalouslupa sekä töiden- ja toiminnanaloittamislupa, Raahe. Pohjois-Suomen ympäristölupavirasto. Lupapäätös Nro 84/09/2, Dnro Psy-2007-y-160. 24.11.2009.

Environmental Permit Authority of Western Finland 2006a. Keliber Resources Ltd Oy:n Kaustisen Kalaveden litiumin tuotantolaitosta koskeva ympäristönsuojelulain mukainen ympäristölupahakemus. Lupapäätös Nro 35/2006/2, Dnro LSY-2005-Y-122. 30.11.2006.

Environmental Permit Authority of Western Finland 2006b. Keliber Resources Ltd Oy:n Ullavan Läntän litiumkaivoksen toimintaa koskeva ympäristönsuojelulain mukainen ympäristölupahakemus sekä ympäristönsuojelulain 101 §:ssä tarkoitettu hakemus päätöksen täytääntöönpanosta muutoksenahausta huolimatta. Länsi-Suomen ympäristölupavirasto. Lupapäätös Nro 31/2006/2, Dnro LSY-2005-Y-123. 7.11.2006.

FQML 2009. Kevitsan monimetallikaivos. 14.12.2009. http://kaivos-fi-bin.directo.fi/@Bin/a6a966cddb-389498cead8eeee07482a4/1274270840/application/vnd.ms-powerpoint/111538/Kevitsa_perusesitys_fi_141209.pps#471,1,Slide 1. Read 19.5.2010.

Keliber Oy 2010. Keliber – Nordic Mining group. http://www.keliber.no/. Read 16.6.2010.

Lappland Goldminers AB 2010. http://www.lapplandgoldminers.se/ Read 17.6.2010.

Lappland Goldminers AB 2011. Mineral Resource and Ore Reserve at Pahtavaara 01.01.2011. http://www.lapplandgoldminers.se/Gismo/files/1170/pressrelease/mineral_resource_and_ore_reserve_at_pahtavaara_20110101.pdf Read 8.7.2011.

Nordic Mines 2010. http://www.nordicmines.se/en/nordic-mines/1261344-finish-page-2-b#Laiva 1b. Read 19.5.2010.

Regional State Administrative Agency for Northern Finland 2010 2010. Hituran kaivoksen ympäristö- ja vesitalouslupa sekä toiminnanaloittamislupa, Nivala. Pohjois-Suomen aluehallintovirasto, Ympäristöluvat. Lupapäätös Nro 66/10/1, Dnro PSAVI/3/04.08/2010. 13.8.2010.

Appendix 2. REACH

1
REACH procedures

REACH requires that manufacturers or importers of chemicals (who handle quantities of one ton or more per year) obtain information on the physico-chemical and health properties of the chemicals as well as on the properties of the substances impacting the environment and determine on the basis of this information how the substances can be used safely. Every manufacturer and importer must submit registration documents to the European Chemicals Agency documenting the information and estimates. The Chemicals Agency evaluates the documents in order to assess the testing suggestions of the registrant or ascertains that the registration documents are in keeping with the requirements. In addition the Agency coordinates evaluation of the substance which the member states carry out in order to investigate problematic chemicals.

A permit is required for primary substances that cause particular concern. A company seeking a permit must demonstrate that the risks associated with the use of these substances are appropriately managed or that the socioeconomic benefits to be realised from use of the substances are greater than the risks. The applicant must also investigate the possibility to replace these substances with safer alternatives or technologies and if necessary draw up a plan for this purpose.

The European Union may impose restrictions or conditions on the manufacture, placing on the market or use of certain hazardous substances or groups of substances or it may prohibit them altogether when risks to people or the environment are identified that cannot be accepted.

Suppliers of the substances must notify downstream users (through a safety data sheet or by other means) of properties of the substances that affect health, safety and environmental considerations. Downstream users may use substances that have been classified as hazardous or substances which are persistent, bioaccumulative and toxic (PBT and vPvB) only if they apply the risk management measures which are specified on the basis of the exposure scenarios applying to use of the substances.

2
Chemicals falling under the scope of the Regulation

REACH applies to the manufacture, placing on the market and use of substances as such, in mixtures or articles as well as to the placing on the market of mixtures. The Regulation adheres to a substance-based approach: the obligations do not apply directly to mixtures and articles but to the substances they contain (with the exception of requirements pertaining to safety data sheets and exposure scenarios, which are also applied to mixtures).

REACH is applied to all substances with a few exceptions. It does not apply to radioactive substances, substances under customs supervision, the transportation of substances or non-isolated intermediate substances. In addition, wastes are expressly excluded from the scope of the Regulation. A number of other substances are partially exempted from the scope of the provisions in REACH, as other legislation is applicable (for example the substances used in medicines).

Polymers are exempt from the registration obligation for the time being.

Special provisions are applied to substances used in research and development and to the registration of isolated intermediate substances.

3 Methods and tools

Application of the REACH procedures requires the use of a number of tools and methods. Some of these existed before the Regulation was adopted; some have been developed in order to apply the instrument.

- A chemical safety evaluation must be performed for all substances which are manufactured or imported in quantities greater than 10 tons per year in order to be able to define and demonstrate the safe use of the substance.
- Exposure scenarios are used to assess exposure of people and the environment to chemicals and to specify the appropriate risk management measures.
- The classification and labelling of substances encompass the evaluation of the hazards associated with the substance or mixture and notification of the hazards through labelling. Classification of a chemical entails certain obligations, such as an obligation to provide a safety data sheet to downstream users of the chemical.
- Using documentary materials as described in Annex XV of the Regulation the authorities (of member states and the Chemicals Agency) may make proposals regarding the possible inclusion of a substance in the list of substances subject to a permit, suggest restrictions and make proposals to harmonise classification and labelling.

A number of computerised tools have been developed in order to support the REACH procedures and to record and exchange the information regarding chemicals: REACH-IT, IUCLID5 and the webpages of the Chemicals Agency.

4 Actors

Three types of actors participate in the REACH procedures: industry, authorities and third parties. Industry actors can be divided into the following groups: manufacturers of the substances, producers of articles, importers, downstream users and distributors. The authorities having obligations and rights in the REACH procedures are the Chemicals Agency (established especially for application of the Regulation), competent authorities of the member states, and the European Commission. Authorities implement the evaluation, permit and restriction procedures mandated by REACH. In addition, the Chemicals Agency and the member states provide guidance services. Member states are responsible for supervising the implementation of REACH.

Third parties in the meaning of REACH are private and public organisations (such as private individuals, civic organisations, enterprises which provide information for documentary materials that do not directly apply to them, international organisations and non-EU countries). Third parties do not have obligations under REACH but they can provide the Chemicals Agency with information on substances and take part in an information exchange forum.

Additional information on REACH can be found at:
http://guidance.echa.europa.eu/about_reach_fi.htm
http://www.chemind.fi/REACH
http://ec.europa.eu/echa/home_en.html
http://reach.startpagina.nl/
http://www.reachcentrum.eu/EN/home.aspx
http://www.reachcentrum.eu/legislation-reports.htm

Appendix 3. Chemical formulae of the minerals presented in Tables 15 and 16

Ore minerals	Formula	Ore minerals	Formula
Pyrrhotite	$Fe_{1-x}S$	Pentlandite	$(Fe,Ni)_9S_8$
Chalcopyrite	$CuFeS_2$	Co- pentlandite	$(Co,Ni,Fe)_9S_8$
Pyrite	FeS_2	Mackinawite	$(Fe,Ni,Co)_{1+x}S$
Sphalerite	(Zn,Fe)S	Arsenopyrite	FeAsS
Magnetite	Fe_3O_4	Chromite	$FeCr_2O_4$
Ilmenite	$FeTiO_3$	Millerite	NiS
Galenite	PbS	Marcasite	FeS_2

Gangue minerals	Mineral formula	Gangue minerals	Mineral formula
Quartz	SiO_2	Magnesite	$MgCO_3$
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$	Dolomite	$CaMg(CO_3)_2$
Sericite	$KAl_2(AlSi_3)O_{10}(OH,F)$	Tremolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Calcite	$CaCO_3$	Cr-garnet (Uvarovite)	$Ca_3Cr_2(SiO_4)_3$
Siderite	$FeCO_3$	Phlogopite	$KMg_3AlSi_3O_{10}(OH)_2$
Hornblende	$Ca_2(Fe,Mg)_4Al(Si_7Al)O_{22}(OH,F)_2$	Diopside	$CaMgSi_2O_6$
Plagioclase	$(Na,Ca)(Si,Al)_4O_8$	Scapolite	$(Na,Ca)_4(Al_3Si_9O_{24})Cl$
Orthoclase / Potassium feldspar	$KAlSi_3O_8$	Andradite	$Ca_3Fe_2(SiO_4)_3$
Talc	$Mg_3Si_4O_{10}(OH)_2$	Epidote	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$
Graphite	C	Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$
Serpentine	$(Mg,Fe)_3Si_2O_5(OH)_4$	Goethite	α-$Fe^{3+}O(OH)$
Tourmaline	$(Na,Ca)(Mg,Fe^{2+},Fe^{3+},Al,Mn,Li)_3Al_6(BO_3)_3(Si_6O_{18})(OH,F)_4$	Limonite	$FeO(OH)\cdot nH_2O$
Biotite	$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$		

Appendix 4. Example of the contents of a baseline study

1 Introduction

1.1 Location and general description of the area

1.2 Operations planned for the area

2 Field investigations and laboratory analyses

Description of the research methods and data used

3 Baseline of the area

3.1 Climate

3.2 Landscape, topography and land use of the area

E.g. infrastructure, planning, traffic, exploitation of natural resources

3.3 Socio-economic factors (population, employment, etc.)

3.4 Natural landscape, nature and forest types, flora and fauna

In particular the presence of threatened, protected and rare species

3.5 Conservation areas and sites and the bases for their conservation status

3.6 Geology of the area and geochemical baseline

3.6.1 Bedrock
Rock types, fissuring, fractures, geochemistry

3.6.2 Soil
Soil types, stratigraphy of the soil, hydrogeological information, background concentrations

3.6.3 Stream/lake sediments, mosses
Geochemical background concentrations

3.7 Waters in the area and their quality

3.7.1 Delineation of the catchment area(s)

3.7.2 Surface waters
Locations, heights of water levels, flow directions, discharges and quality of water
Use of watercourse in the area

3.7.3 Groundwater
Levels, flow directions, discharges and quality of water, sources

3.7.4 Location of the area relative to classified aquifers/groundwater areas and water usage in the area

3.8 Air quality

4 Large-scale materials formed in operations and their environmental acceptability

4.1 Overburden removed

4.2 Waste rock

4.3 Tailings

5 Recommendation/proposals for the location of operations in the area

6 Summary

Appendix 5. Example of a Natura assessment

A Natura assessment includes a description of the following:

- the planned project and related measures, described in detail,
- the natural values of the Natura 2000 site, for whose protection the area has been included in the Natura 2000 network
- the connections between the project and other projects
- delineation of the area that the area of operation of the project will affect and its relation to the Natura 2000 site
- methods and assessment used in the impact assessment
- habitat and species-specific assessment of the impacts on and significance of measures for the conservation objectives of the Natura area and the Natura area as a whole before and after measures taken to mitigate impacts
- measures to mitigate impacts
- possible alternatives for the operations
- evaluation of the uncertainties of the assessment, and
- follow-up measures to determine impacts (cf. Söderman 2003, Idman & Kahra 2007, TEM 2007, Ympäristöministeriö 2007).

References

EC 2001. Assessment of plans and projects significantly affecting Natura 2000 sites. Methodological guidance on the provisions of Article 6(3) and (4) of the Habitats Directive 92/43/EEC. European Commission, Environment DG. European Communities 2002. http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/natura_2000_assess_en.pdf. Read 19.3.2010.

Idman, H. & Kahra, A. (Eds) 2007. Malminetsintä ja kaivostoiminta suojelualueilla sekä saamelaisten kotiseutualueella ja poronhoitoalueella: opas. KTM julkaisuja 28/2007. 86 p.

Söderman, T. 2003. Luontoselvitykset ja luontovaikutusten arviointi – kaavoituksessa, YVA-menettelyssä ja Natura-arvioinnissa. Suomen ympäristökeskus. Ympäristöopas 109. 196 p.

TEM 2007. Natura-alueen huomioon otto valtaushakemuksissa. www.tem.fi/files/17153/Namura_paatos.pdf Read 30.11.2011.

Ympäristöministeriö 2007. Ympäristöasiat kaivoshankkeissa ja kansalaisten vaikutusmahdollisuudet. http://www.ymparisto.fi/default.asp?node=20631&lan=fi. Updated 23.3.2007. Read 10.3.2010.

Appendix 6. Sampling and characterisation of mine wastes

1

Sampling and pre-treatment of samples

The choice of sampling method in the case of mine wastes is guided by how representative the sample is of each waste type and the requirements of the method of analysis where minimum size and pre-treatment are concerned. The sampling method for different waste types may vary in the early stage of mining activities, during activities proper and when activities have ceased (Table 1, see also CEN/TC292/WG1 2011).

The pre-treatment of samples is carried out in accordance with the instruction for each method of analysis (Fletcher 1981, Niskavaara 1995). Generally pre-treatment involves drying, grinding and/or homogenisation of the sample and splitting of the sample for different analyses. Drying is usually done at a low temperature (< 40°C). Samples from which weak extractions are made or which oxidise easily when air dried are dried using freeze drying (Heikkinen & Räisänen 2008). Rock samples are crushed first and then ground to the grain size required by each method of analysis. Some methods also require tailings samples to be ground after drying.

Table 1. Methods suitable for sampling of waste rock and tailings. (See also EN14899, Lottermoser 2007)

Type of mine waste	Applicability
Waste rock	
Single sample: lump sample or sample from drill core from a certain rock type/layer	For determination of the properties of homogenous waste rock, e.g. the rock type contains little visually distinguishable sulphide minerals
Combination sample consisting of 3-6 lump samples or samples from a drill core layer	Determination of properties of heterogeneous waste rock type, when the rock type (topology) of the waste rock surrounding the ore is the same but the composition (e.g. sulphide dissemination) varies in different parts of the deposit
Rock drill mud (rock drill powder) for example from the charging hole	Determination of the content of a single element, e.g. sulphide sulphur and/or carbonate carbon as a basis for classifying waste (final disposal in waste area - beneficial use)
Tailings / mineral precipitate sludge	
Single sample of tailings/mineral precipitate sludge from pilot concentration	Determination of properties of tailings/mineral precipitate before beginning of concentration proper
Sample from tailings/mineral precipitate sludge feed from the waste storage area: single or combination sample (min. 3) from several different feed flows	Monitoring of variation in the properties of the tailings/mineral precipitate sludge during mining activities (single variation or variation over time)
Single tailings sample from the waste storage area feed: regular or single	A sample taken regularly is suitable for determining geotechnical properties. The method is also suitable for monitoring changes in the properties of tailings when the concentration process changes either a single time or when the ore feed changes.
Serial sample from different layers of the tailings/mineral precipitate sludge profile: taken from the wall of a hole dug with a shovel or excavator (dry layer) drilling: sample separated by layers either into a tube sampler and/or split blade sampler or an 0.5 m long flowthrough blade	Evaluation of changes in the composition of/weathering state of stored tailings/mineral precipitate sludge during or after mining activities Determination of changes in composition of surface layers: separate samples according to the degree of oxidation of or variation in composition of the waste (visual differences) For defining variations in the composition of the entire waste profile: separate sample layers are separated e.g. according to oxidation state or variation in composition or are separated at equal intervals (0.5 m and/or 1 m, etc.); also for determination of the properties of the base layers (not for geomembrane structures)

2 Mineralogical studies

The mineralogical analysis of mine wastes is used to identify the minerals which the wastes contain and in which proportions (Table 2, see also CEN/TC292/WG1 2011). The objective of mineralogical studies is to identify acid-generating and neutralising minerals as well as silicate minerals which contain potentially harmful substances and salt minerals that weather readily as a result of the oxidisation reactions of iron sulphides (Weisener 2003, Lottermoser 2007). In addition to the sulphide minerals potentially acid-generating minerals may be, for example, Al- and Fe-bearing silicate minerals (chlorite) and Fe- and Mn-bearing sulphate minerals (Blowes *et al.* 2003, Jambor 2003). In the case of mineral precipitate sludges, identification is made of crystalline precipitate minerals (e.g. sulphate, oxyhydroxide and carbonate precipitates).

Analysis of the minerals in waste rock and tailings is normally carried out using polished thin sections under an optical microscope and possibly also using a fine-grained rock powder and X-ray diffraction analysis (XRD, see Heikkinen and Räisänen 2008). An electron microscope is also often used as an aid in the identification of fine-grained waste fractions as in the case of minerals in tailings (Heikkinen & Räisänen 2008).

Determination of the relative abundances of minerals is generally based on the point counting method using a thin section under an optical microscope or an MLA equipment (Heikkinen & Laukkanen 2007) or the Rietveld method, which is based on X-ray diffraction (Rietveld 1967 and 1969, Raudsepp & Pani 2003). Microscope investigations can also determine the properties pertinent to the beneficial use of the materials such as the shape of the mineral grains, the grain sizes, the grain boundaries of the mineral grains and the state of weathering of the minerals (Weisener 2003). Using an electron microscope and microanalytics it is possible to examine the trace element composition of single fine-grained minerals or the weathering of sulphide minerals. The mineralogy of iron, manganese and aluminium mineral precipitates may be examined using XRD or infrared techniques (IR technique, Kumpulainen *et al.* 2007).

3 Chemical analysis methods

The overall chemical composition of mine wastes can be determined based on a pressed powder pellet using x-ray fluorescence (XRF), or using a total leach method on a ground sample, or the fusion method (Table 2). In the last two of these methods, the element concentrations are determined from leach solutions using the ICP-AES/MS technique. From the total concentrations of elements it is possible to calculate the normative mineral composition of the waste, primarily the relative proportions of the main minerals, silicates and possible carbonate minerals (Paktunc 1999). The concentrations of acid-soluble elements are generally determined using what is known as selective extraction methods, of which the most common are hot aqua regia or strong nitric acid leaching (Niskavaara 1995). The element concentrations in acid leaching solutions are measured using the ICP-AES/MS technique. The element concentrations measured from these acid leach solutions reflect the element concentrations that are bound to mica and clay minerals, salt minerals and sulphide minerals (Doležal *et al.* 1968, Räisänen *et al.* 1992). Elements adsorbed to the surface of minerals and mineral precipitates may also be examined using weak leaching methods with either a sequential or single extractions (Dold & Fontboté 2001, Heikkinen & Räisänen 2008).

Table 2. Determining the mineralogical and chemical composition of mine wastes.

Mineralogy	**Chemical composition**	**Selective extractions (weak leaching methods)**
Identification of minerals Optical microscopy – transmitted illumination (thin section) – reflected light (polished thin section) Electron microscopy (EM)[2)] X-ray diffraction (XRD)[2)] Infrared (IR)[2)]	*Determination of total composition* XRF method Fusion method + ICP-AES/MS Total leaching +ICP-AES/MS S: burning + IR (Leco-S) C: burning + IR (C-analyser) Carbonate C, $C_{carb} = C_{total} - C_{HCl\text{-}leached}$	*Sequential extraction*[1)] – Dold 1999 and Dold & Fontboté 2001 *Selective extraction series*[2)] *Sulphidic metals*[3)] – H_2O_2+citrate leaching (Labtium Oy) Element speciation – e.g. CrVI and CrIII or AsV and AsIII[4)]
Mineral composition X-ray diffraction (XRD) – Rietveld method Scanning-EM + EDAX – MLA determination (Mineral Liberation Analysis)	*Selective extraction methods* – acid-soluble concentrations AR leaching + ICP-AES/MS HNO_3 leaching + ICP-AES/MS	

[1)] Dold 1999, Dold & Fontboté 2001
[2)] Kumpulainen et al. 2007, Heikkinen & Räisänen 2008 and 2009
[3)] Fletcher 1981, Young 1974
[4)] Backman et al. 2006, Koivuhuhta et al. 2008

4
Static tests

The potential acid-generating capacity and neutralisation properties of mine wastes are generally analysed using what is known as static tests or partially on the basis of the mineralogy of the wastes (Table 3). On the basis of the results of the analyses of the acid-base accounting (ABA) it is estimated whether the wastes can form acid mine/rock drainage (AMD/ARD) in the long term (Jambor 2003). The ABA results guide the planning of the disposal and after-care of the waste (Verburg *et al.* 2009).

The acid-generating properties of the waste are related to the presence of iron sulphides and the increase in acidity resulting from their oxidisation. The generation of acid and its neutralisation is analysed according to the oxidation reaction of pyrite (FeS_2): one mole of sulphide sulphur produces two moles of acid (protons), which are neutralised by one mole of calcium carbonate. On this basis the acid production potential (AP) is generally calculated from the total concentration of sulphide sulphur in the waste material (Jambor 2003).

The neutralisation potential can be calculated either from the total content of carbonate carbon, the total amount of carbonate minerals or on the basis of a static test (Table 3). In a static test it is possible to determine either separately the total neutralisation potential (NP) and acid production potential (AP, see above) of the waste or to measure what is known as its net neutralisation potential, which is the sum of the acid released in the oxidation of the sulphides in the waste and its neutralisation. In the method measuring the total neutralisation potential, efforts are made to dissolve the carbonate minerals in the sample by acid leaching in which the acid typically used is hydrochloric acid, HCl (Lawrence & Wang 1997, Jambor 2003) and the neutralisation potential is determined as the amount of acid that is consumed in the titration of the leaching solution, calculated as kg $CaCO_3$/t. The calculation of neutralisation potential on the basis of the total content of carbonate carbon is recommended in the case of wastes which contain slowly dissolving carbonate minerals such as magnesite and ankerite, which do not usually dissolve entirely in a static test.

In the static test based on the oxidisation (dissolving) of sulphides, the reagent used is hydrogen peroxide. This method is called the NAG test (Net Acid Generation), which is in general use in Australia (AMIRA International 2002, Miller *et al.* 1997). The method yields an estimate of the total acid production associated with the weathering of sulphides, because the oxidation reaction in the test simultaneously involves the dissolving of the carbonates and/or silicates and neutralisation of the acid resulting from the dissolution (Räisänen *et al.* 2010). The method can be performed either in a single phase or as sequential leaching depending on the amounts of sulphides. Sequential leaching is recommended for samples in which the total concentration of sulphide sulphur is over 1% and/or the sample contains slowly weathering arsenopyrite or pyrite occurring as cubes. In the leaching, acid is formed from the sulphuric acid produced in the oxidation of the sulphides as well as from the precipitation of the iron dissolved in the oxidation reaction and of other sulphidic metals. The NAG test includes determination of the neutralisation potential either using a static test or by calculating it from the total concentration of carbonate carbon.

According to the Mine Waste Decree (Government Decree 717/2009 Annex 1) the neutralisation potential of acid-generating mine waste is determined in the classification of inert waste using the CEN prEN 15875 method (cf. Lawrence & Wang 1997, see also CEN/TC292/WG1 2011). The classification of waste as acid generating or non-acid generating is based on the ratio of its neutralisation and acid production potentials (NP/AP) and the total concentration of sulphide sulphur (Table 3, EC 2009)

Table 3. Static test methods.

Static tests	**CEN prEN 15875[1)]**	**Sobek test (EPA 600)[2)]**
Description of method	1 M HCl leach (2 g sample / 90 ml acid), titration of leaching solution using a pH 8.3 0.1 M NaOH solution	0.1 M or 0.5 M HCl leaching (2 g sample / 20–80 ml acid), titration of leaching solution using pH 7 0.1 M or 0.5 M NaOH solution[2)]
Determination of acid production potential (AP)	AP = 0.625 * S_{total} (mol H^+/kg) or 31.25*S_{total} (kg $CaCO_3$/t)	AP = 31.25 * (sulphide S % + acid-generating sulphate S %) (kg $CaCO_3$/t)
Determination of neutralisation potential (NP)	NP = 83.34 * C_{carb} (kg $CaCO_3$/t) and/or amount of acid consumed in titration is calculated as mol H^+/kg or kg $CaCO_3$/t	NP = amount of acid consumed in titration is calculated as kg $CaCO_3$/t
Criteria for determining if waste is acid-generating/ non-acid generating	NP/AP<3 and S>0.1% acid-generating waste, NP/AP >3 and S<1 % non-acid-generating waste[3)]	AP>NP and/or NNP (=NP-AP) is less than 20 kg $CaCO_3$/t, acid-generating waste
Static tests	**Single-addition NAG test[4)]**	**Sequential NAG testi[4)]**
Description	15% H_2O_2 decomposition (2.5 g sample / 250 ml H_2O_2), leaching solution pH 4.5 and pH 7 titration with 0.1 M or 0.5 M NaOH solution	Repeat single-addition NAG test leaching 2–3 times (S>1%) or more often depending on the abundance of sulphides
Determination of maximum acid-production potential (MPA)	MPA = 30.6 * S_{total} (kg H_2SO_4/t)	MPA = 30.6 * S_{total} (kg H_2SO_4/t)
Determination of neutralisation capacity (ANC)	ANC: e.g. using Sobek test or other HCl leaching solution, amount of acid consumed in titration calculated as kg H_2SO_4/t	ANC: e.g. using Sobek test or other HCl leaching solution, amount of acid consumed in titration calculated as kg H_2SO_4/t
Criteria for determining if waste is acid-generating/ non-acid generating	NAG_{pH}≥4.5 and NAG=0, non-acid-generating waste; NAG_{pH}<5 and NAG>5, acid-generating waste or NAG≤5, weakly acid-generating waste	NAG_{pH}≥4.5 and NAG=0, non-acid-generating waste; NAG_{pH}<5 and NAG>5, acid-generating waste or NAG≤5, weakly acid-generating waste

1) Proposed standard, EU (CEN/TC292/WG8), cf. Lawrence & Wang 1997
2) Sobek *et al.* 1978 (USA); the molarities of the acid and base is determined using the Fizz test
3) Mine Waste Decree (Government Decree 717/2009)
4) AMIRA International 2002, cf. Miller *et al.* 1997

5 Kinetic tests

The purpose of a kinetic test is to determine if mine waste will generate acid mine drainage. It is suitable in the case of waste material which has been determined to be acid-generating based on the acid-base calculation or for which conflicting results have been obtained when determining its acid-generating and neutralisation properties (Lapakko 2003). The testing conditions are usually set up to assess the maximum weathering of minerals in an oxidising state (Lapakko 2003). However, the test is not designed to replicate the natural conditions in the waste area, whereby the results do not give a sufficiently reliable picture of the weathering of the waste material and the composition of the seepage water under actual waste storage conditions (Villeneuve *et al.* 2009).

There are a number of kinetic testing methods. The test can be performed in a laboratory as a column leaching tests or under field conditions in large tubs. In Finland humidity cell tests have been used for testing mine waste (Kaartinen & Wahlstöm 2005). In the test, the sample is oxidised by drawing moist air through it (a ground sample of 60 mesh). Once a week pH, electrical conductivity and dissolved ion concentrations are measured of the water run through the sample. The duration of the test may be from 20 weeks to a year or several years (see CEN/TC292/WG1 2011).

6 Geotechnical investigations

The aim of geotechnical investigations is to determine the properties which will furnish the basis for designing a safe waste storage area and waste disposal techniques. The extent and content of the measurements are determined by the choice of waste disposal technique and the safety requirements relating to storage (dam safety, risk of major accident, Government Decree 717/2009, Annexes 2 and 3).

The geotechnical measurements of waste rock are confined essentially to the estimation of rock size and possibly of the specific weight. This has bearing on the planning of the slope of the edges of the waste rock pile and taking into account the risk of collapse (safety, after-care) as well as estimating the consolidation of the ground under the pile (load-bearing capacity/estimate of the stability of the base). The need to determine the geotechnical properties of sludge wastes, such as tailings, relates to the planning of the safety and stability of the waste storage area, the key considerations being the choice of materials for and dimensioning of dams and evaluation of the maximum height of the waste storage pile. For tailings and watery sludges those geotechnical properties are determined that are used in planning the dimensions of the waste storage area, the management of safety risks and planning of after-care (Government Decree 717/2009 Annex 3). The properties to be measured include the following:

- distribution of grain size, specific surface area and shape of grains
- density/specific weight
- water content, water retention capacity and capillary conductivity
- pore water pressure (in raised sections of dams made from tailings)
- porosity
- plasticity
- shear resistance (stability) and
- compaction and/or compressibility properties (for additional information see Rantamäki *et al.* 1979, see also CDN/TC292/WG1 2011)

References

AMIRA International 2002. ARS Test Handbook. Project P387A Prediction & Kinetic Control of Acid Mine Drainage.

Backman, B., Luoma, S., Ruskeeniemi, T., Karttunen, V., Talikka, M. & Kaija, J. 2006. Natural Occurence of arsenic in the Pirkanmaa region in Finland. Geological Survey of Finland, Miscellaneous Publications. 82 p.

Blowes, D. W., Ptacek, C. J. & Jurjovec, J. 2003. Mill tailings: Hydrology and geochemistry. Julk: J. L. Jambor, D. W. Blowes and A. I. M. Ritchie (Eds) Environmental aspects of mine wastes. Mineralogical Association of Canada. Short Course Series, volume 31: 95–116.

CEN/TC292/WG1 2011. Technical Report - Characterization of waste - Overall guidance document on characterization of wastes from the extractive industry "– Fifth draft, 19th April 2011.

Dold, B. 1999. Mineralogical and geochemiscal changes of copper flotation tailings in relation to their original composition and climatic setting – implications for acid drainage and element mobility. PhD thesis, Terre et Environment, Université de Genève, Volume 18. 230 p.

Dold, B. & Fontboté, L. 2001. Element cycling and secondary mineralogy in porphyry copper tailings as a function of climate, primary mineralogy, and mineral processing. Journal of Geochemical Exploration 74, 3–55.

Doležal, J., Provondra, P. & Šulcek, Z. 1968. Decomposition techniques in inorganic analysis. Iliffe Books Ltd, London. 224 p.

EN 14899 2005. Characterization of waste - Sampling of waste materials - Framework for the preparation and application of a Sampling Plan. CEN/TC 292 – Characterization of waste, 99/31/EC.

Fletcher, G. J. S. 1981. Handbook of exploration geochemistry. Volume 1. Analytical Methods in geochemical prospecting. Amsterdam, Elsevier. 255 p.

Heikkinen, P. M. & Laukkanen, J. 2007. Rikastushiekkojen ja sivukivien mineraloginen ja kemiallinen koostumus sekä neutraloimispotentiaalisuhteet – tuloksia kahdeksalta eurooppalaiselta kaivokselta. Geologian tutkimuskeskus, arkistoraportti S/49/0000/2007/93. 22 p.

Heikkinen, P. M. & Räisänen, M. L. 2008. Mineralogical and geochemical alteration of Hitura sulphide mine tailings with emphasis on nickel mobility and retention. Journal of Geochemical Exploration 97 (1), 1–20.

Heikkinen, P. M. & Räisänen, M. L. 2009. Heavy metal and As fractionation in sulphide mine tailings – indicators of sulphide oxidation in active tailings impoundments. Applied Geochemistry 24, 1224–1237.

Jambor, J. L. 2003. Mine-waste mineralogy and mineralogical perspectives of acid-base accounting. Julk: Jambor, J.L., Blowes, D.W. & Ritchie, A.I.M. (Eds) Environmental aspects of mine wastes. Mineralogical Association of Canada. Short Course Series Volume 31: 117–145.

Kaartinen, T. & Wahlström, M. 2005. Hituran kaivoksen sivukivien ja rikastushiekan staattiset kokeet ja liukoisuuskokeet. Työraportti, VTT Prosessit 19.5.2005. 32 p.

Koivuhuhta, A., Räisänen, M. L., Hämäläinen, L. & Kekäläinen, J. 2008. Modification of the NH2 column method for chromium speciation in surface water and soil water. Bulletin of Geological Society of Finland Volume 80, 125–136.

Kumpulainen, S. Carlson, L. & Räisänen, M.-.L. 2007. Seasonal variations of ochreous precipitates in mine effluents in Finland. Applied Geochemistry 22, 760–777.

Lapakko, K. A. 2003. Development in humidity-cell tests and their application. In: J. L. Jambor, D. W. Blowes & A. I. M. Ritchie (Eds) Environmental aspects of mine wastes. Mineralogical Association of Canada. Short Course Series, Volume 31: 147–164.

Lawrence, R. W. & Wang, Y. 1997. Determination of neutralization potential in the prediction of acid rock drainage. Proceedings Fourth International Conference on acid rock drainage, Vancouver, B. C. Canada May 31 – June 6, 1997, Volume I: 451–464.

Lottermoser, B. G. 2007. Mine wastes. Characterization, Treatment, Environmental Impacts. Second Edition. Springer Berlin. 304 p.

Miller, S., Robertson, A. & Donahue, T. 1997. Advances in acid drainage prediction using the net acid generating (NAG) test. Proceedings Fourth International Conference on acid rock drainage, Vancouver, B. C. Canada May 31 – June 6, 1997, Volume II: 533-547.

Niskavaara, H. 1995. A comprehensive scheme of analysis for soils, sediments, humus and plant samples using inductively coupled plasma atomic emission spectrometry (ICP-AES). In: S. Autio (Ed.) Geological Survey of Finland, Special Paper 20, 167–175.

Paktunc, A. D. 1999. Mineralogical constraints on the determination of neutralization potential and prediction of acid mine drainage. Environmental Geology 39, 103–112.

Rantamäki, M., Jääskeläinen, R. & Tammirinne, M. 1979. Geotekniikka. Otatieto 464. Oy Yliopistokustannus/Otatieto, Helsinki, 307 p.

Raudsepp, M. & Pani, E. 2003. Application of Rietveld analysis to environmantal mineralogy. Julk: J. L. Jambor, D. W. Blowes & A. I. M. Ritchie (Eds) Environmental aspects of mine wastes. Mineralogical Association of Canada. Short Course Series, Volume 31: 165–180.

Rietveld, H. M. 1967. Line profiles of neutron powder-diffraction peaks for structure refinement. Acta Crystallography 22, 151–152.

Rietveld, N. M. 1969. A profile refinement method for nuclear and magnetic structures. Journal of Applied Crystallography 2, 65–71.

Räisänen, M. L., Tenhola, M. & Mäkinen, J. 1992. Relationship between mineralogy and the physico-chemical properties of till in central Finland. Bulletin of the Geological Society Finland Volume 64 (1): 35–58.

Räisänen, M. L., Kauppila, P. M. & Myöhänen, T. 2010. Suitability of static tests for acid rock drainage assessment of mine waste rock. Bulletin of the Geological Society of Finland, Volume 82: 33–43.

Sobek, A. A., Schuller, W. A., Freeman, J. R. & Smith, R. M., 1978. Field and laboratory methods applicable to overburdens and minesoils. United States Environmental Protection Agency EPA-600/2-78-054. Pp. 47–62.

Verburg, R., Bezuidenhout, N., Chatwin, T. & Ferguson, K. 2009. The global acid rock drainage guide (GARD Guide). Mine Water and the Environment 28, 305–310.

Villeneuve, M., Bussière, B., Benzaazoua, M. & Aubertin, M. 2009. Assessment of interpretation methods for kinetic tests performed on tailings having a low acid generating potential. Conference Proceedings Securing the future, Mining, metals and environment in a sustainable society and 8th ICARD International Conference on acid rock drainage Skellefteå, Sweden June 22 – June 26 2009. http://www.proceedings-stfandicard-2009.com

Villeneuve, M., Bussière, B., Benzaazoua, M. & Aubertin, M. 2009. Assessment of interpretation methods for kinetic tests performed on tailings having a low acid generating potential. Paper presented at Securing the Future and 8th ICARD, June 23–26, 2009, Skellefteå, Sweden. http://www.proceedings-stfandicard-2009.com

Weisener, C. G. 2003. Novel spectroscopic techniques to characterize mine waste. In: J. L. Jambor, D. W. Blowes & A. I. M. Ritchie (Eds) Environmental aspects of mine wastes. Mineralogical Association of Canada. Short Course Series, Volume 31: 181–202.

Young, R. S. 1974. Chemical Phase Analysis. Charles Griffin and Company Ltd. 138 p.

DOCUMENTATION PAGE

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Author(s)	Päivi Kauppila, Marja Liisa Räisänen and Sari Myllyoja (Eds)	
Title of publication	**Metallimalmikaivostoiminnan parhaat ympäristökäytännöt** (Best environmental practices in metal mining operations)	
Publication series and number	The Finnish Environment 29en/2011	
Theme of publication	Environmental Protection	
Parts of publication/ other project publications	The publication is available only on the internet: www.syke.fi/publications | helda.helsinki.fi/syke	
Abstract	Over the past few years, important new mines have been opened in Finland (Suurikuusikko, Talvivaara) while existing ones have upscaled their operations and new mining projects have been started. The mining industry produces the raw materials on which many other industries depend, including the metal, chemical and pulp and paper industries, as well as agriculture and a number of other sectors. Unavoidably, the metal ore mining has impacts on the environment. Prevention of negative environmental impacts calls for the application of BAT (Best Available Techniques) in the mining, starting from ore prospecting and mine planning and extending to mine closure - throughout the mine life cycle. This publication discusses the environmental aspects of metal ore mines throughout the mine life cycle, ranging from the relevant legislation, emissions and environmental impacts of the mining, to the required environmental surveys, methods and techniques used to decrease emissions and diminish environmental impacts. With Finnish conditions in focus, the publication proposes latest solution models for the best environmental practices for the metal ore mining. The publication is a joint project between the Geological Survey of Finland, the Kainuu and Lapland Centres for Economic Development, Transport and the Environment, the Regional State Administrative Agency for Northern Finland, the Finnish Association of Extractive Resources Industry and the Finnish Environment Institute. The publication is intended to use in planning, implementing and closing of the mines for operators and permit and supervisory authorities, as well as for consultants.	
Keywords	Metal ore mines, best environmental practices, environmental legislation, emissions, environmental impact, mine waste, mine closing	
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KUVAILULEHTI

Julkaisija	Suomen ympäristökeskus (SYKE)	*Julkaisuaika* Toukokuu 2013
Tekijä(t)	Päivi Kauppila, Marja Liisa Räisänen ja Sari Myllyoja (toim.)	
Julkaisun nimi	**Metallimalmikaivostoiminnan parhaat ympäristökäytännöt**	
Julkaisusarjan nimi ja numero	Suomen ympäristö 29en/2011	
Julkaisun teema	Ympäristönsuojelu	
Julkaisun osat/ muut saman projektin tuottamat julkaisut	Julkaisu on saatavana ainoastaan internetistä: www.syke.fi/julkaisut | helda.helsinki.fi/syke	
Tiivistelmä	Suomeen on viime vuosina avattu merkittäviä uusia kaivoksia (Suurikuusikko, Talvivaara), toimivien kaivosten tuotantoa lisätään ja useita kaivosprojekteja on käynnissä. Kaivostoiminta on teollisuudenala, joka tuottaa tarpeellisia raaka-aineita mm. metalli-, kemian- ja paperiteollisuudelle, maataloudelle sekä lukuisille muille toimialoille. Kaivostoiminta vaikuttaa vääjäämättömästi ympäristöönsä. Kielteisten ympäristövaikutusten ennaltaehkäisy edellyttää parhaan käyttökelpoisen tekniikan (BAT, Best Available Techniques) soveltamista kaivannaistoimintaan malminetsinnästä ja kaivoksen suunnittelusta alkaen – läpi toiminnan elinkaaren – kaivoksen sulkemiseen ja jälkihoitoon asti. Julkaisussa tarkastellaan metallimalmikaivosten ympäristönäkökohtia kaikissa toiminnan elinkaaren vaiheissa kattaen lainsäädännön, toimintaan liittyvät päästöt ja ympäristövaikutukset, tarvittavat ympäristöselvitykset sekä menetelmät ja tekniikat päästöjen ja ympäristövaikutusten vähentämiseksi. Julkaisussa esitetään ratkaisumalleja Suomen olosuhteisiin soveltuvista metallimalmikaivannaissektorin parhaista ympäristökäytännöistä. Julkaisu on kirjoitettu yhteistyössä Geologian tutkimuskeskuksen, Kainuun ja Lapin ELY-keskusten, Pohjois-Suomen aluehallintoviraston, Kaivannaisteollisuus ry:n ja Suomen ympäristökeskuksen kanssa. Julkaisu on tarkoitettu sekä toiminnanharjoittajien, lupa- ja valvontaviranomaisten että alan konsulttien käytettäväksi kaivostoiminnan suunnittelussa, toteutuksessa ja toiminnan päättämisessä.	
Asiasanat	Metallimalmikaivokset, parhaat ympäristökäytännöt, ympäristölainsäädäntö, päästöt, ympäristövaikutukset, kaivannaisjätteet, kaivosten sulkeminen	
Rahoittaja/ toimeksiantaja	Suomen ympäristökeskus (SYKE)	

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Painopaikka ja -aika	

PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral (SYKE) — *Datum* Maj 2013
Författare	Päivi Kauppila, Marja Liisa Räisänen och Sari Myllyoja (red.)
Publikations titel	**Metallimalmikaivostoiminnan parhaat ympäristökäytännöt** (Bästa miljöpraxis för metallgruvverksamhet)
Publikationsserie och nummer	Miljön i Finland 29en/2011
Publikationens tema	Miljövård
Publikationens delar/ andra publikationer inom samma projekt	Publikationen finns tillgänglig bara på internet: www.syke.fi/publikationer | helda.helsinki.fi/syke
Sammandrag	I Finland har under de senaste åren öppnats betydande nya gruvor (Suurikuusikko, Talvivaara), medan produktionen ökas i gamla gruvor och flera nya gruvprojekt är i gång. Gruvverksamheten är en industrigren som producerar råvaror för behov i bland annat metall-, kemi- och pappersindustrin, inom jordbruket och i många andra branscher. Gruvverksamheten har dock sina miljökonsekvenser. För att förebygga de negativa miljökonsekvenserna bör man tillämpa den bästa tillgängliga tekniken (BAT, Best Available Techniques) under gruvverksamhetens hela livscykel – från malmletningen och planeringen av gruvan genom driftskedet ända tills gruvan stängs och de eftervårdande åtgärderna utförs. I publikationen presenteras miljösynpunkter på alla skedena i metallmalmgruvornas livscykel, bland annat lagstiftningsfrågor, utsläpp som sker i samband med verksamheten, miljökonsekvenser, behövliga miljöutredningar samt olika slags metoder och tekniker för minskande av utsläpp och miljökonsekvenser. I publikationen presenteras lösningsmodeller för bästa miljöpraxis inom metallmalmgruvindustrin när det gäller finländska förhållanden. Publikationen har utarbetats i samarbete med Geologiska forskningscentralen, Kajanalands och Lapplands ELY-centralen, Regionförvaltningsverket i Norra Finland, Kaivannaisteollisuus ry och Finlands miljöcentral. Publikationen är avsedd för verksamhetsidkare, tillstånds- och tillsynsmyndigheter samt konsulter inom branschen och kan användas när gruvverksamhet planeras, genomförs och avslutas.
Nyckelord	Metallmalmgruvor, bästa miljöpraxis, miljölagstiftning, utsläpp, miljökonsekvenser, gruvavfall, stängning av gruvor
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The publication deals with environmental aspects of metal ore mines throughout the mine life cycle, extending from the relevant legislation, emissions and environmental impacts of the mining, to the required environmental surveys, methods and techniques used to decrease emissions and diminish environmental impacts. With Finnish conditions on focus, the publication presents latest solution models for the best environmental practices (BEP) of metal ore mining. The publication is intended to be used in planning, operating and closing of mines by operators and permit and supervisory authorities, as well as for consultants.

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