MANAGEMENT OF MINING, QUARRYING AND ORE-PROCESSING WASTE IN THE EUROPEAN UNION

Study made for DG Environment, European Commission

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Summary

At the request of the Environment Directorate-General of the European Commission, BRGM (Bureau de Recherches Géologiques et Minières) has conducted a study on the management of mining, quarrying and ore-processing waste in the European Union.

This project was completed mainly through the use of questionnaire sent to sub-contractors in almost each country of the EU. To assess this information and to extrapolate to the next twenty years, this approach has been reinforced using published estimators[1] on the waste quantity from the knowledge of produced metals.

Mining-selected waste (or simply mining waste) can be defined as a part of materials that result from the exploration, mining and concentration of substances governed by legislation on mines and quarries

Identification of the environmental risks associated with such waste requires the characterisation and quantification of their different types but also an assessment of the vulnerability of the specific environments contingent upon the geological and hydrogeological conditions and peripheral targets.

1. - Characterisation and quantification of the different types of waste.

This report is based on country-by-country inventory, within the European Union, of sites associated with the management of mining, quarrying and ore-processing waste. It represents the first overview of the current situation in Europe as regards mining waste and presents the current regulatory and management measures specific to each country.

The survey involved two approaches:

- a questionnaire related to the quantities of existing waste, associated with the typology of the mined substance(s), waste deposit(s) and mining systems and ore-processing method(s),

- an estimation, on the basis of the different processes employed throughout the production chain in mining operations and their management at each level, of the main types of waste generated over the last five or ten years.

Comparison between the estimated data with the data obtained from the questionnaires reveals differences in the results that are due mainly to different national regulatory approaches to fill in the questionnaire. Furthermore, legal definitions concerning the types of mining waste, from both the exploitation and processing standpoints may differ in spite of a common glossary defined at the beginning of the study.

For example, certain materials have an important recycling potential within a given environmental and economic framework and are not always considered locally as waste despite the legal definition of waste.

2. - Assessment of risks linked to mining waste.

The notion of environmental impact of mining activities is only fully meaningful if it includes a change in the initial environmental parameters, due to such activities. These parameters, which govern the "quality of the environment", may have several components: chemical composition of the waters, soils, etc.; biological diversity; visual aesthetic qualities, etc.

The major risks linked to mining waste for the environment are twofold:

- Risks associated with not only potential pollutant source (*e.g.* acidity and heavy metals in non-ferrous metallic ore) but also the specific environmental context and the presence of targets in the event of liberation. The possible risks from the potential pollutant source (such as acidity and heavy metals) in waste is dependent not only on the mineral characterisation of the solid but also on the quality of the potential leachates, the direct environment (soil, groundwater, surface water, air) and the potential targets (human, fauna and flora). The realisation of a Geographic Information System (GIS) specific to mining waste quantities and their pollution potential in different environmental contexts would thus constitute a tool in the assessment of risks linked of such materials. At the moment, such systems are used by some regional governments for the information management on land planning. The risk management with a GIS system in mining requires a considerable collection of specific data and additional series of external analyses. This system should be well defined and studied before to be developed. Then, results can be visualised successfully in the GIS system.

- Risks associated with the stability of the tailings dam, as indicated by the recent spectacular accidents in Spain (Aznalcollar) and Romania (Baia Mare). As regards the potential risk from tailings dams, it will be necessary to evaluate on each site the stability of tailings dam. Particular parameters such as exceptional climatological conditions should be carefully taken into consideration during the evaluation. In addition, common minimum safety standards for the design, construction, operation and monitoring should be developed and applied. These minimum safety standards could be built on the know-how of the profession.

3. - Improvement of management of waste.

Mines in all European Union countries are governed by a set of laws, generally combined in a Mining Code. The numerous regulatory texts, laws and standards, reveal that mines are a matter of concern to the national administrations. Mining waste are governed by general waste laws and texts. The extent, to which environmental concerns are addressed in these national laws, varies from Member States to Member States.

According to the contract's tasks, this report refers superficially to some technical processes, the amounts and types of wastes as well as a short description of the national legislation of the various Member States.

According to the returned questionnaires, a distinction can be made between the following three types of mine and related generated waste:

- Abandoned/old mines,
- Operating mines based substantially on old operating methods,
- Operating mines based on new design.

For abandoned mines, it is important:

- to undertake site monitoring (including land form(s), geology, soil type(s), hydrogeology, flora and fauna, land use, heritage, overburden and waste characterisation, recycling potential, etc.) to obtain a clear picture of the situation;
- to establish treatment objectives according to required future land use (for example, pollutant level in soil after treatment to be fixed depending on the proposed land use).

For operating mines based substantially on old operating methods, it is essential to evaluate the control routine as regards pollution risks and the stability of the tailings dams, and to take all necessary measures to limit risks (for example, installing leachate collection tanks, etc.). Substantial changes in the operation and monitoring phases are likely to be necessary to ensure a sufficient level of environmental protection.

For operating mines based on new design, it should be evaluated whether these installations as well as their control routine are sufficient to prevent risks of pollution or accident. Additional measures could be considered if necessary.

The performance of old and new installations in terms of emissions and discharges have to be evaluated in order to see if differences in methods have an impact.

All management of mining waste disposal facilities must taken into consideration long term environmental issues, because these structures will more than likely survive both the mine and the mining company. This raises a legal problem as regards the responsibility for maintenance and repair of these facilities since liability, under most laws, cannot be endless. Even where the facility becomes a permanent structure, it is still necessary to fit the site with a permanent analytical and inspection system. Closure and after care operations are therefore of paramount importance to lower, as far as possible, the long term environmental risks.

Research and development programs should continue around sets of themes specific to the various methods of mining-waste management. Today's decisions and future research and development must be based on current knowledge (for example results from foreign countries) but detailed further knowledge should be developed on:

- the reactivity of specific mining waste; this could be approached in different ways such as leaching tests, long-term column tests and normalised tests as being developed in the context of the Landfill Directive. Even if there are no international standard, there exist a number of normalised test protocols for static and kinetic tests of acid drainage potential, which is a key characteristic with regards to waste originating from sulphidic minerals,

- the behaviour of metallic molecules (originating from mining waste) in the subjacent geologic layers and prediction of their fate using tools such as geochemical and solute-transport modelling, Their behaviour within the waste deposit is also important (adsorption and other attenuation processes),

- the discrimination between geochemical background and mine-impacted soils and waters,

- the long term stability of dams,

- the improvement of recycling practice related to the characteristics of mining waste,

- the potential risks raised by certain covering techniques of tailing ponds (e.g. water cover),

- the process management and protection measures during operation and their subsequent impact on the closure phase.

This report presents the methodology employed, the obtained results and the current status of mining waste in the European Union. The attached CD-ROM presents the replies to the questionnaires filled in by the partners of the study. It also presents the legislation set up in each partner country of the European Union.

The above-mentioned considerations support the initiatives launched by the European Commission to set up an appropriate Community framework to ensure the safe and environmentally sound disposal of mining waste. Needs for coordination, information and specific actions on hot spot are necessary.

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INTRODUCTION

At the request of the Directorate-General Environment of the European Commission, BRGM has conducted a study on the management of mining, quarrying and ore-processing waste in the European union (Tender DG XI E3/ETU/980116).

This project was completed mainly through the use of questionnaire sent to sub-contractors in almost each country of the EU. To assess this information and to extrapolate to the next twenty years, this approach has been reinforced using published estimators[1] on the waste quantity from the knowledge of produced metals.

Mining-selected waste (or simply mining waste) can be defined as a part of the materials that result from the exploration, mining and processing of substances governed by legislation on mines and quarries. It may consist of natural materials without any modification other than crushing (ordinary mining waste, unusable mineralised materials – see definition in glossary) or of natural materials, processed to varying degrees during the ore-processing and enrichment phases, and possibly containing chemical, inorganic and organic additives (see Fig.1). Overburden and topsoil are classified as waste.

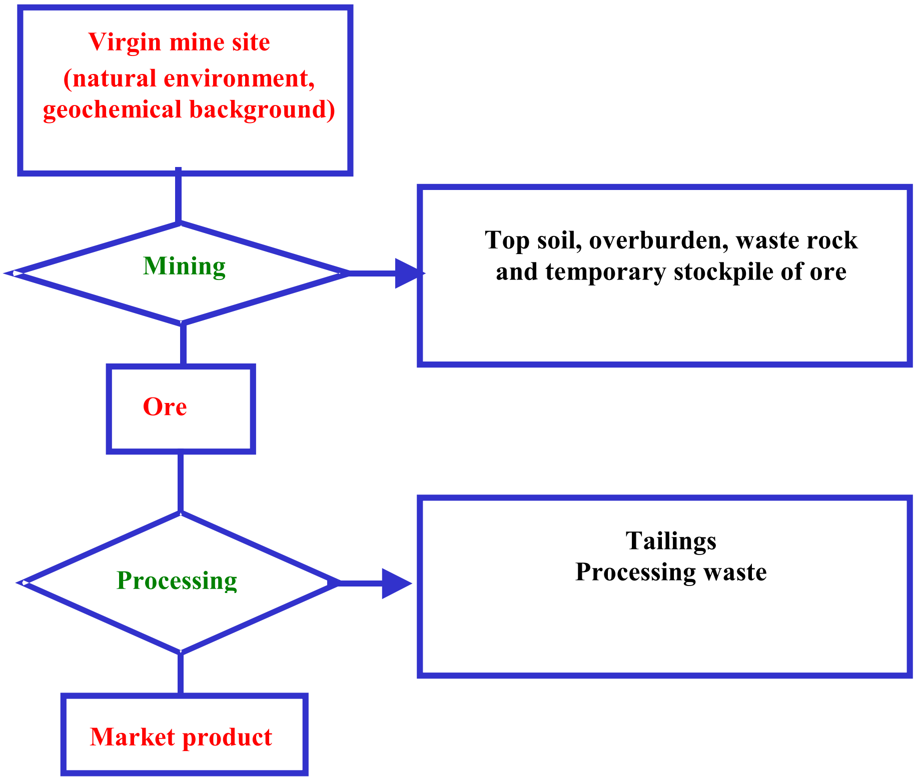


Figure 1: Mining waste types

This waste can affect the environment through one or more of the following intrinsic criteria:

- its chemical and mineralogical composition,
- its physical properties,
- its volume and the surface occupied,
- the waste disposal method.

Besides these parameters, one must also take into account extrinsic parameters such as:

- climatic conditions liable to modify the disposal conditions,
- geographic and geological location,
- existing targets liable to be affected (man and his environment).

Thus, identification of the environmental risks associated with the exploitation of mines and quarries and with ore processing at the scale of the European Union not only requires the characterisation and quantification of the different types of waste, as well as a knowledge of the processes used, but also an assessment of the vulnerability of the specific environments contingent upon the geological and hydrogeological conditions and peripheral targets.

Since this is a generic description, it is important to keep in mind that not all plants or deposits will release any pollutants to begin with.

Figure 2 shows how meteoric precipitation can transfer pollutant from a tailings dam or a processing plant to the river if the waste management is not efficient. If there is no impermeable layer, below the deposit, the infiltration of meteoric precipitation through deposit can transfer the pollutant(s) to the river *via* groundwater flow. The extraction process can itself modify the water flow and accelerate this transfer. Infiltration can also occur below a decantation basin.

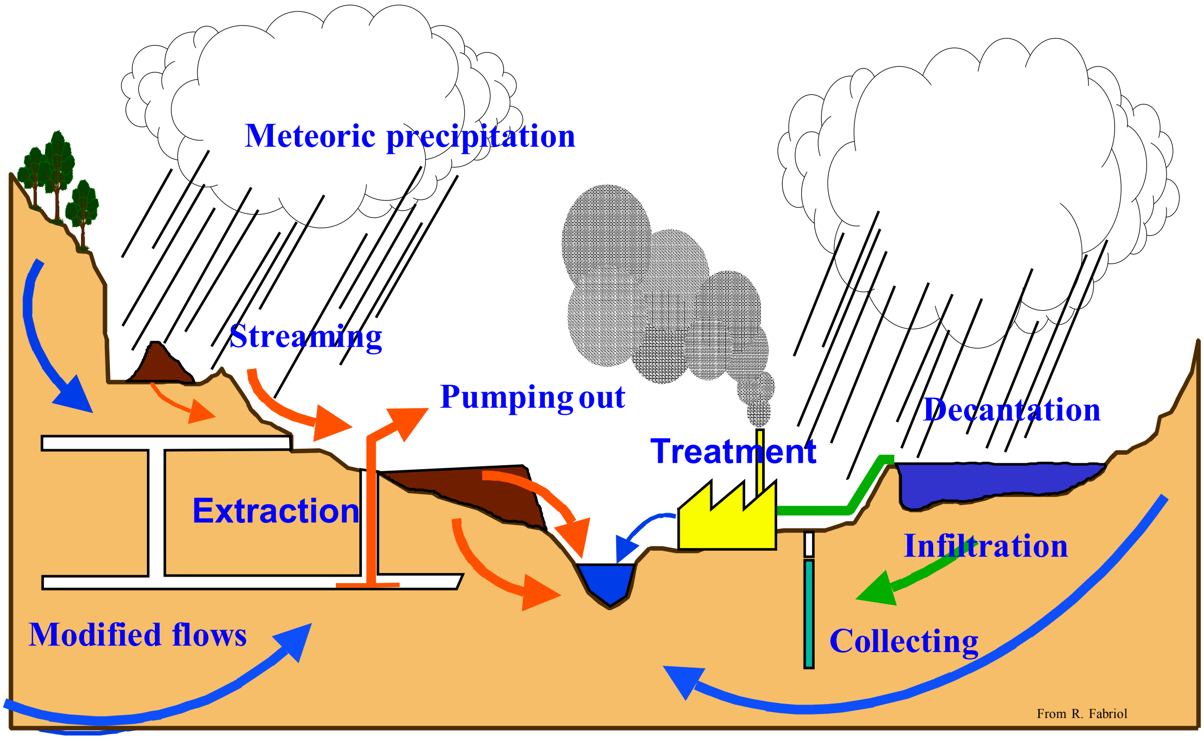


Figure 2: Pollutant transfer

All the different risks associated with the waste generated by these activities need to be identified for the management. An example is the failure of mining waste disposal dams, which can damage nearby biotopes and ecosystems. Apart from problems connected with releases into surface and ground waters, we can also add the dispersion of waste fines and heap leaching.

The present study concerns waste from current and old mines of most industrial metals and minerals that are, or have been, the subject of significant exploitation in the 15 countries of the European Union. It concerns mines associated with the following substances: antimony, bauxite, chromite, cobalt, copper, iron, fluorite, gold, lead, lithium, magnesium, manganese, mercury, nickel, platinum, silver, tin, tungsten and zinc, as well as andalusite, asbestos, barite, clays, coal, graphite, gypsum, kaolin, lignite, limestone, mica, rare earths, refractory minerals, phosphates, potash, pyrite and talc. The study did address neither aggregate quarries nor uranium due their specific characteristics.

Here we look at the general issues, that must be taken into account in examining potential impact. We do not address all the specific problems that could exist on each mine site.

The report presents the results from the defined methodology, an overview of the problems and the current status of mining waste in the European Union. An attached CD-ROM presents the questionnaires filled in by the partners of the study, for each member state of the European Union. It also presents the legislation set up in each country of the European Union.

The list of participants and subcontractors involved in the preparation of this report is given in Annex 1.

1. METHODOLOGY

The methodology described here, at European Union scale, provides elements leading to the distinction between sites where waste does not present harm to human health or to the environment and sites that may cause substantial and long-lasting harmful effects.

The existence of a risk implies the concomitant presence of a hazard source (H), a mode of transfer (Tr) and a target (Ta, considered as man at this stage of the process), with the four main pollutant transfer vectors (Tr) being the air, surface water, groundwater and direct contact (soil). If one of the factors (H, Tr, Ta) does not exist, the risk is not to be considered as such and the assessment of potential risks for the given milieu and usage is no longer applicable[2].

The following points have to be completed in the frame of this study:

1. Assessment of quantities of mining waste generated,
2. Description of management methods in the 15 European countries ("hazard" point of view) and the type of waste,
3. Identification and analysis of potential environmental impact(s) associated with waste management.
4. Mining waste management practices and identification of improved actions by the industry,
5. Inventory and analysis of legislation (legislative and standards) in each country.

Thus, the following method has been applied (cf. figure 3).

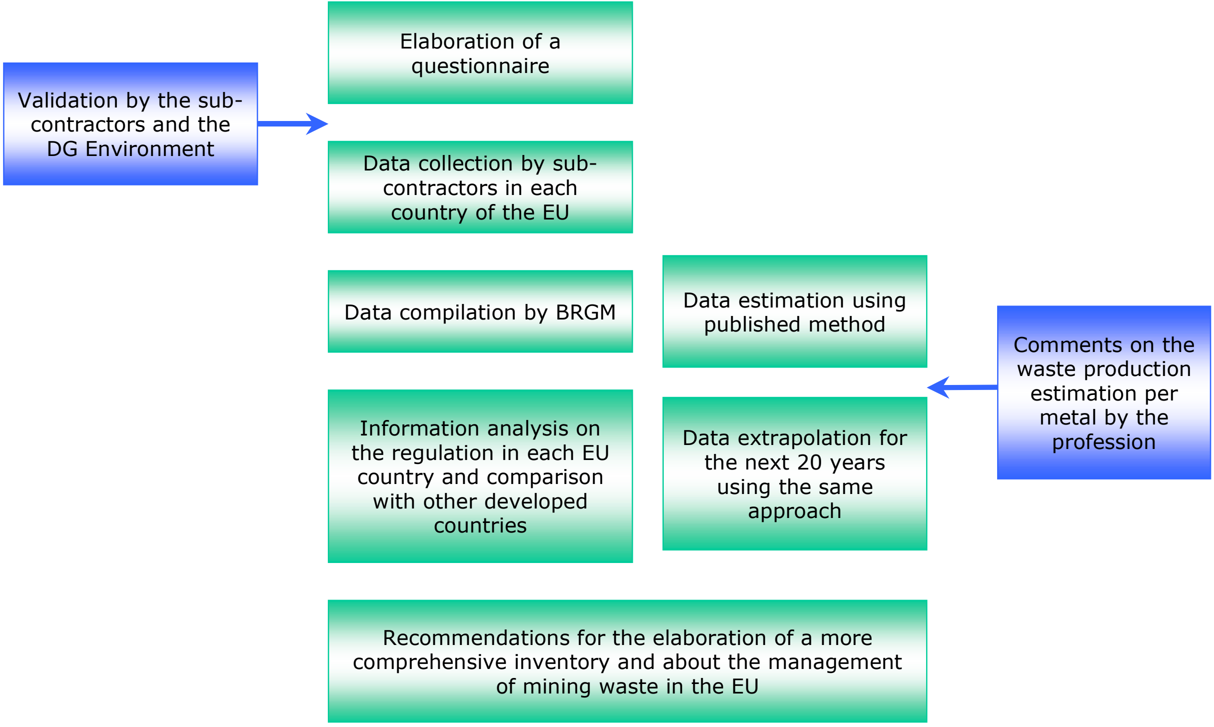


Figure 3: Project main steps

The study of mining waste draws on a vocabulary related to mining as well as to polluted site management. We have therefore prepared a glossary of the words and expressions pertaining to these two fields (see Annex 2) and which is used throughout this study.

1.1. ASSESSMENT OF QUANTITIES OF MINING WASTE GENERATED

The basic principle was to identify the waste and define it in qualitative and quantitative terms. The results for each country are presented in the CD-ROM related to this report.

An inventory of European mining sites per country was essential to assess the quantities of mining waste generated since the start of the mining activities. These inventories supplied information on the substances mined, the typology of the ore deposits, the operating systems and processes used. They also included information and data on the quantities of ores extracted and processed, the quantities of marketable products generated, and the quantities of residual waste.

1.1.1. Inventory of mining sites

The inventory was aimed at identifying for each country of the European Union:

- Mining sites, whether operational or not, currently being managed,
- Sites for which waste management has been completed.

Whenever possible the information required was both qualitative and quantitative. The data gathered at this stage concerned the identification and location of the sites, the associated mining steps, the operating companies, any known accidents and pollution, any known on-site studies related to overall product and waste management, and a bibliography of the documents consulted.

The work essentially consisted in a documentary research conducted by the subcontractors, supplemented where applicable by direct contact with the administrations and/or mining industry professionals.

Compiling the inventory involved the following main steps:

- Setting a frame and preparing of the inventory forms,
- Search of existing archives (pre-inventory) and files on sites in operation,
- Analysis of the data gathered,
- Location of the sites,
- Validation of the information and possible widening of the search.

The questionnaire produced from the first step and, validated by all the partners is presented in Annex 3. Each subcontractor filled it in, usually by incorporating data from several neighbouring mines into a single body of data presumed to represent the mining district.

1.1.2. Description and analysis of mining systems

The operations performed on a mine site to exploit and utilise an ore deposit can be divided into three main steps:

- access to the ore deposit (clearance, and galleries producing barren waste)

- *in situ* ore extraction and selection,
- ore-processing.

The aim was to identify typical systems accounting for the main techniques of mining and processing mineral substances which are, or were, used in the European mining industry, bearing in mind that:

- The topographic, geological and hydrogeological situation, as well as the geometry and morphology of the ore deposit, determine the mining method used for its exploitation,
- The chemical composition and mineralogy of the ore deposit determine to a large extent the processing,
- The reserves and economic conditions determine the production rate.

1.1.3. Typology and quantities of waste generated by the different mining steps

Each mining step is liable to generate mining waste, normally with different physical and chemical properties. Their respective volumes, especially for access to the ore deposit, depend on the type of mining method and the type of the raw material. Similarly, their chemical composition depends on the type of ore, its geological envelope and its processing.

For example, if two copper ore have respective contents of 7% and 0,7%. For one ton of produced copper, the first one will produce 11,5 tons of waste while the second will produce 164,4 tons of them.

Two approaches were combined for this assessment:

- The use of existing data published or supplied by operators or administrations, so as to obtain an approximate assessment of the mining waste flows generated;
- If no data was available, then an estimation was made that took into account of the type of deposit, the mining and processing techniques employed, and declared commercial production.

In their publication, I. Douglas and N. Lawson[1] used the known sources of mineral data, such as the British Geological Survey, US Bureau of Mines and the UN Industrial Commodity Production statistics. They examined them critically. The primary source was the 1988 production figures in the United Nations Industrial Commodity Statistics which use many different national sources and especially including those compiled by the US bureau of mines.

Multipliers were derived from figures published in standard textbooks and in other works on minerals production and materials use and then discussed with specialists to obtain maximum and minimum multipliers of individual commodities. Global estimates, given by multipliers, are likely to indicate the real contribution of the world's mining activities to global environmental change. The different multipliers are the following:

- Coal, hard : x 4.87
- Coal, brown, including lignite : x 9.9
- Iron-bearing ores : x 5.2
- Copper-bearing ores : x450
- Bauxite : x 3
- Gold-bearing ores : x 950 000

The multiplier for coal plays a major role in the magnitude of the global figure of total material extracted. Whilst most overburden removed during opencast operations will be put back, no overburden replacement in this assessment of earth surface change even though good site restoration programmes can, in time and in certain locations, successfully return the land to up to 80% of original productivity.

The global multipliers and estimates are also a step towards the objective of understanding how the quantities of materials shifted through mining vary in terms of regional climatic and geologic situations, as well as with differing socio-economic conditions. The multipliers can be used with national and local data, but can be checked against the evidence derived from the local case studies. Inevitably, the multipliers will differ greatly from one mine to another and from one means of extraction to another, but by working at global and regional scales as well as through case studies, our aim was to obtain a balanced picture and to be able to make reasonable estimates for those commodities and countries for which there is a lack specific case study information.

1.2. DESCRIPTION AND ANALYSIS OF WASTE-MANAGEMENT METHODS

At each stage of mining operations, management measures are generally taken for the generated waste. These can differ according to the mining operation, and in particular due to the different parameters such as geographic, geological, hydrogeological and climatological disparities.

Based on our knowledge of the profession and a bibliographic analysis, we were able to review the main techniques employed.

1.3. IDENTIFICATION AND ANALYSIS OF POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH MINING WASTE MANAGEMENT

At this stage, the objectives were:

- the identification of potential pollution resulting from mining waste and a quick identification of the impact of this type of activity on human health and the environment,
- compilation of the requested information on specific sites for a simplified assessment of the risks associated with mining waste and environmental repercussions (knowledge of geological and hydrogeological aspects, characteristics of the pollution source, etc.)
- analysis of two recent major accidents (Aznalcòllar in Spain –1998; Baia Mare in Romania - 2000).

1.3.1. Identification of potential pollution generated by mining waste

Besides the identification of potential pollution sources and their characteristics, our work essentially consisted in:

- assessing the vulnerability to pollution of a) the sites with active management of the mining waste, and b) their environment; this is done for the different environments concerned (water, air, soil) and for different possible targets (human, flora and fauna),

- identifying any transfer forms, as well as the characteristics of the sites containing the mining waste, as well as the physicochemical mechanisms liable to be involved, so as to facilitate, delay or even prevent migration (drainage of acid waters, for example).

For the pathways, our work was based on some 15 geological and hydrogeological contexts commonly encountered in Europe.

1.3.2. Needed information for a simplified assessment of mining-related risks

For each main type of mine, we tried to assess the hazard posed by the waste generated. We estimated an overall assessment by estimating the risk of environmental impact on quantitative and qualitative aspects alike. This estimated risk then indicates the measures to be taken.

The simplified assessment, drawing on necessarily simplifying options, helps to differentiate the final waste basically not exhibiting any threat to human health and the environment, from final waste generating significant pollution.

This simplified framework of “risk assessment” took into account the parameters conditioning the waste-generated pollutant transfer modes (particularly factors slowing down or accelerating migration), and the potential targets liable to be reached, incurring a risk to the environment and to human health.

1.4. MINING-WASTE MANAGEMENT PRACTICES AND IDENTIFICATION OF THE NEED OF IMPROVEMENT

1.4.1.. Design of tailings and waste rock facilities

We examined a number of actual practices in waste management and legislative tracking, as well as voluntary operator/administration agreements.

1.4.2.. Examples of accidents connected with the disposal of mining waste and redevelopment

We specifically examined examples of mining-waste disposal-site remediation (yard, heaps or dumps).

1.5. INVENTORY AND ANALYSIS OF LEGISLATIONS

Mining activity has subjected it to a body of national legislation known as the Mining Code.

We studied the state of the play of the different laws in force in the 15 EU countries investigated, as well as foreseeable developments in the regulations. We also made an inventory of the different regulations (legislative and legal) in each country, both for general texts and more "thematic" texts covering mining waste.

To address this legal framework, the different partners have questioned the relevant State services concerned with the management of mining waste. The national and international professional organisations or non-governmental associations concerned also made their contribution.

This part of the questionnaire contains headings related to the collection, transport and classification of waste (including hazardous waste), as well as to the permits for waste-management installations, inspection of disposal sites, tracking of sites after the operating period, etc.

2. MAIN RESULTS

As mentioned previously, the quantities of the various types of mining waste and their potential polluting capacities are determined by:

- the substance, which may undergo processing (i.e. its mineralogical context and its association with other elements),
- the characteristics of the layer (depth, nature, size),
- the environment in which the waste is disposed and the regulatory regime in place at the time,
- the time of the mining activity (economic context, treatment used, age of the waste).

2.1. ASSESSMENT OF QUANTITIES OF MINING WASTE GENERATED

2.1.1. Inventory of European mining sites

Constructed from the answers received from the subcontractors, Table 1 indicates the number of mining sites (including known abandoned or closed sites) covered by the questionnaire. Four main categories of ore were considered into which all extracted substances, within the scope of the study, can be placed:

- ferrous metals,
- non-ferrous metals,
- industrial minerals,
- coal.

The partners adopted different approaches. Some of them made a general study at national level (e.g. Denmark, United Kingdom), while others used an approach of a questionnaire per mining district, or even per mining site.

More than half of the mining sites within the European Union is now closed. According to the questionnaires, it appears that whereas almost all metal and coal mining is closed; the majority of industrial-minerals mining is still active. Among the closed sites, some have been rehabilitated or are subject to a rehabilitation project, some are now used as landfill sites for industrial (internal landfill) or domestic waste, whereas others are abandoned. In the north of European Union, the number of rehabilitated sites appears to be higher than in south of European Union.

The acid mining drainage is less important for the old mining sites. The metals contained in waste can be find in small quantity. The potential risk is low.

It should also be noted that the number of sites quoted in the following table cover only the sites mentioned in the questionnaires by the subcontractors. This table should not be interpreted as presenting all sites in the European Union. The methodology used in the questionnaires was a first attempt to carry out an inventory at the European level. The difficulties faced during this exercise should serve as lessons for future work at Community level.

Country	Ferrous metals		Non ferrous metals		Industrial minerals		Coal	
	total sites	**closed sites**	**total sites**	**closed sites**	**Total sites**	**closed sites**	**total sites**	**closed sites**
Austria	2		1		>500 *		2	
Belgium	>500	all	>300	all	>4700	>4500	>4000	all
Denmark	local	closed	a few		Opencast pits		lignite	Closed
Finland	5	5	38	26	12	7		
France	17	17	160	158	119	77	81	77
Germany	3	1	3	3	105	1	44	2
Greece	3		6	1	15	1		
Ireland			21	17	6	4	4	4
Portugal	8	7	9	9			1	1
Spain	20	18	58	45	47	20	73	25
Sweden	3		20	14				
United Kingdom	35	35	31	29	22	?	23	?

*** Most of these sites are related to aggregates production**

Table 1: Number of Mining sites mentioned in the questionnaires given by national partners within European Union countries (see CD-ROM for location)

2.1.2. Description and analysis of mining systems

The ore consists of minerals, each containing a combination of chemical elements, whose common forms are oxides and sulphides. In addition to coal, there are two main types of mineral raw material:

- industrial minerals, usable as such after concentration and purification (kaolin, potash, talc),
- concentrates resulting from the extraction of an element present within a mineral, and demanding further processing steps after separation of the mineral from its gangue.

For metals, the process culminating in the industrial product generally involves three steps:

- ore or mineral processing (enrichment of the ore by separating the mineral from the gangue),
- extractive metallurgy (pyrometallurgy, electrometallurgy, hydrometallurgy), which culminates in a material having a certain degree of purity,
- refining.

A technical (hence universal) definition of a mine includes all developments, structures and ore-extraction and-processing equipment, as well as all temporary and permanent storage dumps for materials and/or waste resulting from the exploitation and upgrading of a mineral resources.

A mine is a raw-material production site that comprises the phases of ore extraction from the deposit to the concentration of the useful mineral. It is organised around large civil engineering, equipment and consumables infrastructures. It manages all the inputs and outputs attached to it, whether liquid (wastewater, effluents), solid (fines, dump stocks, plant releases, semi-finished and finished products, chemical reagents) or gaseous (pyrometallurgy).

However, it is also necessary to add an administrative definition that can substantially modify this technical view with the local regulatory framework.

As a rule, the substances are usually classed in two categories, those governed by the regime of mines and those, which depend on the regime of quarries. The origin of this distinction can be found in the rarity of the substances in the mines, a rarity that has historically incited the States to arrogate ownership.

- The State grants permits to private individuals and companies to prospect and exploit, hence the name of concessible substances. This authorisation is subject to a number of regulations making up the Mining Code. During mining, and up to site remediation, the operator is subject to the Mining Authority. On the other hand, ore-processing installations are governed by laws on environmental conservation (Integrated Pollution Prevention Chart type - IPPC) and not the Mining Code. Insofar as a permit has been granted, the owner of the land under which a deposit is located does not have the right to exploit the deposit.

- Substances coming under quarry regulations belong to the owners of the land, who can either exploit them themselves, or entrust the exploitation to third parties in exchange for payment. Although exploitation in this case is governed by common law, the same Administration can supervise the operations. The most common rule is to define the list of concessible substances in a law, all the others pertaining to the regulations on quarries. However, a number of mining codes in the world set the list of substances belonging to the regime of quarries, with all the others belonging to the regime of mines.

This difference in classification of mineral resources is an important factor that ultimately affects the management of products and waste and the overall qualification as an extractive industry or the more specific qualification as a mining industry, whereas the extraction methods and problems associated with waste management commonly display many common features.

Given the variety of morphologies of natural deposits and the large variety of useful mineral substances, numerous mining techniques have been developed to address the problem of extracting ores and materials. Technological evolution has consistently improved these different techniques, which generally culminate in different types of waste and thus waste-management methods.

Metallic ores mined in the European Union are concentrated:

- in the Mediterranean (Portugal, Spain, Greece),
- in Ireland, which has become the leading country in Europe for the production of zinc and lead,
- in the two countries that recently joined the European Union (Sweden and Finland), particularly in Scandinavia with the Baltic shield.

In Germany, France and Italy, and in the Benelux countries, nearly all the metallic mines have been shut down or anticipate closure.

In contrast, the non-metallic substances extracted in the member countries are varied (sand, gravel, stone, calcium carbonate, slate, clays, gypsum, phosphate rock, salt, barite, fluorspar, kaolin, bentonite, etc.). The building sector in particular reflects the abundance of natural non-metallic resources, while demonstrating the low value per tonne of product obtained and thus its restricted mobility.

Europe currently retains a modest position in world mining activity in terms of scale of production and mineral reserves, but maintains a non-negligible role in the world mineral industry due to the fact that many companies in the sector are domiciled in Europe (often based in London). Although the mineral industry is modest within the European frontiers, it preserves a major role in the management of world resources on the international market (cf. Table 2). In addition, many engineering organisations and equipment manufacturers are located in Europe.

The annex 4 shows the current ore production rates within European Union and the world for 1997.

Substance	Units	Quantity	% cf. world reserves
Antimony	Kt Sb	440	10.5
Arsenic (1)	Kt As	180	18
Asbestos	Mt	51	30
Barite	Mt	36	20.5
Bauxite	Mt	1642	7.1
Beryllium	Kt Be	61	16.3
Bismuth	Kt Bi	0	0
Chromium	Mt Cr_2O_3	47	2.9
Cobalt	Kt Co	140	3
Copper	Mt Cu	53	17.1
Diamonds	Mct	200	19.2
Fluorine	Mt	90	42.9
Gold	Kt Au	3	7
Iron	Mt Fe	26650	38.1
Kaolin	Mt	2865	14.6
Lead	Mt Pb	20	31.7
Lithium	Kt Li	0	0
Manganese	Mt Mn	142	21.8
Mercury	Kt Hg	96	73.5
Molybdenum	Kt Mo	241	4.4
Nickel	Kt Ni	7050	15.7
Niobium	Kt Nb	680	16.1
Phosphates	Mt	670	5.6
Platinum	T Pt, Pd	14010	21.2
Potash	Mt K_2O	4455	47.3
Rare earths (2)	Kt oxide	19050	19.1
Silver	Kt Ag	73	26.1
Sulfur	Mt S	500	35.7
Talc	Mt	90	20.5
Tantalum	Kt Ta	2	7.3
Tin	Kt Sn	325	4.5
Titanium	Mt Ti	50	16.2
Tungsten	Kt W	355	16.1
Uranium (2)	Kt U	60	2.8
Vanadium	Kt V	5005	49.6
Zinc	Mt Zn	19	10
Zirconium	Mt ZrO_2	4	12.5

(1) arsenic present in lead and copper ores
(2) in oxide equivalent, including yttrium.

Table 2: European mining reserves (Russia and Ukraine included) of different substances [3]

(Sources: Mineral Commodity Summaries, AEN (Uranium), OMP)[4]

a. Definitions (cf. glossary in Annex 2)

The definitions presented here relate only to the essential terms useful to the understanding of this report. Many dictionaries of geology present more detailed definitions.

According to the working group, a **deposit** results from the natural accumulation of one or more mineral substances in a limited portion of geological space. This can be used scientifically within a certain period of time, in opposition of “occurrences” which are scientifically unusable accumulation of mineral resources.

Three criteria are conventionally recognised to define the limits of a deposit:

- **geological limits** of the **mineralization,** which correspond to the distribution zone of known mineral resources. These limits are liable to change in time due to possible progress in the general degree of knowledge of the actual mineral accumulation and its geological environment. Exploration engineers and technicians (geologists, geophysicists, geochemists, etc.) are generally involved in the process of delimiting the ore. However, this cannot be stated since the information technology and databases have considerably improved and can be simulated successfully with 3D computer models.

- the **economic limits,** which differentiate the mineral accumulation or mineralization of **ore** or **material**. Thus economic concepts are used to define zones of rich ore(s) and zones of lean ore(s) within a deposit from the contents of cuts, which are calculated according to a number of criteria, based on a balance between general production costs and net income, including a profit margin. Market fluctuations could lead to the consideration in turns of one part or another of the mineralization as a rich ore, or as a **lean ore**, or as **mining waste**. Economic engineers are involved in determining the feasibility of mining an ore or a material.

- The **technological limits** associated with the optimal conditions for mining the ore. Depending on a number of morphological criteria associated with the ore (depth, dissemination, or segregation in a formation or datum level, dip, type of substance), a mining method designed for optimal recovery in terms of quality and cost will be set into action among the many mining methods available for surface or underground workings. For the miner, only the part of the ore accessible by the mining techniques actually implemented defines the **deposit**.

We can also mention:

- The **limit grade**: this is the content of an elementary mining block (bucket or shovel in quarry, blasting of a working front) such that the concentrate produced from this block, paid for with the metal prices of the time, pays all the costs of extraction, transport and processing of this block, to the exclusion of financing costs and depreciation,
- The **cut-off grade** is the bottom content selected by the operator, below which no block will be mined. It is easy to demonstrate that the optimisation of a mining operation is successfully achieved when the cut-off content is equal to the limit content.

A deposit can exist under two statuses (specific to some Member States):

- Those in which the passage from the ore to the waste is settled and where it is not possible to make a sorting or selection within the deposit. The geostatisticians refer to this as "all or nothing".
- Those within which a selection can be made according to the different cut-off contents. These deposits display a variable tonnage depending on the cut-off content.

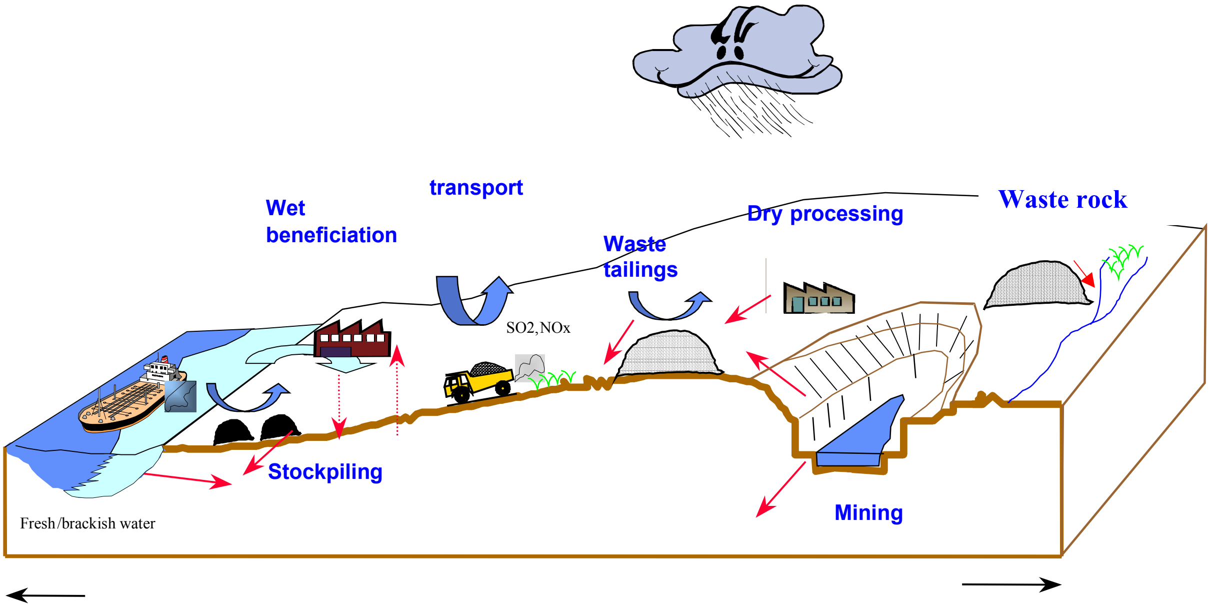
b. Types of mining operation

Several factors (location, geometry, morphology, depth, economics, environment, and even mining tradition) underlie the choice of method(s) for mining a specific ore deposit. Depending on this method, and on the size of the mine site, the projects display different ore-extraction capacities, and consequently larger or smaller quantities of mining waste. A major difference from the environmental standpoint can also be demonstrated in the composition of the waste associated with the mining method employed.

- **Open pits and quarries**

There are many alternatives within open pits and quarries but the great principles are identical.

Most industrial materials and shallow metallic deposits (< 300 m) are mined by this method, which is the cheapest in practice. The scale of the projects, and particularly their depth, is conditioned by an economic threshold above which it is better to continue mining through underground workings.



From F.Cottard - BRGM

Figure 4: Different steps of a mining activity

As a rule, after the stripping operations (removal of the soil and superficial horizons), actual mining is carried out in successive steps, imparting a roughly conical shape to the mine (cf. Fig. 4). The mining of each step or bench produces a tonnage of extracted material corresponding to the overburden surrounding the deposit, which is sent directly to the waste dump, and a tonnage corresponding to the ore that is selectively routed either for storage or directly to the processing plant. The variation in the ratio between the tonnage of waste to be extracted and the quantity of ore recoverable (also called stripping ratio) strongly conditions the economic viability of the mine. If this ratio becomes too high, especially when the quarry is deepened, it is no longer economically profitable to continue strip mining.

- **Underground (quarries and) mines**

When deposits are difficult to reach from the surface (depth, cliffs permitting side access), the only alternative is underground workings. A broad range of methods are available (chamber and pillar, long-wall, under-level caving, under-level stoping and filling, shrinkage) all of which are roughly adapted to the characteristics of the ore or the geometry of the deposit: dip of the layers or veins, thickness, continuity of the mineralization, grade of ore (disseminated or massive). The workings are generally opened by levels with a 60 m vertical spacing and then sublevels at 15 m intervals. Two criteria are vital for all these workings: selectivity of the ore and its percentage recovery.

All the operations conducted in the ore are connected to one another and to the surface by a series of passages, all opened in the overburden surrounding the deposit: shafts, inclines, drifts, chutes, cross-cuts for personnel and machine access, for removal of ore and drainage water, as well as for ventilation.

This organisation of the operations has the following consequences:

- the ore extraction capacities are generally much lower than for surface quarries;
- the quantity of waste produced per unit of ore mined is much lower than for surface quarries;
- the ground area of this type of underground mine is considerably smaller than for surface quarrying, except for subhorizontal layers;
- the mechanical risks are different (subsurface collapse, structural weakness around shafts and other inclines).

c. Mining phases and operations

The operations carried out on a mine site to exploit and upgrade a deposit can be divided into three (or sometimes four) main steps:

- Preparatory or development operations providing access to the deposit: the scale of these clearance (or stripping) operations in the case of an open-pit mine and for drilling drifts, shafts or inclines for an underground mine, vary considerably according to the characteristics of the deposit. Opencast pits generally produce about ten times more waste on average than underground mines, which are more selective.
- Ore extraction operations (or workings), and crushing or preliminary sorting operations to optimise the transport and grade of “crude ore” before its transfer to the processing unit.
- Ore processing (in many cases for metallic mines), set of operations corresponding to generally grouped in a specialised unit (called “concentrator”) used to separate the mineral phases containing the useful substances from the waste gangue; the product of the plant, enriched with useful materials, is called the "concentrate". In most cases, the concentrate is the marketable product. Note however that mines of so-called high assay substances (iron, manganese, bauxite) are often simplified installations only rarely containing ore processing units on site; as a rule, in these cases, the ore is exported without processing to distant sites where its metallurgical conversion is more advantageous, particularly in terms of energy. Note also that methods of chemical, or sometimes biological, processing of the ores are

also used in mine sites, in addition to physical and physicochemical methods (gravity separation and flotation). This applies in particular to gold ones (cyaniding) more recently to copper and nickel oxide ores (heat leaching or autoclave), and even more recently, to copper and cobalt sulphide ores (bioleaching).

In some exceptional cases, no physical or chemical process is applicable. A smelter must accordingly be installed nearby and, in these conditions, forms part of the mine (nickel saprolite).

2.1.3. Typology of waste generated by the different mining steps

Each of the ore-mining and-processing steps can generate mining waste[5]. This waste generally has different physical and chemical properties, resulting in different potential environmental impacts. The respective volumes of waste produced essentially depend on the type of deposit and the technological alternatives used for mining and for ore processing; stripping of the deposits in strip-mined quarries is often one of the steps producing the most waste during ore extraction operations. The chemical composition of the waste varies considerably according to the substance mined and the nature of the geological formation containing the deposit.

The main types of mining waste in addition to topsoil and overburden can be classed into two categories (see Fig. 5):

- waste rock (mine rock piles);
- tailings (processing waste);

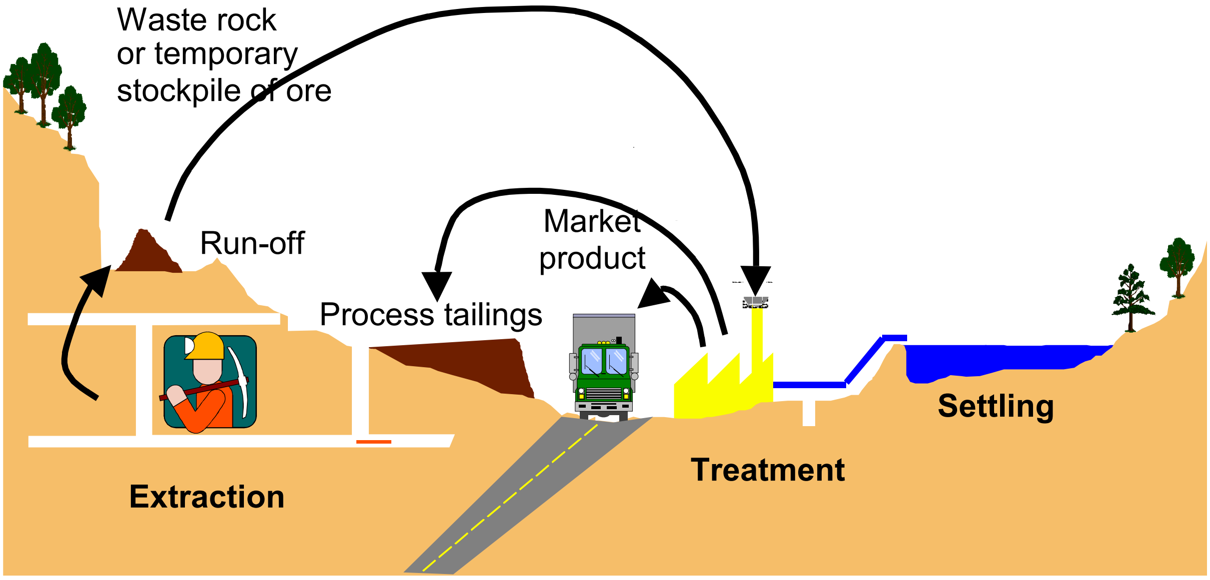


Figure 5: Different types of mining activity waste

We can mention two further types of "waste" because of the need of their environmental management:

- temporary stockpiles of ore;
- slags (out of the scope of the present study, because slag derives from a later stage of metal utilisation)

It is interesting to note that for some Member States, the term "waste" is not applied to residues (coarse or fine) resulting from the quarrying and processing of crushed-rock aggregates. In the most part, these are saleable products, which will be sold if local market conditions are favourable. In addition, both coarse and fine residues are routinely required for site restoration and landscaping.

a. Waste rock

Waste rock is hence durably unused extraction products that is generally stored indefinitely in a landfill site which, for economic reasons associated with transport costs, is located in the immediate vicinity of the main mining centre. The quantity of mining waste that can be stored at a mining centre varies considerably and mainly depends on the selectivity of the mining method. As a rule, opencast pits and quarries generate much more mining waste than an underground mine.

The main type of waste rock is generated by surface (or barren rock) stripping to expose the shallow ore. This is rock that is weathered to varying degrees, although increasingly fresh with depth and showing the geological characteristics of the local surrounding material. Its composition is similar to the rocks of the sector. The largest (in tonnage) quantity of barren rock comes from stripping for opencast mines. In underground mines, these barren rocks are generated by the passages (shafts, crosscuts).

b. Tailings (processing waste)

At a mine, an ore mill normally abuts on the extraction centre to produce the first marketable products (metallic concentrates, sorted ore, and ingots). The technological processes are very different according to the type of substance mined, and the modernity of the technologies employed (flotation, leaching, and biotechnology).

These units produce various types of waste, which can include:

- aqueous solutions from cyaniding,
- slurries of finely ground particles that have undergone one or more types of physical or chemical treatment, and which frequently contain one or more industrial additives that have participated in the conversion process (xanthates, miscellaneous salts, starch, etc.). These tailings are normally dumped in a sort of lagoon or settling basin within an embankment at the exit of the mill ;
- in some case, atmospheric releases from sulphide roasting. Emissions to air would come under the heading of "environmental impact".

Mill waste is generally referred to as **tailings**, or releases or effluents. It is generated by the various mineral-upgrading processes employed to meet demand. For a given mineral, it will have different physicochemical properties according to the conditions in which it has been generated. Its volume and variety has increased to match raw material demand, combined with the proliferation of upgrading methods and their degrees of sophistication. It is found in solid, liquid and gaseous form. Waste is generated at all levels of the recovery process to upgrade the minerals, within the same process chain, and is considered as ultimate or stripped of useful elements. Its content depends on the time that it was generated.

Through the years, **solid waste** has evolved in line with technological progress, from multi-centimetre grain size with a still high content of the desired element (i.e. low tonnage and hence low exchange surface areas [culling or manual sorting waste]) to micron grain size with very low chemical contents (i.e. high tonnage implying commensurate exchange surface areas [flotation waste, colloids, fines]).

The release mesh varies from one ore deposit to another, depending not only on the level of technology but also on the geological and mineralogical characteristics.

c. Ore stockpiles

Intermediate storage of products, ore stockpiles are not waste and are normally temporary dumps of lean ore at the mine site, depending on the cut-off content, which may vary with time. This type of mine project management is included in the overall mining plan. This management requires maintenance on the mine site for a period sometimes longer than a decade.

Selectivity materials correspond to ores of lower grade than the limit assay. These ores have a content which, while lower than the limit content when stored, can be handled later without loss in the processing plant when it is not be saturated, in which case it is treated as lean ore.

d. Slags

Slag does not fall under the scope of the study. In many old mines (Fe, Cu, Sn), the ore or concentrate was also burned or smelted nearby to remove certain components (e.g. sulphides) in order to produce a purer marketable product. In this case, slag heaps can be found on these old sites, forming a specific type of waste. Ash produced by cleaning furnaces or smoke stacks is frequently associated with them. These oxidised products are found either accumulated near the mine, if smelting was conducted nearby, or often stacked in heaps near the smelter. This study does not carry on slags.

2.1.4. Quantities of waste generated by the different mining steps

Two approaches have been combined to estimate the quantities of waste generated:

- the study of the data provided in the inventory of mining waste carried out by the subcontractors in the questionnaires. This investigation made it possible to obtain a realistic estimation,
- an estimation based on the quantities of ore produced by mine sites in the various European Union countries. Using ore grade and the relationship between the run-of-mine ore and the commercial concentrate, it is possible to estimate a weight or volume of the waste generated during the lifecycle of the exploitation.

a. Approach by the questionnaires

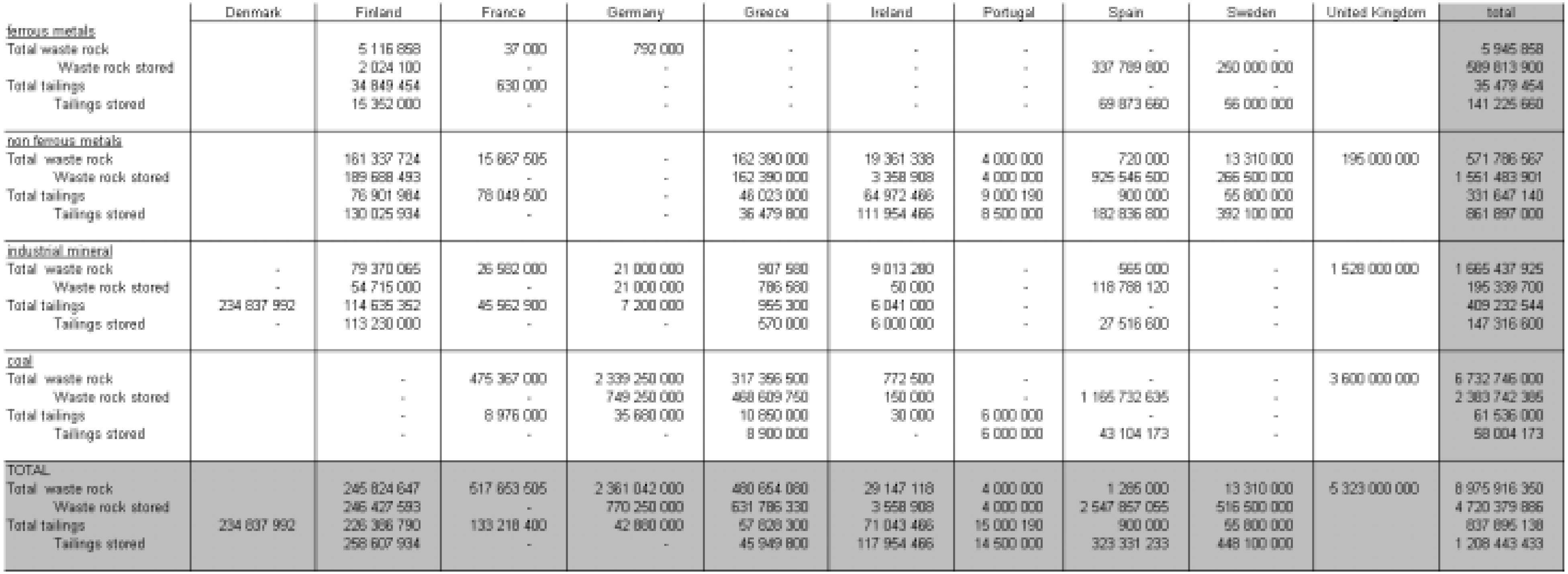
We defined two main categories of waste according to the relevant step of the exploitation: waste rock and tailings (process waste). For each type, we defined the quantity of waste stored on site and the quantity of total produced waste. The difference is the quantity of reused (recycled for example) waste.

Stored waste is all material, which has not been reused, poured back into or used to refill mining shafts. The quantity of stored waste should be less than the quantity of total waste, but this was not always the case due to certain inconsistencies found in the returned questionnaires. Some sites did not give any statistics on total mining waste or total tailings, and others only provided the quantities of stored waste. It appears that the stored mining waste or stored tailings are the most reliable data generated by this approach.

Table 3, constructed from all the questionnaires, presents, for the whole period of the mining activity (generally, from the middle of the XIXth century, although data for some sites starts from the Roman period), the quantities of waste within the European Union, for the four categories mentioned earlier:
- ferrous metals,
- non-ferrous metals,
- industrial minerals,
- coal.

It is certain that the exploitations in activity fifty years ago can present the highest risks to the environment but changes of physicochemical conditions for oldest mines could remove some chemical elements.

The questionnaires do not integrate the abandoned mines, which are not referenced. Thus, the real quantity should be larger than that presented here. Moreover, for some countries, the total quantity related to the whole period of activity has been estimated from the rate given by the subcontractor (in tonnes per year) for a period covering the most representative activity (last 150 years).



	Denmark	Finland	France	Germany	Greece	Ireland	Portugal	Spain	Sweden	United Kingdom	total
ferrous metals											
Total waste rock		5 116 858	37 000	792 000	-	-	-	-	-		5 945 858
Waste rock stored		2 024 100	-	-	-	-	-	337 789 800	250 000 000		589 813 900
Total tailings		34 849 454	630 000	-	-	-	-	-	-		35 479 454
Tailings stored		15 352 000	-	-	-	-	-	69 873 660	56 000 000		141 225 660
non ferrous metals											
Total waste rock		161 337 724	15 667 505	-	162 390 000	19 361 338	4 000 000	720 000	13 310 000	195 000 000	571 786 567
Waste rock stored		189 688 493	-	-	162 390 000	3 358 908	4 000 000	925 546 500	266 500 000		1 551 483 901
Total tailings		76 901 984	78 049 500	-	46 023 000	64 972 466	9 000 190	900 000	65 800 000		331 647 140
Tailings stored		130 025 934	-	-	36 479 800	111 954 466	8 500 000	182 836 800	392 100 000		861 897 000
industrial mineral											
Total waste rock	-	79 370 065	26 582 000	21 000 000	907 580	9 013 280	-	565 000	-	1 528 000 000	1 665 437 925
Waste rock stored	-	54 715 000	-	21 000 000	786 580	50 000	-	118 788 120	-		195 339 700
Total tailings	234 837 992	114 635 352	45 562 900	7 200 000	955 300	6 041 000	-	-	-		409 232 544
Tailings stored	-	113 230 000	-	-	570 000	6 000 000	-	27 516 600	-		147 316 600
coal											
Total waste rock		-	475 367 000	2 339 250 000	317 356 500	772 500	-	-	-	3 600 000 000	6 732 746 000
Waste rock stored		-	-	749 250 000	468 609 750	150 000	-	1 165 732 635	-		2 383 742 385
Total tailings		-	8 976 000	35 680 000	10 850 000	30 000	6 000 000	-	-		61 536 000
Tailings stored		-	-	-	8 900 000	-	6 000 000	43 104 173	-		58 004 173
TOTAL											
Total waste rock		245 824 647	517 653 505	2 361 042 000	480 654 080	29 147 118	4 000 000	1 285 000	13 310 000	5 323 000 000	8 975 916 350
Waste rock stored		246 427 593	-	770 250 000	631 786 330	3 558 908	4 000 000	2 547 857 055	516 500 000		4 720 379 886
Total tailings	234 837 992	226 386 790	133 218 400	42 880 000	57 828 300	71 043 466	15 000 190	900 000	65 800 000		837 895 138
Tailings stored		258 607 934	-	-	45 949 800	117 954 466	14 500 000	323 331 233	448 100 000		1 208 443 433

Table 3: Calculation from the established questionnaires of mining-waste and tailings quantities within the EU (tonnes)

« Waste rock stored » and « tailings stored » should mean waste, which are still stockpiled
For Austria, Luxembourg and Netherlands, we only got data on mining production rate but not on waste production rate.
This table should be read carefully because of the low comparability and reliability of data for the different countries. Moreover, definitions of waste rock and tailings are specific for each Member State

This table shows that coal is the ore with the largest quantity of waste (especially in United Kingdom, Germany, Spain, Greece and France). Then come non-ferrous ores (especially Spain, Sweden, United Kingdom, Finland and Greece), industrial minerals (United Kingdom, Denmark, Spain, Finland and France) and ferrous ores (Spain and Finland).

According to the answers of the questionnaires by partners, more than 4.7 billion tonnes of mining waste and 1.2 billion tonnes of tailings waste are stored all over European Union.

b. Approach through an estimation based on production

This estimation was established starting from the known data concerning the production of metal ores and industrial minerals within the European Union between 1986 and 1995. The polymetallic deposits (such as Zn-Pb-Cu or Cu-pyrite) were classified according to their dominant production. It was not possible, within the framework of this study, to distinguish the various types of deposits according to their morphology, their mineralogy, etc., parameters that are potentially important with regard to the quantities and nature of the produced waste. The lowest size limits represent an artificial cut-off, often defined by the contained metal and which takes into account only the significant mines, albeit giving a good general idea of the mining activity. The upper limit gives a good approximation of the largest known deposits.

Such a calculation gives a very rough total cumulated volume of the waste produced by mining and of the non-economic mineralization rejected with the dumps or stored for a possible later valorisation. We are conscious that the ratio between production and ore can vary by a factor 10 or more, within EU. There is a significant difference between opencast and underground mines (less waste in the underground). Underground mines in general have significantly higher ore grade. Taking copper as one example, ore grades in European mines vary from 0,4 to 5%.

An other example is the amount or residues generated from crushed-rock aggregate operations which varies according to rock type quarried, as well as being dependent on the type and degree of quarry processing. Certain sandstone quarried for high PSV roadstone may generate up to 40% fine-grained residues, whereas limestone quarries are more likely to generate around 10-15%residues. However, most of this will be utilised over time.

These estimated figures are very approximate for various reasons:

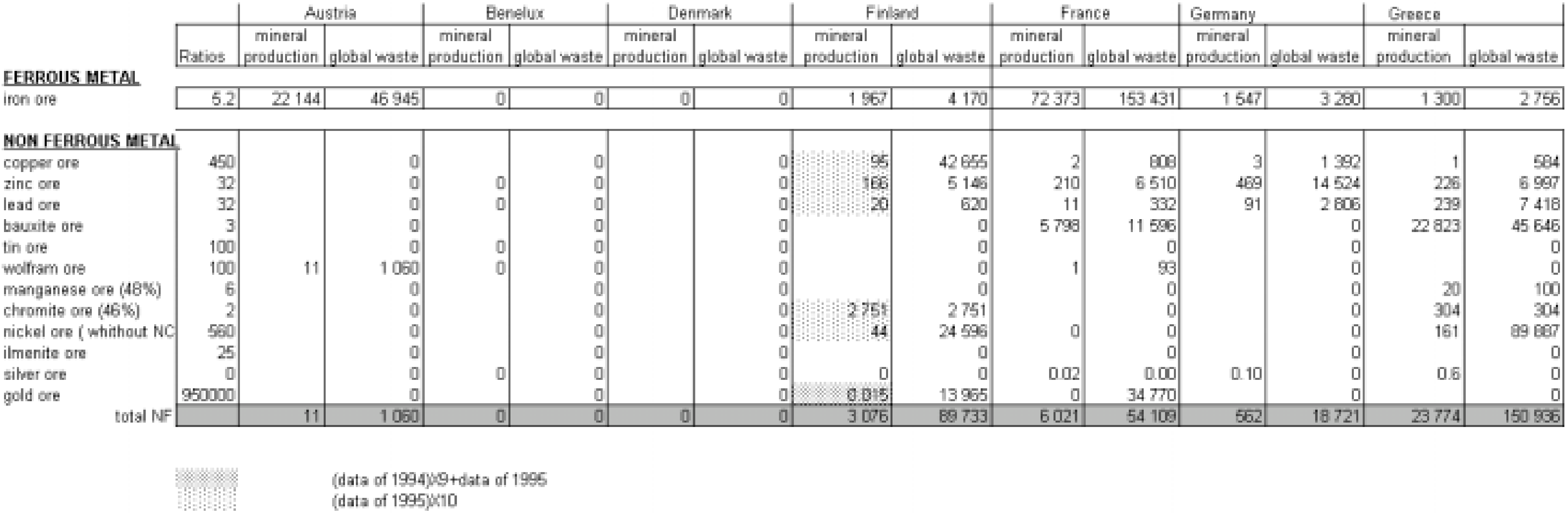
- for the old mines, data on the practices then in force (manual sorting at the bottom, etc.) is fragmentary,
- for certain recent mines, protection measures of the sites were not taken into account in the estimation. Mining waste of all types, including tailings, was sometimes used to stabilise the work in progress (back-filling), or exploited as aggregate for roadway systems. It was also, at times, processed extract the residual metal contents (heap leaching).

Adopting the specific approach mentioned earlier (Ian Douglas and Nigel Lawson – School of Geography, Manchester - 2000), we used a list of mass of material shifted globally in the production of different minerals and other mined products, and a multiplier to estimate overburden and tailings from statistics of mineral production. The development of global estimates of the total movement of materials is thus likely to indicate the real contribution of the world's mining activities to global environmental change.[67] The data were obtained from the British Geological Survey, the U.S. Bureau of Mines and the UN Industrial Commodity Production Statistics. Ratios had been calculated from "case studies" and verified at the global scale. The estimated quantities incorporate all mining waste.

Tables 4 to 8 present the results of the estimation (for a 10 years period) for ferrous ores, non-ferrous ores, industrial minerals and coal (for a 5 years period).

The global waste estimation is given by the formula:

Global waste = (ratio X global production)-global production



		Austria		Benelux		Denmark		Finland		France		Germany		Greece	
	Ratios	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste
FERROUS METAL															
iron ore	5.2	22 144	46 945	0	0	0	0	1 967	4 170	72 373	153 431	1 547	3 280	1 300	2 756
NON FERROUS METAL															
copper ore	450		0		0		0	95	42 655	2	808	3	1 392	1	584
zinc ore	32		0	0	0		0	166	5 146	210	6 510	469	14 524	226	6 997
lead ore	32		0	0	0		0	20	620	11	332	91	2 806	239	7 418
bauxite ore	3		0		0		0		0	5 798	11 596		0	22 823	45 646
tin ore	100		0	0	0		0		0		0		0		0
wolfram ore	100	11	1 060	0	0		0		0	1	93		0		0
manganese ore (48%)	6		0		0		0		0		0		0	20	100
chromite ore (46%)	2		0		0		0	2 751	2 751		0		0	304	304
nickel ore (whithout NC	560		0		0		0	44	24 596	0	0		0	161	89 887
ilmenite ore	25		0		0		0		0		0		0		0
silver ore	0		0	0	0		0	0	0	0.02	0.00	0.10	0	0.6	0
gold ore	950000		0		0		0	0.015	13 965	0	34 770		0		0
total NF		11	1 060	0	0	0	0	3 076	69 733	6 021	54 109	562	18 721	23 774	150 936

▓ (data of 1994)/9+data of 1995

░ (data of 1995)X10

Table 4: Metallic ore production and waste moved in the extraction process (10-year estimation x 10^3 tonnes)

This table should be read carefully because the ratios are seen in a global sense. It could be a large gap between real waste quantity and the calculation.

		Ireland		Italy		Portugal		Spain		Sweden		UK		total	total
	Ratios	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste
FERROUS METAL															
iron ore	5.2		0		0	188	399	35 146	74 510	200 965	426 046	1 053	2 232	336 683	713 768
NON FERROUS METAL															
copper ore	450		0		0	989	443 926	175	78 710	836	375 364	4	1 706	2 105	945 145
zinc ore	32	1 821	56 436	305	9 455		0	2 262	70 131	1 679	52 049	31	961	7 168	222 208
lead ore	32	397	12 316	139	4 300	1	19	523	16 222	1 001	31 031	14	425	2 435	75 488
bauxite ore	3		0	276	552		0	9	18		0		0	28 906	57 812
tin ore	100		0		0	22	2 188	1	69		0	30	2 940	53	5 198
wolfram ore	100		0		0	11	1 065	1	72	1	109	0	10	24	2 408
manganese ore (48%)	6		0	31	157		0		0		0		0	51	257
chromite ore (46%)	2		0		0		0		0		0		0	3 054	3 054
nickel ore (whithout NC	560		0		0		0		0		0		0	205	114 483
ilmenite ore	25		0		0	703	16 872		0		0		0	703	16 872
silver ore	0	0	0	0.13	0	0	0	2.0	0	3	0	0	0	6	0
gold ore	950000		0		0		0	0.062	58 805	0.064	60 895		0	0	168 435
total NF		2 218	68 752	751	14 464	1 725	464 070	2 973	224 028	3 520	519 448	78	6 042	44 711	1 611 360

Table 5: Metallic ore production and waste moved in the extraction process (10-year estimation x 10^3 tonnes) (cont.)

This table should be read carefully because the ratios are seen in a global sense. It could be a large gap between real waste quantity and the calculation.

1986 - 1995

Masses	Austria		Benelux		Denmark		Finland		France		Germany		Greece	
	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production
crushed rock aggregates	246.00	93.48	233.00	88.54	9.12	9.12	159.00	60.42	1407.00	534.66	1363.00	517.94	0.00	0.00
sand and gravels	600.00	228.00	426.00	161.88	157.70	157.70	400.00	152.00	1967.00	747.46	3230.00	1227.40	0.00	0.00
dimension stone	0.00	0.00	5.26	1.05	0.00	0.00	4.30	0.86	10.46	2.09	3.40	0.68	16.43	3.29
clays	24.84	12.42	34.81	17.40	2.34	2.34	0.00	0.00	45.88	22.94	97.68	48.84	0.00	0.00
cement => cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
gypsum - anhydrite	10.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	61.18	12.24	31.06	6.21	4.47	0.89
lime stone - dolomitic	11.41	4.34	31.54	11.99	0.85	0.85	4.68	1.78	49.70	18.89	108.64	41.28	7.34	2.79
phosphate rock	0.00	0.00	0.00	0.00	0.00	0.00	6.71	20.14	0.00	0.00	0.00	0.00	0.00	0.00
potash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.17	0.00	27.94	0.00	0.00	0.00
barite	0.00	0.00	0.30	0.30	0.00	0.00	0.00	0.00	0.86	0.86	1.77	1.77	0.01	0.01
fluorspar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.77	1.77	0.65	0.65	0.00	0.00
kaolin	0.72	2.16	1.98	5.95	0.37	0.37	0.07	0.21	3.29	9.86	7.75	23.25	1.64	4.92
refractory materials	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	4.48	0.00	0.00	0.00	0.00
bentonite ...	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.42	9.18	27.55	5.95	17.84
asbestos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.30
diatomite	0.00	0.00	0.00	0.00	0.18	0.18	0.00	0.00	0.80	0.16	0.44	0.09	0.00	0.00
feldspar	0.07	0.01	0.00	0.00	0.00	0.00	0.46	0.09	3.14	0.63	3.31	0.66	0.22	0.04
magnesite	7.77	1.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.58	1.32
perlite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.64	1.00
quartz - quartzite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
silica sand	60.00	12.00	251.12	50.22	0.47	0.47	1.60	0.32	60.55	12.11	89.82	17.96	0.32	0.06
talc	1.38	0.28	0.00	0.00	0.00	0.00	4.10	0.82	3.13	0.63	0.12	0.02	0.15	0.03
total	**962**	**356**	**984**	**337**	**171**	**171**	**581**	**237**	**3 628**	**1 369**	**4975**	**1914**	**46**	**32**

Table 6: Industrial mineral production and waste moved in the extraction process (10-year estimation x 10^6 tonnes)

This table should be read carefully because the ratios are seen in a global sense. It could be a large gap between real waste quantity and the calculation.

1986 - 1995

Mtonnes	Ireland		Italy		Portugal		Spain		Sweden		UK		total	
	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production	industrial minerals production	waste production
crushed rock aggregates	78.00	29.64	644.00	244.72	214.00	81.32	1096.00	416.48	240.90	92	1228.00	466.64	9663.84	3664.14
sand and gravels	80.00	30.40	1438.00	546.44	50.00	19.00	746.00	283.48	586.20	223	1027.00	390.26	12891.40	4187.18
dimension stone	0.00	0.00	73.31	14.66	8.72	1.74	30.87	6.17	2.80	0.56	3.66	0.73	179.58	31.84
clays	0.00	0.00	199.75	99.88	0.00	0.00	70.68	35.34	0.00	0.00	35.48	17.74	674.30	256.89
cement => nd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
gypsum - anhydrite	3.32	0.66	12.46	2.49	3.98	0.79	68.75	13.75	0.00	0.00	31.74	6.35	260.23	45.37
lime stone - dolomitic	1.86	0.71	61.29	23.29	3.30	1.25	19.14	7.27	6.99	2.66	33.17	12.61	402.17	129.70
phosphate rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.14
potash	0.00	0.00	0.69	0.00	0.00	0.00	6.99	0.00	0.00	0.00	5.06	0.00	52.87	0.00
barite	0.94	0.94	0.56	0.56	0.01	0.01	0.09	0.09	0.00	0.00	0.61	0.61	9.50	5.05
fluorspar	0.00	0.00	1.12	1.12	0.00	0.00	1.47	1.47	0.00	0.00	0.94	0.94	11.39	5.94
kaolin	0.00	0.00	0.55	1.64	0.55	1.64	3.91	11.73	0.00	0.00	28.67	86.01	186.38	147.63
refractory materials	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.21	80.00	480.00	0.00	0.00	545.27	484.69
bentonite ...	0.00	0.00	3.18	9.53	0.00	0.00	7.35	22.04	0.00	0.00	1.86	5.57	110.59	82.94
asbestos	0.00	0.00	0.38	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.49
diatomite	0.00	0.00	0.26	0.06	0.02	0.00	0.75	0.15	0.00	0.00	0.00	0.00	2.82	0.66
feldspar	0.00	0.00	14.33	2.07	0.69	0.14	2.26	0.45	0.39	0.08	0.08	0.02	39.28	4.99
magnesite	0.00	0.00	0.00	0.00	0.00	0.00	4.90	0.98	0.00	0.00	0.00	0.00	13.77	3.85
perlite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.64	1.00
quartz - quartzite	0.00	0.00	0.62	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.24
silica sand	0.28	0.06	35.97	7.19	4.06	0.81	23.61	4.72	4.50	0.90	40.69	8.14	311.75	114.97
talc	0.00	0.00	1.62	0.30	0.09	0.02	0.69	0.14	0.16	0.03	0.10	0.02	7.13	2.38
total	**164**	**62**	**2488**	**955**	**285**	**107**	**2083**	**804**	**922**	**799**	**2437**	**996**	23940	9033

Table 7 Mineral production and waste moved in the extraction process (estimation on 10 years) (end)

This table should be read carefully because the ratios are seen in a global sense. It could be a large gap between real waste quantity and the calculation.

		Austria		Benelux		Denmark		Finland		France		Germany		Greece	
production 1990-1994	Ratios	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste
COAL not bithuminous															
anthracite hard coal	4.87		0		0	0	0	0	0	46 228	88 850	313 700	602 931	0	0
coal brown+lignite	9.9	9360	46 238	1498	7 400		0		0	11 607	57 339	1307000	6 456 580	262159	1 295 065
total		9 360	46 238	1 498	7 400	0	0	0	0	57 835	146 189	1 620 700	7 059 511	262 159	1 295 065

		Ireland		Italy		Portugal		Spain		Sweden		UK		total	total
production 1990-1994	Ratios	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste	mineral production	global waste
COAL not bithuminous															
anthracite hard coal	4.87	80	154		0	1 003	1 928	96 671	185 802	129	248	8 250	15 857	466 061	895 769
coal brown+lignite	9.9		0	5286	26 113		0	88158	435 501		0	28	138		8 324 374
total		80	154	5 286	26 113	1 003	1 928	184 829	621 302	129	248	8 278	15 995	466 061	9 220 143

Table 8 Coal production and waste moved in the extraction process (estimation x 1000 tonnes on 5 years)

This table should be read carefully because the ratios are seen in a global sense. It could be a large gap between real waste quantity and the calculation.

c. Comments

All estimations need to be validated within each country. For example, an assessment of the estimations for Sweden show that corrections must be made on ratios proposed by Ian Douglas and Nigel Lawson:

- Global waste for ferrous metal should be 108 Mt,
- Global waste for non ferrous metal should be 327 Mt,
- Waste from crushed rock aggregates should be close to 0 as the quarries are stared in good rock and there is nothing that cannot be used,
- Waste from sand gravel should be close to 0 as in that country, the deposits are glacial sands and gravels where everything can be used,
- For refractory materials, the quartzite is mined in open-pits with selective methods and hardly any waste is created. The estimation of waste should be 6 Mt;
- Coal has just been exploited as by-product from clay pit. The estimated quantity of waste should be then close to 0.

Then, carrying out a precise estimation of the volume of mining waste in EU would be possible but would require a complete site-by-site inventory, which could be inspired by the inventory questionnaire presented here. The results should be controlled by the different actors in the mining field of each country. A classification of the ore by types could reduce work.

A precise determination the volume of mining waste would also require consultation of mine registers (when they still exist), evaluation of productions and processing to measure the real quantities of waste still on the sites by knowledge of amount of potentially reusable material (low-grade ore for later processing, waste for road aggregates or backfill material). Often, natural erosion has moved part of the waste, especially when the waste is stored at the river's edge (a frequent in areas of broken relief).

The data on mining waste quantities, collected *via* the questionnaire, has been expressed in tonnes, cubic meters or tonnage per year, depending on the usage in each country. Several estimations and approximations were thus needed.

A certain number of sites were not mentioned in the questionnaires, particularly in Spain and in East Germany. For example, the mining of the cupriferous schists in the area of Mansfeld, Germany ended in 1990[89]. Total production of the site was 2.6 Mt of copper and 14200 t of silver. All the neighbourhood mediums (air, water, and soil) are polluted, mainly because of the degradation of metallurgical fall-out dust. Currently, only measurements of the setting safety of the metallurgical sites are undertaken. The data relating to this site need to be added to the provided data.

d. Evaluation of future quantities of demobilised materials from mining activities

Table 9 and table 10 give an evaluation of the quantities of demobilised materials which will need to be managed, in the future, on the base of the EU currently exploitable ore reserves, in terms of the current economic context and current production rate. The results are not based on the current ratio of production.

According to the questionnaires, the closures of most mining sites in the European Union, are planned relatively early (a lot of them before 2010), but new mines will open. The quantities of waste would be certainly less than those presented here, as is confirmed by some production rates given by the subcontractors.

Mtonnes	Austria		Benelux		Denmark		Finland		France		Germany		Greece	
	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production
Ferrous metals														
Non ferrous metals														
copper							1	449						
zinc									1	31	1	31	1	31
lead														
bauxite													600	1200
tin														
wolfram	0.1	1							0.2	2				
chromite							17	17						
sub-total	**0.1**	**1**	**0**	**0**	**0**	**0**	**18**	**466**	**1.2**	**33**	**1**	**31**	**601**	**1231**
Industrial minerals														
gypsum									300	60	250	50		
phosphate							580	1740					29	87
potash									12				0.9	87
fluorspar									10	10				
asbestos													1	1
diatomite									13	3				
magnesite	15	3											30	6
perlite													50	19
talc							16	3	29	6				
sub-total	**15**	**3**	**0**	**0**	**0**	**0**	**595**	**1743**	**364**	**79**	**250**	**50**	**110.9**	**200**
Coal													3570	17636
TOTAL	**15.1**	**4**	**0**	**0**	**0**	**0**	**613**	**2209**	**365.2**	**112**	**251**	**81**	**4281.9**	**19067**

Table 9 Prediction of mineral production and demobilized materials (calculation from exploitable ore reserves)

Mtonnes	Ireland		Italy		Portugal		Spain		Sweden		UK		total	total
	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production	mineral production	waste production
Ferrous metals									**1600**	**3400**			**1600**	**3400**
Non ferrous metals														
copper					3	1347			1	449			5	2245
zinc	6	166	2	62	2	62	4	124	1	16			18	543
lead													0	0
bauxite													600	1200
tin					0.5	7							0.5	7
wolfram					0.3	3							0.6	6
chromite													17	17
sub-total	**6**	**186**	**2**	**62**	**5.8**	**1419**	**4**	**124**	**2**	**465**	**0**	**0**	**641.1**	**4018**
Industrial minerals														
gypsum			150	30			300	60					1000	200
phosphate			60	180									669	2007
potash			19	180			24				24		79.9	267
fluorspar			6	6			6	6			2	2	24	24
asbestos													1	1
diatomite							684	137					697	140
magnesite							32	6					77	15
perlite													50	19
talc			8	2									52	11
sub-total	**0**	**0**	**243**	**398**	**0**	**0**	**1046**	**209**	**0**	**0**	**26**	**2**	**2649.9**	**2684**
Coal													**3570**	**17636**
TOTAL	**6**	**186**	**245**	**460**	**5.8**	**1419**	**1050**	**333**	**1602**	**3865**	**26**	**2**	**8461**	**27738**

Table 10 Prediction of mineral production and demobilised materials (calculation from exploitable ore reserves) (cont.)

2.2. DESCRIPTION OF MINING-WASTE MANAGEMENT METHODS

2.2.1. Disposal of mining waste and tailings

Disposal of coarse mining waste consists in conversing large areas with dumps or in filling abandoned open-pits

By order of importance, the disposal of tailings is generally by:
- Terrestrial impoundment (tailings ponds),
- Underground backfilling,
- Deep water disposal (lakes and sea),
- Recycling.

a. Terrestrial impoundment

Terrestrial deposition is the predominant method for tailings disposal. It concerns fine waste and slurries such as mill tailings. The principle of tailings dams (or ponds) is to dispose of the tailings in an accessible condition that provides for their future reprocessing (once improved technology or a significant increase price makes it profitable). Actually, the vast majority of tailings facilities are design as permanent disposal facilities.

Tailings are often transported to the impoundment *via* pipelines.

b. Underground backfilling

This method is possible only for ore deposit without communication with an aquifer. Such an operation is usually costly and will be carried out for stability and safety reasons.

c. Deep water disposal

The disposal of tailings and solid waste directly into bodies of water although sometimes used in past operations, is rapidly becoming non-authorised as a standard practice due to the significant pollution effects it can have on the receiving waters and the possible subsequent impacts on the livelihoods of the local communities. This method requires specific conditions. and specific impact assessments. There seems to be a consensus among scientists that an appropriately designed underwater disposal of sulphidic tailings is the ideal solution from an environmental point of view in the short term with control of the level of water.

d. Recycling

Coarse mining waste and especially barren rock is sometimes considered as materials for roads, building foundations or cement factories, depending on its geotechnical and geochemical characteristics. Recycling is not classified as disposal.

In the German Potash Industry, the solid waste is 22% recycled, 58% dumped and 7% backfilled, the liquid waste is 8% deep well disposal and 5% discharged into rivers (Kali und Salz GmbH).

Waste rock may have no market at the moment occurs. If a market will emerge later, the rock stored temporarily can be sold as aggregate when environmental specifications are met. With new techniques, the tailings can be reprocessed.

2.2.2. Environmental issues

Some waste generated by mining operations, due to the mass it represents or to its chemical (or physical) nature, can pollute the environment, in particular media as water, soil, vegetation, and targets like the fauna and human.

Among the environmental problems, associated with tailings deposition, the principal ones are:

- Safety and stability of dams,
- Water pollution,

a. Safety and stability of dams

Tailings dams need to designed for the mine life and shaped at the initial stage. This reduces the need for reshaping dams at a later stage and so avoids costly earthworks and "double handling". We are conscious that in practise, the building of tailings dam at the initial stage of a mine's life is difficult, due to the fact that in most cases the ore reserve, the mine life and hence the total amount of tailings will increase over time. This is due to a continuous development of mining and processing methods and to the fact that the knowledge on the orebody will increase with time.

The placement of waste on steep slopes is to be avoided when possible so as to reduce the risk of land slip and dam failure, particularly in areas of high rainfall and areas prone to landslides, earthquakes and tremors.

Embankment of dam are shaped during the building stage so that slopes are gentle enough (15 to 20 degrees, or 27% to 36%) to reduce erosion and to allow vegetation to become established and so reduce the negative visual impact of unsightly waste rock.

A major factor in the design of tailings embankments is stability, from a geotechnical point of view. Factors influencing this geotechnical stability include:

- Embankment height,
- Embankment slopes,
- Strength of the embankment and degree of compaction,
- Permeability of the embankment and groundwater position in relation to it,
- Strength and compressibility of the embankment foundations.

Guidelines are available that define certain good geotechnical characteristics of embankments (UNEP (1996) *Guide to Tailings Dams and Impoundment* – Bulletin 106).

The type of dam embankment to some extent dictates the system of tailings discharge to be adopted. For example, embankments that are designed as water retention structures are made of low-permeability materials and tailings are discharged well upstream of the embankment.

b. Water pollution

Acid rock drainage can be a significant concern in the management of waste rock but is not in the scope of that study.

Water pollution may appear at different stages in the management of tailings. For example, failure of the discharge may cause spills and damage the surrounding environment.

Alternatively, rain and process water may create leachates when passing seeping through tailings (essentially in respect of tailings from ferrous and non ferrous ores), giving rise to:

- sulphide oxidation and potential acid generation,
- sulphide oxidation and production of soluble salts,
- metal leaching and migration to the surrounding environment,
- leaching of residual process chemicals in the tailings, e.g. cyanide, acids, alkalis,
- geochemistry and toxicity of the waste materials impacting on humans, vegetation and fauna.

These can also result from:

- seepage through and below impoundment walls,
- percolation to the subsoil and groundwater,
- overflow of the dam walls or spillways.

2.3. IDENTIFICATION AND ANALYSIS OF POTENTIAL ENVIRONMENTAL IMPACTS OF MINING WASTE

The environmental issues mentioned above refer explicitly or implicitly to the risks, related to the hazards and the potential environmental impacts.

There is a need to recall the main types of impact generated by mining waste, beginning with a comment on the "relative" notion of environmental impact before looking at the source of potential pollution, the transfer pathways and the targets. These are three aspects needed for a simplified risk assessment.

The behaviour of the waste is dependent on the waste management procedures put in place.

2.3.1. Identification of potential pollution generated by mining waste

It is important to attribute a ranking to the different environmental impacts from mining waste, representative of their real importance. Starting with point zero, the duration of these impacts and their evolution with time, and their treatment, must be examined in light of the different phases of operations, and treated by preventive, curative or specific confinement measures. It is hence important to distinguish between harmless impact, or harmful chemical impact or pollution, and harmful physical impact or detriment.

The notion of environmental impact is here only fully meaningful if it includes a change in the initial environmental parameters due to mining activity. The environmental impact must be assessed against the environmental quality targets for the affected zone, not against the initial environmental aspects. The parameters, which govern the "quality of the environment", may involve several components: chemical composition of the waters, soils, the biological diversity; and aesthetic qualities, etc.

To be able to judge the degree of impact, it is therefore necessary for:

- each component to be expressed in terms of a quantifiable parameter (pH, concentration of a metallic element, quantity of matter in suspension, measurement of biological diversity, speciation of species conditioning their mobility),
- the measured value of each component to be compared with the range of its natural background values for the environment of the mine site, i.e. those that existed before the mining operations, and which are often unknown.

This point is important since ore deposits are usually indicated at the surface by strong natural geochemical anomalies that are often used by the prospector to discover the deposit.

Any survey aimed at determining the impact of a mining operation (anthropic pollution) thus requires the most accurate possible knowledge of the natural environment of the site before operations.
From the geological aspect, and given the diversity of geological contexts, the “geochemical background” can vary considerably in the different countries of the European Union.

From the hydrogeological aspect, various parameters must be taken into account to define the hydrogeological settings, such as the lithologies of the geological formations (particularly as regards presence or absence of a clay layer, the type of porosity and permeability, the topography of the investigated site, the typology of pollution sources).

2.3.2. Assessment of mining related risk: potential sources of pollution

Every ore, whether metallic or non-metallic, is rarely mono-minerallic, but composed of a complex mineral paragenesis liable to contain a large number of potential pollutants, in addition to the material to be upgraded. Moreover, industrial processing methods use chemical components, which may also create pollution. These components are present in small quantities and are often organic, dissociating fairly rapidly in other molecules.

Consequently, analysis of the "pollutant potential" of the extraction and physical preparation of an ore, whatever its type, must take into account the "pollutant potential" of each mineral species, including those resulting from the *in situ* weathering of the primary minerals making up this ore and its surroundings. This study must naturally consider both the major and trace elements present in the concerned ores. Since excavation and reworking gives rise to different physicochemical conditions from those prevailing in the deposit in place, the chemistry of the elements concerned must also be considered.

Some mineral species are believed to be stable in the natural environment and harmless to man and the environment, apart from possible detriment attributable to the "fines" fraction. The "pollutant potential" of this type of ore has to be analysed individually in accordance with the processes employed for their conversion and for their adaptation to their intended use. Ores that fall into this category include aluminium (bauxite), tin (cassiterite), iron, manganese, talc, titanium (rutile or ilmenite), zirconium.

Analysis of the "pollutant potential" associated with ore processing has to take into account the industrial method(s) used to process the concerned ore in order to extract the useful components (e.g. flotation, cyaniding, amalgamation).

a.- Non-metallic minerals and materials

Some rocks mined in quarries or mines may contain sulphides that convert to sulphates during mining and are soluble in contact with water. Such acid drainage waters can cause the release of heavy metals.

Some non-metallic materials mined for anthropic uses nonetheless have a pollutant potential (see Table 11 and Annex n°5) when associated with certain minerals, especially those containing metalloids. Primes among those are:

- arsenic minerals,
- barium (barite) minerals, combined with lead and zinc,
- fluorine minerals (fluorite, cryolite),
- sulphuric minerals,
- fossil materials such as coal and graphite containing carbonaceous matter, formed in a reducing medium, combined with iron sulphides (pyrite); e.g. crude oil with sulphur,
- evaporitic materials (rock salt, potash, gypsum, nitrates, borate), those salts can paces into solution in aquifers and the drainage system,
- zeolites, which are basically "no-pollutants", but have the ability to substitute the water present in their crystal lattices with a variety of substances (NH_3, Hg, Cl), that makes them "potentially pollutant" materials.

b.- Metallic minerals and materials

Some metallic elements are considered stable in the natural environment such as iron, magnesium and manganese. Most metallic ores exhibit hazardous components (see Table 11 and annex 5).

Industrial activities	Antimony	Silver	Arsenic	Barium	Beryllium	Bismuth	Boron	Bromine	Cadmium	Chromium	Cobalt	Copper	Tin	Iode	Lanthanum	Lithium	Manganese	Mercury	Molybdenum	Nickel	Palladium	Lead	Selenium	Tellurium	Thalium	Uranium	Vanadium	Zinc
Coal extraction			■							■												■						■
Other hydrocarbons extraction				■				■						■														■
Ferrous metallic ore extraction																												
Non ferrous metallic ore extraction			■					■	■	■		■						■				■						■
Non ferrous metals production	■	■	■		■		■		■	■	■	■						■		■		■	■		■		■	■
Industrial minerals extraction																												
Industrial minerals production																	■											

Industrial activities	Calcium	Magnesium	Sodium	Potassium	Iron	Silica	Strontium	Titanium	Aluminium	Nitrogen	Chlorine	Fluorine	Phosphorus	Sulphur	Cyanide
Coal extraction	■	■	■			■				■	■			■	■
Other hydrocarbons extraction	■	■	■							■				■	
Ferrous metallic ore extraction			■		■						■			■	■
Non ferrous metallic ore extraction	■		■	■	■						■	■		■	■
Non ferrous metals production										■	■	■			■
Industrial minerals extraction											■				
Industrial minerals production									■						

Industrial activities	Aromatic Hydroc.	Poly Aromatic Hydroc.	Monocyclic AH	Bicyclic AH	Halogeneous aliphatic Hydroc.	Halogeneous arom. Hydroc.	Halogeneous polyarom. Hydroc.	PCB	Organometallics	Alcohols	Phenols	Etheroxydes	Carboxy.acids & salts	Acid anhydrides	Acid halides carbox. & salts	Esters	Aldehydes	Cetones	Amines	Amides	Nitriles	Nitrates	Sulphides	Heterocycles	Pesticides	Several chemical functions
Coal extraction	■	■			■						■												■			■
Other hydrocarbons extraction	■	■			■				■																	
Ferrous metallic ore extraction											■															
Non ferrous metallic ore extraction											■												■			
Non ferrous metals production	■	■			■																					
Industrial minerals extraction																										
Industrial minerals production																										

Table 11: Correlation between industrial activity and pollutants (metals, minerals, organics)[2]

2.3.3. Assessment of mining related risks; transfer pathways

Many parameters have to be considered in characterising the geological and hydrogeological aspects related to the transfer of pollutants. Given the complexity of the subsoil in the European Union, the chosen characterisation criteria should be as simple as possible and are normally given binary treatment in order to facilitate the identification of the setting which the analysed site is located.

The selected criteria, which should be defined during the prior investigation campaigns (soil survey, in-depth diagnosis), characterise either the geological formations immediately below the site, or the specific conditions of the site. The following section describes 16 geological and hydrogeological contexts where generic waste management measures have to be taken.

A number of elements have to be considered in the determination of these geological and hydrogeological contexts ^{10}.

- Formations comprising the site substrate:

A geologic substrate is described with several terms (see table 12) whose definition is given below:

- *type of the waste deposit*
- *formation* ***type*** on which the waste is dumped: it may be impermeable (consisting of low permeability materials, like clay) or aquiferous; in most of the cases analysed, it concerns formations either capping an aquifer, or the unsaturated zone of the aquifer,
- ***formation*** *of the* ***thickness***, particularly for a clay cap rock protecting a groundwater reservoir: thin (for settings where the pollution from waste crosses the impermeable horizon) to thick (for cases in which the cap rock still exists and accordingly will delay pollution transfer),
- the ***structure of the lithological formations*** making up the aquifer: unconsolidated or compact formations (see table 12),
- the ***type of aquifer porosity***: porous, fractured or karstic (see Table 12),
- the ***type of aquifer***: unconfined or confined.

- Specific conditions of the site:

- the ***topography*** of the geographic sector in which the site is located: e.g. in a valley or on a slope,
- rainfall,
- *groundwater* ***flow direction and speed***,
- ***presence of groundwater catchworks***, locally altering the flows,
- seasonal fluctuations in aquifer water.

Other specificity connected with the geographic location may also complicate the local systems considered above, namely, the superimposition of several aquifer types, the natural heterogeneity of the subsurface formations, their chemical properties (in terms of exchange capacity, sorption), the existence of resurgence zones, etc.

Type of waste deposit (subaerial or buried	Type of formation (or medium) underlying the waste or known under the polluted soil	Thickness of clays around the waste deposit or supporting the polluted soil		Lithological support of the nearest aquifer	Type of aquifer			superposed aquifers		Topography		resurgence area	influence of a pumping	heterogeneous aquifer	perched water table	number of the context
		thick	not very thick		confined emergent	confined not emergent	unconfined	unconfined/unconfined	unconfined /confined	hollow	sloping					
aerial	clay	X		Loose/compact		X					X					1
buried	clay	X		Loose/compact		X				X						2
buried	clay	X		Loose/compact		X					X					3
buried	clay	X		Loose/compact		X				X	X		X			4
buried	clay		X	Loose/compact		X				X	X					5
buried	clay		X	Loose/compact	X					X	X					6
buried	clay	X		Loose/compact			X			/	/					7
aerial/ buried	clay		X	compact			X			/	/					8
aerial/ buried	every type of aquifer			compact			X			/	/					8
aerial/ buried	every type of aquifer			compact			X			X						9
aerial/ buried	porous aquifer			Loose			X			X	X					10
aerial/ buried	aquifer			Loose/compact			X			/	/	X				11
aerial/ buried	clay	X		Loose/compact	X					/	/	X				11
aerial/ buried	aquifer			soft			X			/	/			X		12
aerial/ buried	aquifer			Soft/compact			X		X	/	/		X			13
aerial/ buried	aquifer			Soft/compact			X	X		/	/				X	14
aerial/ buried	mainly clay	X		Soft/compact		X				/	/			X		15
aerial/ buried	aquifer			Soft/compact			X	X		/	/					16

Table 12: Environmental contexts mentioned in the report and number of the relative description in Annex 5

The different cases developed here intentionally present relatively simple situations. It is clear that the realities in the field will inevitably confront the investigator with more complex cases, likely to result from the combination of several simple situations.

Table 12 serves as an entry key for different "subsoil" scenarios (see Annex 6). Its refers to the numbered data sheets presenting a typical system and a brief explanation of the case concerned.

2.4. IDENTIFICATION OF IMPROVED MINING WASTE MANAGEMENT BY THE INDUSTRY

2.4.1. Design of tailings and waste-rock facilities

The location of a new mine is the key issue, and a considerable amount of information of the immediate environment is required in order to make the "best choice" in terms of tailings and waste-rock facilities. The choice also concerns minimisation of mining waste (backfilling, selective waste handling of various types of wastes).[11] Many factors must be considered when selecting sites for the surface disposal of mining waste. Planning during the preliminary design stage of any mine development generally considers the following environmental issues:

- Existing land use,
- Where to site dumps in relation to topography, drainage systems, water bodies and residential areas, so as to minimise dump instability, water pollution (surface and underground), dust problems and adverse visual impacts,
- Location and direction of the groundwater flow, which can influence the migration of any contaminants reaching the groundwater,
- Allowing sufficient area around dumps for bunds or trenches to collect acid water runoff or for the placement of dams to collect seepage (leachate), runoff and sediments,
- Prevailing wind direction and strength, as waste dump materials may cause dust and noise problems downwind,
- Distance of disposal sites from the mining area or processing facilities,
- The siting of sub-economic grade material for possible future reprocessing when either technology or commodity prices permit,
- Avoiding the siting of tailings deposits (which can fluidise) above existing or proposed underground workings.
- Minimising transport-energy costs from the processing plant through using gravity transport when possible.

If a waste deposit can be located as close as possible to both plant and mine, this reduces the amount of land required to be disturbed and significantly reduces transport-related operating costs, particularly if any of the material is likely to be reclaimed for further processing. However, the selection of the location of waste facilities should take into consideration the environmental consequences of such decisions.

2.4.2. Tailings dam stability

Terrestrial embankments (dams) in areas subject to earthquakes or landslides are particularly vulnerable. Foundation conditions (rock or sediment type, compaction rate, etc) are important in terms of safety, environmental protection, reducing risks of seepage and groundwater pollution[12].

It is important that impoundment is designed with future closure in mind, so that it will remain stable, secure and virtually pollution free, with little maintenance required.

Standards should be laid down to ensure the safe management of tailing dams.[13] They do not prevent the realisation of a specific study

2.4.3. Waste characterisation

The waste characterisation is crucial to ensure a proper waste management and should systematically take into account all the following parameters:

- the different mineral species (speciation) present in the primary ore, including weathering minerals,
- the non-upgraded elements present, even in very low concentrations, can cause significant pollution if the tonnage handled is large,
- the industrial processes employed to treat this ore, as well as their yield and efficiency in terms of the recovery of the elements present in the various raw materials used,
- the material balance of the materials employed and those generated in the processes applied,

The state of the potential source is related to its behaviour into liberation of pollutants. A liquid source could be more transportable than a solid one.

The two phases of the potential pollution source are:

- **solid phase**: grain size distribution of materials, uniformity and isotropy of the soil, density, water content, permeability, pH, redox conditions, organic carbon and clay contents,

- **liquid phase**: pH, redox conditions, total and dissolved carbon contents, content of suspended matter (particularly for surface waters and effluents), major physicochemical composition (sulphate, chloride, phosphate, nitrate concentrations, as well as iron and manganese), aquifer lithology, hydraulic gradient, effective porosity.

Other parameters have to be considered:

- ***type of source***: dump/waste deposit or polluted soil, the latter possibly including waste or backfill spread on the surface,
- ***type of waste deposit/dump***: aboveground or buried.

2.4.4. Water management

Different steps have to be checked:

- Avoid pollution of groundwater and surface water,
- Collect and treat the polluted water and leachates,
- Minimise the water volume that require treatment,
- Manage the dust.

Measures used to control seepage from tailings dams include:

1. Controlled placement of tailings,
2. Foundation grouting,
3. Foundation cut-offs,

4. Clay liners,
5. Underdrains and toe drains,
6. Artificial liners.

1. Controlled placement of tailings is the most cost-effective method of controlling seepage. Provided that the tailings are of low permeability they will form a cohesive system.

2. Foundation grouting involves the injection of fluidised material and could not be effective unless there is high permeability rock beneath the impoundment or where there are high permeability zones in the rock.

3. Foundation cut-offs are necessary when soil foundations are sand or sand and gravel. A significant reduction in seepage may be achieved by construction of an earth fill cut-off or a slurry trench cut-off wall. They may be applied to extremely weathered rock such as laterised, highly permeable rock.

4. Clay liners can be effective in areas where the storage is located in an area of high permeability. They are susceptible to cracking on exposure to the heat (by sun), which can increase permeability.

5. Underdrains below the tailings should be constructed. The drains act to attract the seepage water and discharge it to a collector system, ideally for recycling to the process plant.

   Some methods of collecting and treating this seepage are required, such as:
   - Toe drains,
   - Pump wells,
   - Seepage collection,
   - Artificial wetlands.

6. Artificial liners are used to line waste disposal facilities, often with provision for drainage layers beneath the membranes to collect any leachate, which leaks past the first. However, these liners do not seem to be always appropriate for all tailings disposal situations (such as in case the underground water is confined and spouting out).

The control of the water balance in the system should include process water, tailings water, storm water runoff, precipitation, seepage from impoundment and into the ground, and evaporation (see fig. n° 6)

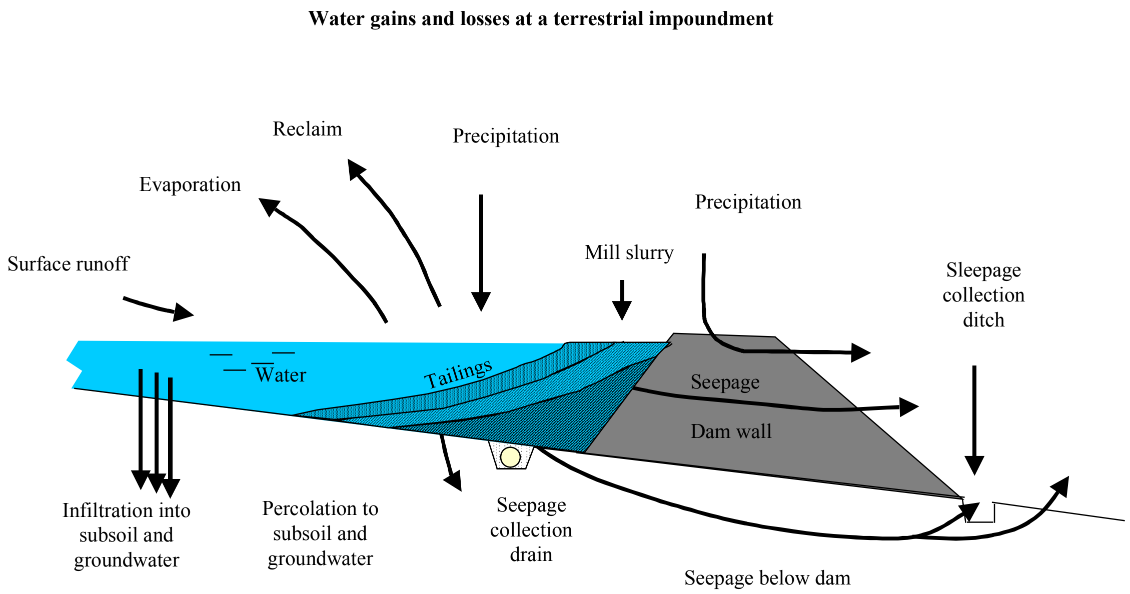


Figure 6: Scheme from Environmental Management of sites (UNEP[14])

Measures to minimise acid drainage and pollution from water containing dissolved metals, salts and process chemicals, are as follows[15]:

- Minimise percolation to subsoil and groundwater, by low permeability of the substrate and low permeable cover,
- Minimise seepage through the impoundment wall,
- Collect seepage by a collection and treatment system,
- Minimise influx of surface runoff by trenching and by-passing the tailings depository,
- Maximise circulation of process water,
- Minimise infiltration of water into the tailings dam.[16]

We can mention one of the most efficient ways to minimise the oxidation of sulphides and subsequent production of acid drainage, namely water covers (or water saturation).

A number of parameter has to be considered in selecting the solution to treat the different media affected, in relation with the investigated site. A partial list of factors necessary for this pre-selection of treatment techniques likely to be applied to the three media (air, soil, and water) is presented below. Others are specific to the pollutants to be treated.

For each of the geological and hydrogeological contexts (sheets Nos. 1 to 16 - cf. annex 5), a panel of actions is presented, aimed to limit or treat a potential pollution (cf. Table 13). These actions should be applied to reduce the effects if pollution of mining waste is shown. They are related to the different aspects (design, waste characterisation, dam stability, water management).

The recommended actions concern low permeability of the layer and the embankments, water and leachates treatments, aftercare actions and some extreme cases. The presented actions are just generic measures requiring detailed programmes for the implementation on site.

Action N°of context	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
to check the thickness and the homogeneity of the layer of clay (or with the lowest permeability) located between the bottom of the stockpile and the highest piezometric level of the subjacent underground water	X	X	X	X			X									
to measure the coefficient of permeability of the clay layer (or the lowest permeability)	X	X	X	X			X									
to divert surface waters (not polluted) coming from the upstream of the site	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
To pump the leachates to treat them		X		X	X	X	X	X				X	X	X	X	X
to channel the leachates to recover them and treat them (dams, channels)	X		X	X		X					X					
to cover with a tight cover and monitoring the site	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
to continue pumpings of underground water out on the existing works						X										
to create an hydraulic stopping by establishing pumpings immediate downstream of stockpile in order to create a cone of folding back to avoid the dispersion of the pollutants. Pumped water will have to be treated					X			X	X	X	X cas 1	X	X	X	X	X
to create a pumping of decompression to avoid the submergence of the stockpile						X										
to treat water of the upper underground water (if need be)	X	X	X		X		X	X	X	X	X cas 1	X	X	X	X	X
to seal old drillings and defective well				X									X			
to seal the sides of the deposit in unsaturated zone with underground water									X	X		X	X	X	X	X
to seal the bottom of the discharge in unsaturated zone								X				X	X	X		
to seal the sides and/or the bottom of the discharge in unsaturated zone					X	X			X	X	Xcas 1				X	X
to remove waste by excavation in unsaturated zone							X	X				X	X	X		
to remove waste by excavation in saturated zone					X	X			X	X	X				X	X
to collect and divert the underground water before it does emerge at the point of resurgence under waste											X					
to treat in situ waste on not very permeable layer	X	X	X	X												
to treat in situ waste on aquiferous layer in unsaturated zone							X	X					X	X		
to treat in situ waste on aquiferous layer in saturated zone					X	X		X	X	X	X cas 1	X			X	X

Tableau 13 Context description of possible action, according hydrogeological context

2.4.5. Case studies

This part of the report describes several environment accidents and their consequences. Table n°14 presents some examples of accidents or noted impacts, which have occurred in the field of the mining activities. Some examples of management of these environmental impacts are following in the table n°15 and 16.

Location	Date	Material & Causation	Size of Movement	Consequences	Reference
Cilfynd Common, South Wales (Coal)	1939	Waste flowslide	180,000 tons moved 0.4 km at not less than 30-35 kph and at times may have reached 80 km/h	Diverted river Taff, blocked 176m of road, blocked canal	Bishop 1973 Mc Kehnie Thomson & Rodin, 1973
El Cobre, Chile (Copper)	1965	Mine Tailings dams failures due to an earthquake	El Cobre: 2 Mt of material flowed up to 12 km	Pollution	Jeyapalan et al. 1981 Bloomfield & Seibel 1981
East Texas (Gypsum)	1966	Flow of liquefied tailings from impoundment caused by seepage	80,000-130,000 m3 of gypsum flowed 300m beyond toe of slope and failure extended 100 m back into the pond	Pollution	Jeyapalan et al. 1983
Florida (Phosphate)	1971	Tailings dike failure caused by seepage	0.8Mt released. Clay size particles with high water content and no residual strength flood like water	Peace river polluted over a distance of about. 120 km	
Mike Horse Dam Lincoln, Montana	1978	Tailings dam at a mill serving several mines breached by flood water following a small landslide	30m. wide breach released 153,000 m3 of tailings	Environmentally unacceptable material released into the upper Blackfoot River drainage area	Toland 1977
Vancouver Ridge, (Ok Tedi), Papua New Guinea (Copper & Gold)	1989	Mountain ridge at mine site failed	170 Mt of rock disintegrated and flowed 3,500 meters into the valley downstream from the ridge. Material moved at a velocity of 70-90 kph for first 2,400 meters	Landslide removed support from side of a mine waste dump and part of waste dumps also failed and released 4 million tons of mine tailings.	Read and Maconochie 1992
Placer Dam, Surigao Del Norte, Philippines (Silver & Gold)	1995	Failure of dam wall. Possible connection with magnitude 3.4 earthquake 7 days prior to failure. Top of dam wall used as road for trucks	50,000m3	Coastal pollution	Mining Journal Research Services 1996

Table 14 Example of major environment problems resulting from mining activities

Mine location, ore type	Start date of activities, mine type, total current annual volume of material extracted	Waste ; type and quantity or quantity of mineral produced	Disposal of waste	Environmental impact and geomorphic effect of waste	Source
Nike Collierry, Ohmuta City, Kyushu, Japan Coal	Underground 5 Mt clean coal		Tailings are thickened, the thickener overflow passing to settling ponds for clarification prior to discharge into the sea	Ventilation required the construction of two artificial islands	Mining Magazine 1985
Mount Isa and Hilton Mines, Mount Isa, Townsville, Queensland, Australia Lead-Zinc-Silver and Copper (Mt. Isa only)	Mt Isa 1935, Underground 12 Mt, Hilton 1987, Underground 1,5 Mt	Ore grade : Copper 3,75% Cu, Lead 5,4% Zinc : 7,6% Silver 133 g/t	Hydraulic fill is produced by desliming concentrator tailings in hydrocyclones, with about 57% weight of the tailings solids being recovered as fill and the remaining 43% being pumped into tailings dams.	Large quantities of fill of various types are used at Mt. Isa. The company operates a quarry nearby to obtain 3 Mt year suitable rock, which is mixed with, cemented hydraulic fill in a 2:1 rock/CHF ratio. In total, around 5Mt of solid fill material is used annually at Mt. Isa	Mining Magazine 1985
Mamut Mine, Ranau Sabah Malaysia (Copper Gold and Silver)	1975 Opencast 16Mt	15Mt overburden pre-stripped 10Mt waste rock and 5.9 Mt ore waste	Rock dumps. Tailings thickened to 45% pulp density flow by gravity through a 16km long pipeline to the tailings dam 900 m below the mine. To reduce the speeds of flow, the pipeline is sectionalised into 180 open drop tanks. Pipes are used on gentle slopes and open channels on steep slopes.	Hydroclorine separation of sand from tailings for dam wall construction. After tailing slime has sunk to dam bottom, remaining water flows into Lohan River	Faridah Fung 1992

Table 15 Case studies of some of the larger operational mines in S.E. Asia and Oceania[17]

Mine location, ore type	Start date of activities, mine type, total current annual volume of material extracted	Waste ; type and quantity or quantity of mineral produced	Disposal of waste	Environmental impact and geomorphic effect of waste	Source
P.T. Inco, Soroako, Sulawesi, Indonesia Nickel	1978 Opencast (integrated mine and smelter complex) 32,3Mt (expected to rise to 46,2Mt)	15,9Mt Litomite overburden. 12,7Mt oversize rejects 3,8Mt dry ore. Averaging about 1,9 %nickel is fed to the processing plant	Thin layer of topsoil (usually less than 0,5m) is stored for use in later revegitation. Limonite overburden (5-15m depth) trucked to disposal sites and later stabilised by revegitation	Revegitation of 440ha of land where mining has been completed, including 135 ha in 1995. Since 1993 the annual area reclaimed exceeds the annual area cleared. Ongoing studies of dust emission reduction and water recirculation	Chadwick (1996)
The Worsley Project, Boddington, Western Australia, Bauxite	1984 Opencast 7,75Mt (5,8Mt bauxite, whose horizon averages 6m and is overlain by av. 0.8m overburden)	Average grade of Bauxite is 30-32% alumina. The gangue minerals are predominantly iron oxides with some anatase and free quartz	Overburden is stripped and returned to nearby mined pits or separately stockpiled or later reclamation	All the bauxite is underneath native eucalyptus forest. The immediate post-mining landscape can be irregular due to variable floor depths and ridges of waste within the pit boundaries. Rehabilitation includes ripping any compacted areas, bulldozing the pit sides, and spreading gravel overburden, addition of topsoil and forest litter and re-seedling. No surface run-off control has been found necessary.	Hinde and Marantelli (1993)

Table 16 Case studies of some of the larger operational mines in S.E. Asia and Oceania (continued)

a. The tailings pond failure at the Aznalcóllar mine, Spain

The accident occurred on 25 April 1998 in the installation of Boliden-Apirsa, which exploited a mine at Aznalcóllar, Boliden-Apirsa had acquired the mine in 1987, while the mine had been in exploitation for a considerable number of years already.

The mine produces zinc-, silver-, lead- and copper-concentrates from a pyritical ore body. The pyritical ore, which also contains arsenic, cadmium, thallium and other metals in lower concentrations, is broken in the mine installations and milled down to a rather fine grain. Then, different metal compounds are separated from this fine-grained ore with the help of a flotation process, where water is used, to which sulphur dioxide (SO^2) calcium hydroxide ($Ca(OH)^2$), copper sulphate pentahydrate and an organic compound are added as agents, in order to promote flotation.

At the time of the accident, the tailings (the waste resulting from the above process) was discharged into an artificial pond (tailing pond), a common method for managing and disposing of this type of waste.[18] The pond covered a surface of about 1.5 km^2 and contained, at the time of the accident, about 31 millions tons of sludge. Around this pond, a dam had been erected to contain the tailings; the dam was regularly increased, as more quantities of tailings were added. The main material that was used for the construction of the dam came from the mining activity itself.

In the night between 24 and 25 April 1998, the dam around the pond broke at a length of about 50m. Some three million m^3 of sludge and four million m^3 of acidic waters were discharged into the adjacent environment, where about 4.500 hectares of land on the border of the Coto Doñana National Park were polluted, and into the river Guadiamar. The major part of the sludge remained in the neighbourhood of the pond, where layers of sludge with a thickness up to two meters were found, the thickness decreased progressively with large parts of the affected land being covered with a layer of about 20 cm, but diminishing down to some millimetres. No damage to humans occurred. 2500 ha of the affected area was covered with tailings; the other 2000 ha were affected by acid waters but not by tailings. The spill entered the Agrio River, which flows into the Guadiamar River 4 km south of the tailings pond. The Doñana national park was not affected by the spill.

Local, provincial and regional authorities and the operator of the mine undertook emergency work to contain the sludge and waters, in particular in order to protect the natural reserve of Coto Doñana. Clean-up work continued during most of 1998 with additional re-cleaning of some areas in 1999. The sludge and contaminated soil were brought and disposed of in the old pit of the mine of Aznalcóllar in the north of the tailing pond. The tailings pond is currently undergoing decommissioning. Following authorisation from the regional government of Andalusia, the mining operation restarted in 1999, temporarily using the old pit of Aznalcóllar for tailings disposal.

Phase one – 1998: The immediate damage had been done. Apirsa's priority was to avoid secondary damage in the medium or long term. The spill had happened just as the rainy season was ending. [19]It was urgent to complete the cleanup before the next rainy season began, and prevent the rains from causing the metals in any remaining tailings to leach into the environment. Apirsa built a private road to keep trucks off public thoroughfares. The waste was deposited for safe, approved storage in the depleted Aznalcóllar open pit adjacent to the Los Frailes mine. By late 1998, more than 99% of the tailings in Apirsa's northern sector had been removed and safely deposited in the depleted Aznalcóllar open pit. Site-specific criteria for metals in soil were established by Spanish environmental authorities providing guidance for further remedial actions. Chemical elements in soil and sediments have to respect the following criteria (table 17), according to the near future land use. The clean up results show the rate of soils passing criteria.

		Criteria		Clean up results	
	Baseline	Sensitive land use	Less sensitive land use	Sensitive land use	Less sensitive land use
	mg/kg	mg/kg	mg/kg	% passing criteria	% passing criteria
As	52	52	100	3	59
Cd	-	5	10	100	100
Cu	120	250	500	92	100
Pb	86	350	500	76	99
Zn	366	700	1200	86	100

Table 17 Re-use criteria for soil

Arsenic concentrations meet the criteria on at least 59% of the affected lands (on 73% of agricultural land). The remaining affected lands; mostly abandoned gravel pits, and may require additional remedial action in the future. This could involve chemical stabilisation of arsenic and metals, possibly combined with the application of clean soil. Water quality in the river improved rapidly.

Phase two – 1999: With phase one of he cleanup completed, the rehabilitation phase has begun and will continue through 1999. Investigations to form the basis for resuming the agricultural use of the land began in 1998 with greenhouse tests using soil from various areas. Once rehabilitated, the land is expected to be safe for agriculture. The Spanish governmental authorities have, however, stated their preference to turn the area into a Green Corridor linking Doñana National Park with Sierra de Aracena y Picos de Aroche National Parks. An international panel was commissioned to review the environmental impact of the accident and the reclamation planning.

The Apirsa tailings ponds was designed and built in 1977-78. Boliden bought Apirsa in 1987. The tailings dam was regularly inspected. In 1996, independent experts conducted a full-scale stability study of the dam. No signs of instability were detected. At the recommendation of the study, Boliden installed extensive new instrumentation to enhance monitoring.

Apirsa assumed responsibility of cleaning up the northern sector below the tailings dam (an area of approximately 800 ha containing about 80% of the discharged tailings). The Spanish governmental authorities assumed responsibility for cleaning up the southern sector below the tailings dam (an area of approximately 1,800 ha containing the remaining discharged tailings). According to he final results of the in-depth expertise, all the geological parameters have not been taken into account during the conception of the dam, in particular geological structures. Indeed, the accident is due to a slip of the whole of the dam. The slip thus caused a breach in the dam.

It has been concluded that any mismanagement or other actions did not cause the accident. The cause of the accident was a slide in the subsoil 14m below the foundation of dyke. Neither the dyke itself nor the management was the reason for the failure. The mistakes committed were done already in the characterisation of the geotechnical properties of the underlying clay during the design phase in the seventies.

b. Cyanide dumping at the Baia Mare mine, Romania

This abstract is made from different reports including report from the Baia Mare Task Force.

On 30 January 2000, a dam at the Aurul smelter of the "Baia Mare" goldmine at Sasar/Romania broke[20]. An estimated 100,000 m3 of mud and wastewater with a 126 mg/litre cyanide load entered through de-watering channels into the Lapus River, a tributary to the Somes (Szamos) river and from there into the Tisza river and the Danube upstream of Belgrade and finally entered the Black Sea. The acute transboundary pollution had the potential of having a severe negative impact on biodiversity, the rivers' ecosystems, drinking water supply and socio-economic conditions of the local population.[21]

Romania, Hungary and the Federal Republic of Yugoslavia performed sampling and analyses. Measurements on 1 February 2000 at Satu Mare on the Somes showed a maximum concentration of cyanides reported to be 7.8 mg/litre (compare with maximum limit value for surface waters of 0.01 mg/litre). A 30-40 kilometre long contaminated wave wiped out flora and the fauna of the central Tisza River with damages estimated of hundreds of thousands of €. The cyanide plume was measurable at the Danube delta, four weeks later and 2000 km from the spill source.

Acute effects, typical for cyanide, occurred for long stretches of the river system down to the confluence of the Tisza with the Danube: phyto- and zooplankton were down to zero when the cyanide plume passed and fish were killed in the plume or immediately after. The Hungarian authorities provided estimates of the total amount of fish killed in excess of one thousand tons, whereas the Romanian authorities reported that the amount of dead fish reported was very small. According to the Yugoslavian authorities a large amount of dead fish appeared in the Yugoslavian part of the Tisza river. No major fish kills were reported from the Danube. Soon after the cyanide plume passed, the aquatic microorganisms recovered rapidly. Long-term effects on bio-diversity will have to be shown from further analysis. Environmental experts fear that some rare and unique species both of flora and of fauna have been endangered, e.g. the five ospreys living in the Hortobagy National park in Hungary. It is difficult to assess the exact damage caused by the accident as the river had been subject to long-term chronic pollution from the mining activities in the region.

Timely information exchange and precautionary measures taken by the Romanian, Hungarian and Yugoslavian authorities, including a temporary closure of the Tisza lake dam, mitigated and reduced the risk and impact of the spill. The water supply of the two largest cities along the Tisza River, Szolnok (120,000 inhabitants) and Szeged (206,000 inhabitants) was not endangered due to the prompt action of the local authorities.

Villages close to the accident site were provided with alternative water sources, but were allegedly not informed about the spill sufficiently early. Downstream drinking water was not affected because of the use of alternative supplies and deep wells. Consequently, immediate human health risk seems to be minimal from this spill alone, but chronic health impacts due to long-term pollution by heavy metals are possible.

The spill occurred in an area already contaminated with heavy metals from a long history of mining and metal processing. Upstream locations unaffected by this particular spill also contained high levels of some heavy metals. Thus, the accident occurred in a region with a number of poorly maintained and operated plants and flotation ponds containing cyanide and/or heavy metals, many of which are leaking continuously. There is a risk of further pollution of surface and groundwater as well as soils due to continued leaking or acute accidents.

The allowed standards of drinkable water out of cyanide are of 0.2 mg/l (source US-EPA) and 0.07 mg/l for WHO. The UNEP report mentioned 15 tons of dead fish.

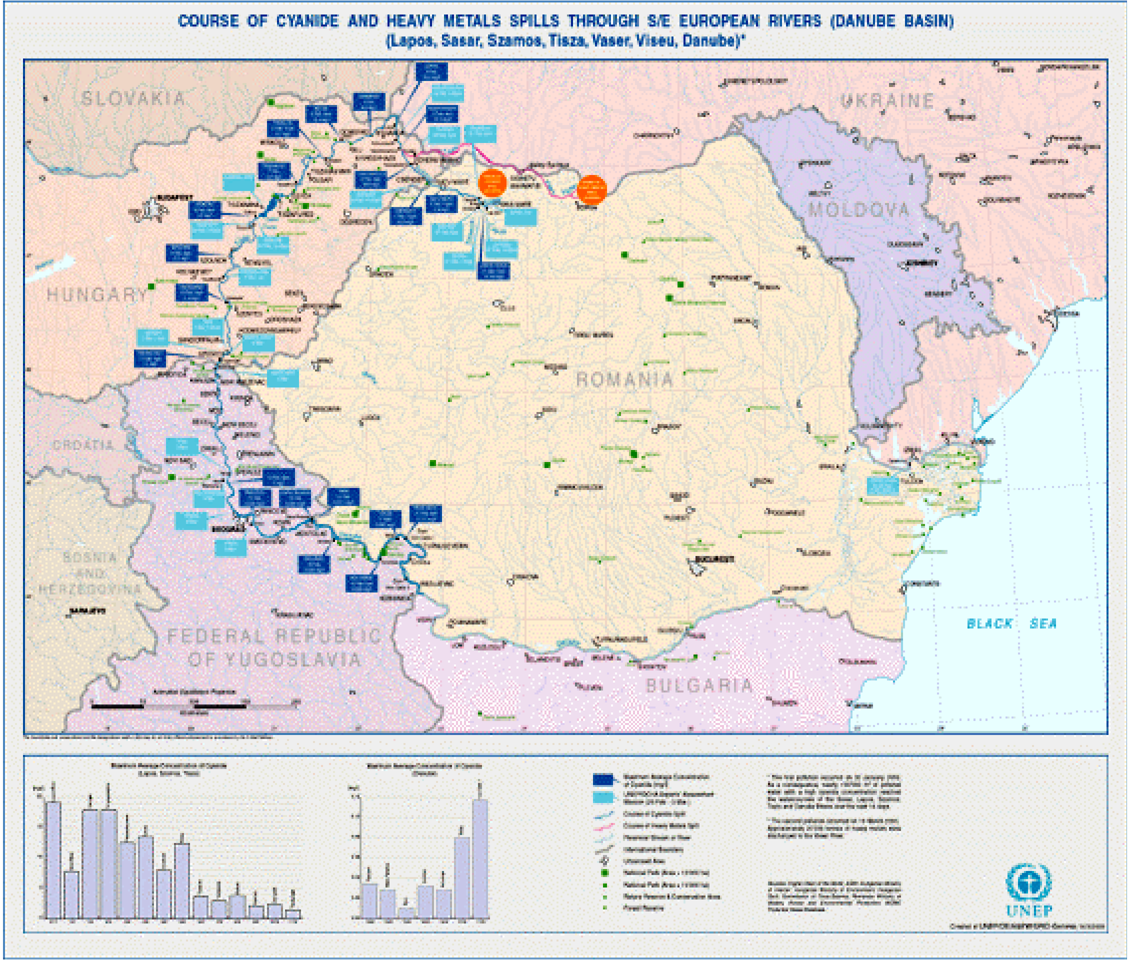


Figure 7: Evolution of cyanide levels belong the Danube river (UNEP)

The direct impact of the discharge of cyanide seems to have had finally a limited impact along the time but widespread heavy metals will have probably more persistence[22]. Cyanide, when released in the environment is not stable and can quickly be degraded by numerous reactions.

The use of cyanide for an industrial economical extraction of gold from ores is practically at this stage of technological development unavoidable. World practice has demonstrated the need to take appropriate measures, in particular to remove cyanide from the tailings.

An analysis of the accident reveals design deficiencies, operational shortcomings and outlet structures to prevent overtopping of the embankment. Moreover, due to effects like acid mine drainage, soil erosion and wind blown dust, which can be observed at many places in this area, chronic pollution of soil, water and air is caused by heavy metals. High concentrations in river sediments were found not only downstream but also upstream from the Aurul dam accident area. There is a high background contamination of heavy metals all around the mining area. Important are long-term effects of the mining activities on public health and nature.

The essential questions are:

- did waste management methods seem adequate?
- did the companies involved have certified environmental management systems (ISO 14000, EMAS) in place?
- were the installations well designed, operated or controlled?
- were regulatory and enforcement powers duly exercised by the competent authorities?

2.5. INVENTORY AND ANALYSIS OF LEGISLATIONS

Mining today, like other industrial activities, is subject to environment protection laws, regulation and standards. Mining operation and environment protection requirements are most commonly implemented through a variety of different legal tools, such as:

- Mining legislation,
- Environmental planning and assessment legislation,
- Environment protection legislation,
- Other legislation and standards, including occupational health and safety.

Government roles in environment protection are gradually evolving in response to changing perceptions in mining operations. Developments in the ownership and control of mines and metal production facilities have greatly influenced both the locations of mining and investment in new mines in Europe and around the world.

2.5.1. Mining waste

In the industrially developed countries, the growing attention of the public and the governments paid to methods of mining waste disposal and the quality of the effluents discharged into the environment has led to the publication of laws as well as regulations. The regulations accordingly fit into a national framework in most cases.

a. Canada, the United States of America, Australia, Malaysia, Mexico

More specifically, in Canada, laws have been enacted both for the Provinces and at federal level.

Apart from radionuclides, which come under the Atomic Energy Control Bureau, the Canadian Federal Ministry of the Environment has stiffened the legislation on effluents generated by mining waste. The main points that emerge are:

- Prohibition to dump certain substances,
- Establishment of limit values on quality of the effluents,
- Determination of limit contents authorised in terms of chemical compounds present in the materials stored.

This regulation applies to:
- Geotechnical stability of disposal sites,
- Pollution control in the different environments,
- Environmental impact of disposal, management, remediation and redevelopment operations.

The standards drafted at the federal level in Canada represent maximum basic values and the local environmental agencies must define the specific values for the sites concerned, values, which may be lower than the nation wide values. The regulations on water management are based on controlling releases and in this sense, reinforce the responsibility of the mine operators in the management and treatment of the waste within the geographic limits of the mine, using the best technique at the optimal economic level.

Whether in **Canada** or the **United States**, the guide values applied at the periphery of the mines are determined according to each type of operation, based on the hydrogeological, physical, chemical and biological properties of the waters receiving the effluents.

In **Australia**, another country with a large mining industry, the mining industry is governed by the Australian Mineral Industry Code for Environmental Management, published in 1996.

This Code requires the companies to publish a public report each year on the environment (Public Environment Report). The terms of this report must normally at least contain information on the following subjects:
- Position of the company with respect to environmental permits,
- Position of the company with respect to environmental laws,
- Any prosecution or conviction,
- Regulations or orders relative to the environmental legislation specific to the industry and the site,
- Major incidents,
- Facts or circumstances which may have an effect on the environmental aspects and which have had an impact on the performance of the company.

Malaysia's current mining legislation is limited in scope because it deals almost exclusively with the small-scale alluvial tin mines that have dominated the country's mineral sector. In order to attract foreign investment, Malaysia has proposed new legislation for large-scale hard rock mining. The proposed legislation includes specific requirements for tailings management such as:
- A detailed plan,
- A design that complies with good engineering practice,
- Construction under the supervision of a professional engineer,
- Stability against any static and dynamic loading,
- Free board not less than one metre.

The Mexican Official Standard, approved in 1997, stipulates the compulsory requirements for site selection, construction, operation and monitoring of tailings dams. These requirements include:

- An environmental impact study,
- Compliance with laws governing the preservation of historical or cultural heritage,
- Assurance that there will be no percolation of toxic leachates to the nearest aquifer or surface water body during the next 300 years,
- Approved plans for surface and groundwater monitoring,
- Detailed characterisation of the underlying geological structure and the mechanical properties of rock formations and soil deposits,
- Land surveys of the site to delineate elevations and features such as roadways and pipelines,
- Compliance with civil works design standards for dams of the Federal Electricity Commission,
- Monitoring instruments for dams over 50m in height.

b. European Union

At the European Union scale, no specific legislation exists today on waste from mining operations, neither the extraction of industrial materials, the processing of ores or industrial materials. Each of the member States has its own mining and environmental legislation which more or less completely and sometimes separately covers the different branches of activity mentioned above.

European legislation distinguishes between horizontal legislation relative to environmental management and legislation by specific sectors, products or types of emission (Air, water, and waste…). The horizontal legislation concerns the environment management: the collection and assessment of the information on the environment and on the impact of a large number of human activities. The vertical legislation concerns the specific sectors.

“Mining waste” stands for “waste resulting from prospecting and extraction treatment, and storage of mineral resources”. The definition of “waste” is laid down in Directive 75/44/EEC on waste as amended by Directive 91/156/EEC. “Mining waste” therefore covers all material which “the holder discards or intends or is required to discard”. “Mining waste” would cover in particular topsoil, overburden, waste rock and tailings, which are discarded.

The environmental aspects are playing a growing role in the mining of ore. The extraction of mineral substances can no longer be considered without reference to an environmental legislative framework. Among the Directives listed in the following paragraph § 2.6.2., we can mention the European Directive of March 3, 1997 (97/11/CEE) (J.O. L73 of the 14/03/97) modifying the Directive n° 85/337/CEE related to the assessment of the effects on the environment of some projects (private or public). It specifies in its appendices the types of projects, which must be subject to an evaluation of the environmental impact. Among these human activities, we can quote the quarries and the open pit exploitations whose surface exceeds 25 ha and the plants producing non-ferrous metals from ores, concentrates or secondary matter. The quarries or the smaller open pits and the underground mines are prone to evaluation according to criteria determined by the Member States (Appendix n°II of the Directive).

2.5.2. Framework of European legislation on industries, waste and water

A specific legislation on mines and mining activities does not exist in the European Union. Mining operations are covered indirectly by more general legislation than that of the IPPC. In fact, in certain Directives, the mine is excluded if specific legislation exists.

There is a need to train the decision-makers and for stiffer legislation in connection with the enlargement of the European Union. Legislation could be one of the tools to prevent accidents as the twos mentioned earlier (Spain and Romania).

On the 23rd of October 2000, the European commission published a communication on sage operation of mining activities [COM(2000) 664 final] presenting existing Community environmental legislation related to mining activities. The Communication sets out three priority actions envisaged to improve the safety of mines, relating to industrial risk management, management of mining waste and integrated pollution prevention and control:

- an amendment of the Seveso II Directive to include mineral processing of ores and, in particular, tailings ponds or dams used in connection with such mineral processing of ores[1];
- an initiative on the management of mining waste covering the environmental issues of the management of mining waste as well as the best practices, which could prevent environmental damage during the waste management phase[2];
- a Best Available Techniques reference document (BREF) describing the Best Available Techniques of waste management to reduce everyday pollution and to prevent or mitigate accidents in the mining sector[3].

The European legislation relating to industries and waste must be regarded as a framework in which the Member States and the Union, in close collaboration, must develop the basis of a durable protection and a management of underground water.[23]

a. Legislation on waste

The definition of responsibilities at national level in the area of waste is governed by Article No. 5 of the Council Directive 75/442/EEC of 15 July 1975, which states that "the Member States shall establish or designate the responsible competent authorities, in a given region, for the planning, organisation, authorisations and control of operations pertaining to waste dumps".

European Directive on waste management: this is the Framework Directive on waste 75/442/EEC amended by Directive 91/156/EEC. Mining waste are excluded if they are

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[1] For more information on this initiative, see the following web page on the revision of the Seveso II Directive: http://www.europa.eu.int/comm/environment/seveso/consultation.htm

[2] See following web site: http://www.europa.eu.int/comm/environment/waste/mining.htm

[3] This initiative falls under the competence of the European Integrated Pollution Prevention and Control Bureau (http://eippcb.jrc.es/), part of the Institute for Prospective Technological Studies (IPTS) in Sevilla.

not covered by another legislation. At present, there is no Community legislation covering mining waste. As confirmed in the Communication of the Commission on the safety of mining activities, mining waste fall under the scope of the framework Directive on waste. Directives 75/442/EEC and 91/156/EEC state in Article 4 that the Member States must take the necessary measures to ensure that "the waste are recovered or disposed in such a manner that they have no impact on human health or any environmental damage".

The European Directive concerning landfill of waste: Directive 1999/31/EC of the Council, dated 26 April 1999. Directive 1999/31/EEC on landfill of waste entered into force on 16 July 1999 and will be effective 16 July 2001. This Directive lays down a number of provisions related to safe disposal of waste. According to the scope of this Directive (Article 3.2), the deposit of non-hazardous inert waste resulting from prospecting and extraction, treatment, and storage of mineral resources as well as from the operation of quarries is excluded from the Directive. In addition, according to Article 3.3, Member States may, under certain circumstances, exempt from certain technical provisions of Annex I of the Landfill Directive the following waste: non-hazardous, non-inert waste resulting from prospecting and extraction, treatment, and storage of mineral resources. In this Directive, the surveillance programme for water, leachates and gases was set up. The results of this monitoring must be sent to the competent Authorities. In Article No. 12, the Directive specifies the inspection and monitoring procedures to be set up. Hazardous and non hazardous (not inert) wastes from mining activities are covered by this landfill Directive.

It should be noted that the Landfill Directive was adopted primarily to regulate the disposal of waste into normal landfill sites. All the issues related to tailing ponds management have not been specifically considered in this Directive. However, there are a number of provisions of the Landfill Directive, which are relevant to mining waste management. This provision of Directive 1999:31/EC should apply to this waste and should be laid down in the “mining waste initiative”.

Article 4 requires that different types of waste should not be mixed (some specific examples can be in contradiction, these can be considered excluded from the scope of the Landfill Directive, because considered as treatment operations). Article 7 includes essential provisions for the management of “mining waste” such as the requirement for a plan for closure and after-care procedures. Specific issues are added such as the expected long-term behaviour of mining waste, the question of dam stability and the requirement that a waste management plan be drawn up and accepted by the competent authorities. Article 14 specifies that deadlines of existing landfill sites should be further elaborated.

The definition of treatment in the Landfill Directive does not specify in technical details the treatment to be applied to each type of waste. This could include various techniques, which are applied for the disposal of “mining waste”. Processes generating waste should be designed in such a way as to reach the objectives of waste prevention as well as to facilitate the handling and recovery of “mining waste”. The treatment requirement should apply to some type of waste and not to certain exemptions as certain waste from potash or coal mines.
The article 11 mention that the composition, leachability, long-term behaviour and general properties of “mining waste” to be landfilled should be known as precisely as

possibly. One of the main characteristics to be tested is the potential for the production of acid leachate. There is a need for a rapid test (the current one may take several weeks). The other tests standardised in CEN/TC 292 could be applied when the material is not sensitive to oxidising conditions.

In conclusion, mine waste management, as an integrated part of the mining process cannot be compared directly to the landfill concept. This issue actually presents opportunities and set limits:

- Process design will have an impact on the waste and the properties of the waste can be influenced through changes in the process,
- the waste management practices put in place will influence the characteristics of the waste,
- the tailings pond is often used as a passive water treatment facility and can be used to increase water recycling,
- backfilling of tailings underground means certain requirements on infrastructure and mine planning.

The European Waste Catalogue and the list of hazardous waste have been revised (Decision 2001/118/EC) are currently being revised. Certain mining waste are now covered in the list of hazardous waste.

Council Directive 92/104/EEC 3 December '92 refers to tailings dams as well as other EU environmental legislation which is applicable to the sector.

The increase in the technical definition criteria for sites able to receive disposal facilities and operating criteria inevitably means a decrease in the capacities of the sites and higher costs. This consequence encourages the companies to minimise the production of waste and to identify new recycling opportunities.

b. Legislation on industries

The European Directive on pollution prevention 96/61/EC of 24th September 1996 (IPPC: "Integrated Pollution Prevention and Control (IPPC)" is the title of a framework Directive adopted in September 1996 presenting the measures and procedures necessary for an approach to protect human health and the environment, by preventing or minimising emissions from industrial installations. This regulation stipulates inter alia that the operating permits must be based on environmental quality standards (air, water, soils and waste), considering the requirements of the best available techniques (BAT). This document on the best available techniques takes into account each metal and presents the processes and techniques applied the consumption and metal emission levels. [24]

Installations producing "chemical concentration of metals produced from ores" are included in Annex No. 1 (cat. 2.5.a.) of the Directive on classified installations. The activities concerned must use secure techniques derived from the Best Available Techniques, monitor and prevent any accidental pollution. It is the duty of the local authorities to specify the notifications and financial aspects in case of environmental impact. This Directive has been applicable since 1999 to new activities, and will be mandatory from 2007 for existing operations.

The IPPC Directive may not cover all sites in the European Union where tailings dams are used. They could either not be production sites, not be producing crude metals, or not be regarded as landfills falling under category 5.4 of Annex 1 of the Directive.

The Council Directive 85/337/EEC relative to the assessment of environmental impact. This Directive, related to the assessment of the effects of certain public or private projects on the environment, has been amended by Directive 97/11/EEC and Directive 92/104/EEC relative to the safety and health of the workers in surface and underground mining industries. It is an integral part of the laws on mining operations in most of the Union countries. It clarifies the 1985 Directive on certain points:

- It broadens the field of application to new projects,
- It specifically requires an examination procedure through which the member States will determine the projects requiring an environmental impact assessment,
- It reinforces the requirements pertaining to projects with inter-border effects,
- The Member States had to transpose the Directive on the Environmental Impact Assessments before 14 March 1999. The Commission set regulatory measures against a number of States which had not done so (Austria, France, Luxembourg, Germany, Greece, Spain and the United Kingdom) by this date.

The Directive related to Strategic Environmental Evaluation: Political agreement was reached on the future Directive on the strategic environmental assessment. The aim of this future Directive is to ensure that the environmental impacts of certain plans or programmes are identified and evaluated during their preparation and before adoption.

The Environmental Management System (EMS) and the Audit and Eco-Management Scheme (EMAS): The concept of Environmental Management System was set up on 29 June 1993 (1836/93) and amended in Regulation (EC) N°761/2001. It allows the voluntary participation of the companies in the mining sector in an audit and eco-management scheme. This structure addresses sites, which have established an environmental management system and produced a public statement on the environmental management of the site. This system applies to industrial sites and waste disposal sites, recycling sites, mining operations and electric power plants demonstrating their systematic and approved approach to any potential impacts.

Council Directive 76/464/EEC on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community

For relevant pollutants, which have to be identified out of a wide range of other substances including cyanides and heavy metals, the Member States must establish national emission reduction programmes. In relation to mining activities, there is pollution potential from certain dangerous substances, which may cause a deleterious effect on the aquatic environment. The identification of such pollution leads to a requirement of authorisation of discharges containing the relevant pollutants. Hence, an effective pollution control of point sources from mining would be possible under the Directive.[25]

c. Specific legislation on water

At European level, the management of water is based on an integrated management. This management depends on quality standards of the environment, limiting values of emission and other legislation related to the habitat, the clarification sludge, SEVESO or the impact studies.

Directive 2000/60/EC adopted on 22 December 2000 is the operational tool for the implementation at national level of the European Water Policy.

The addition legal texts are mainly the following:

- **Directive 75/440/CEE** on potentially drinkable water, which introduce the notion of protection of raw water resources and define target values.
- **Directive 76/464/CEE** on hazardous substances (two lists : the most hazardous substances which need authorisation and an inventory and the other substances which only need authorisation and a reduction programme,
- **Directive 80/68/CEE** on underground water (substances from list 1 do not be rejected, substances from list II have to be studied and need an authorisation before any reject). This Directive mentions the precautions to manage the pollution by monitoring, asks for information when underground water is under two countries and ask for information to the Commission,
- Some other Directives such **82/176/CEE or 84/156/CEE** on mercury**, 85/513/CEE** on cadmium,

2.5.3. Regulation on the closed mining sites

No European regulation exists today that applies specifically to close mines and closure procedures. However, since the mine sites can be identified under cover of the Landfill Directive, Articles No.12 and 13 of this Directive (1999/31/EEC) specifies the closure conditions of this type of site. Existing operations, as far as they are covered by the Landfill Directive, have to comply with the Landfill Directive after the closure of the mine. Proper closure and remediation procedures should be applied for “mining waste” disposal sites.

Old mining sites can be taken into account within the framework defined by the work groups CARACAS (concerted action on risk assessment on contaminated sites) or CLARINET (Contaminated lands and risk assessment network on European technologies).

2.5.4. Comparison of legislation related to mining waste in the member countries of the European Union

We gathered the great principles of each national legislation within the European union as regards waste and more specifically of mining waste (cf. Annex n°7).

In a general way, the overall scope of the raw materials acts is to ensure that exploitation of raw material deposits takes place as an element of sustainable development and is balanced against other planning needs and also takes into consideration various environmental and socio-economic aspects. The raw materials planning is incorporated into the overall land-use planning. [26]

The study of the answers given by the questionnaires shows that the previous European legal framework is integrated in the national legal framework of the different countries of the European Union.

The mechanisms for controlling mineral extraction in part reflect the historical evolution of the ownership of mineral rights. A number of Member States have a strong tradition of centralised control over mining and quarrying through a mining authority, which is usually part of the department of trade, industry or economic affairs. Although the same countries generally have a land use planning system also complements the mining legislation; the principal means of control usually still resides with a mining authority. In England, the control of mineral extraction is exercised through the Town and Country Planning Acts administered by the Department of the Environment, but implemented principally by local planning authorities.

Environmental assessment seems to be harmonised in the extractive industry. Co-ordination of procedures has been achieved. Nevertheless, some significant variations between countries do exist in term of permitting procedures and level of environmental requirements.

Restoration of worked out mineral workings is considered as a high priority in most Member States, and restoration conditions or their equivalent are in use in certain countries. Aftercare conditions are less common, although the principle of long term management of restored land is broadly accepted.[27]

3.CONCLUSIONS/ RECOMMENDATIONS

At the request of the Environment Directorate-General of the European Commission, BRGM (Bureau de Recherches Géologiques et Minières) has conducted a study on the management of mining, quarrying and ore-processing waste in the European Union.

The mining sector is a major contributor not only to the material needs, but also to the development and economic growth of the European countries. On the other hand, it is obvious that exploitation of mineral resources requires a responsible approach to avoid adverse effects on the environment.

3.1. MINING WASTE INVENTORY AND RISKS EVALUATION

The first aim of this study is to assess the different types and the quantities of mining waste, all over the European Union. An inventory was carried out on the basis of a questionnaire relating to the activity of the mining sites (type of ore, production, duration, mining and ore processing techniques, etc) the quantities of waste obtained, the nature. Furthermore, the environment of the sites (air, underground water, surface water, and population) and the mining waste regulation in each Member State were analysed.

This study was carried out by subcontractors chosen amongst the specialised organisms of the EU countries, in general, the National Geological Surveys (institutions having often in their responsibilities the inventory of mining waste inside their respective countries), under the coordination of BRGM.

Such inventory is the first one to have been carried out on a systematic basis at the European scale. At a next step, two possibilities are possible: simplify the questionnaire or make the inventory by one specific and homogeneous team with environmental, mining and chemical aspects.

3.1.1. Risks linked to mining waste

An important conclusion of the study is that the major risks linked to mining waste (not all mine or all mine waste) are double:

- Risks linked to the liberation of acidity and heavy metals caused by the modification of the relationship between the minerals, the surface and ground water and the atmosphere (especially metallic ore). Such risks could correspond to a continuous and long-term pollution, which will not stop before total oxidation of the waste exposed to the atmosphere. This risk is the combination of a potential source of pollution with transfer pathway and the existence of targets (human here).
- Risks linked to the stability of the tailings dam. Such risks could create spectacular accidents as those occurred recently in Spain and Romania.

The combination of the two kinds of risks could cause the worst problems (Aznalcòllar – Spain).

a.- Liberation of acidity and heavy metals

A specific characterisation of representative waste samples resulting from mining, quarries and ore processing operations should be carried out on each site. Such characterisation should include specific studies related to the potential of pollution of the waste. Not only the solid composition but also the nature of the leachates resulting from mining waste should be defined (as it is a common practice for industrial waste within the framework of the Landfill Directive) and be correlated to the quantity of corresponding waste. Indeed, the effluents resulting from deposits of mining waste may be acid and contain heavy metals in significant quantities, with a potential impact on the environment.

The leachate of mining waste will also depend on the waste management practices implemented.

b.- Stability of the tailings dams

It seems necessary, at the scale of EU, to have a global estimation of the risks presented by the stability of the different existing tailings dams. Experience sharing must be promoted.

The two recent accidents, which have occurred in Spain and in Romania, were directly linked to the stability of tailings dams, under very different geological, climatic, legal and administrative circumstances. We could consider that the stability conditions of the tailings dams are today well defined[28] and should be part of minimum technical requirements. In each member states, it is the responsibility of the National authorities to assess the corresponding risks. In addition, an approach at EU level seems necessary to address this issue.

3.1.2. The different types of mine

It is obvious that the pillar of sustainable development related to the protection of environment has not always been sufficiently considered, in particular in the past. As a consequence, a distinction should be made between the following three types of mines:

- Abandoned/ old mines,
- Operating mines substantially based on old designed operations,
- Operating mines based on new design.

1. Serious problems are arising from abandoned mines and mines which activity is based on old operations which have been conceived without environment management. There is a need of basic criteria for mine closure plans, which can be based on the methodological approaches such as defined in European working groups like CARACAS (Concerted Action on Risks Assessment for Contaminated Sites) or CLARINET (Contaminated Lands and Risks Network for European Technologies). In particular, for abandoned mines, it is important:

- to establish objectives for required future land use and not accept multifonctionality of sites,

- to undertaken survey (including land form, geology, soil types, hydrogeology, flora and fauna components, existing land use, heritage, characterisation of overburden and waste material, recycling potential,…) to obtain a clear picture of the situation.
- The following methodology is proposed :
    - inventory of the sites (location, types of facilities, waste),
    - prioritisation of the sites in term of general environmental impacts and risks,
    - evaluation of the risks (including dam safety) and measures to be taken,
    - remediation plans to address the most problematic sites.

2. For operating mines substantially based on old designed operations, it is essential to evaluate the reliability of the control routine related to the stability of the tailings dams. It seems also necessary to improve the waste management conditions of these sites. Relatively diverse situations do exist in the EU and between sites in the same countries, in terms of environmental protection[29].

3. Existing mines based on new design ensure a higher level of environmental protection. However, these sites should also be evaluated with the views of taking additional measures if necessary. The closure phase should also be carefully prepared. This is often taken into account.

3.1.3.Research and development

The recycling of valuable elements of the waste should be encouraged, through R&D efforts. Certain waste contains elements which could be very useful for the industry and which are obtained from other sources at a non-negligible energetic and environmental cost.

Environmental disequilibrium is created rather by the physicochemical changes related to the extraction of the ores that by the chemical substances added during the processing. This could be further studied.

Research and development programs must be built on sets of themes, specific to the various methods of mining waste management.

3.1.4. Limits of the method

This report is based on country-by-country inventory, within the European Union, of sites associated with the management of mining, quarrying and ore-processing waste. It represents the first overview of the current situation in Europe as regards mining waste and presents the current regulatory and management measures specific to each country.

The survey involved two approaches:

- a questionnaire related to the quantities of existing waste, associated with the typology of the mined substance(s), deposit(s) and mining systems and ore-processing method(s),
- an estimation, on the basis of the different processes employed throughout the production chain in mining operations and their management at each level, of the main types of waste generated over the last five or ten years.

The data provided by the questionnaire is very diverse, heterogeneous and not easy to assess and compare.

To get a reliable set of information of the EU situation regarding the mining waste disposal, we also have been extrapolating the current production data in order to get a preliminary estimate of what could be the waste production, over the last five or ten years.

The comparison of this estimate with the data issued from the questionnaire shows several differences, which are due to:

- different kinds of mining waste, both from exploitation and processing,
- different approaches and definitions. Several materials, which can be called waste, have an important potential of recycling within a given environmental and economic framework and are not regarded locally as waste despite the legal definition of waste.

3.2. EVALUATION OF THE LEGISLATION

The second aim of the study was to evaluate the current national and EU legislation on mining waste.

It is necessary to find a compromise between the approach by legislation and the approach by Best Available Technologies. Legislation fix objectives and rules, and BAT present the technical aspects (as said earlier, legislation and guidelines do exist in Australia, Canada, Norway, Sweden and the United States).

In EU countries, the mining industry is currently regulated by either mining codes, which include waste management regulations, or by general environmental regulations.

The control of the environmental impact of mining waste has known a recent development within the European Commission. This is why, it is suggested to consider the conclusions of the different studies and corresponding laws, done in developed mining countries such as Canada, the USA or Australia where programmes have been carried out and are going on, in particular the programmes MiMi (Mitigation of the Environmental Impact from Mining Waste) (Swedish programme) or MEND 2000 (the Canadian Mine Environment Neutral Drainage Programme) (see Proceedings from the fifth international conference on acid rock drainage – ICARD 2000 – ISBN 0-87335-182-7)[30]. Various initiatives relating to the development of a Code of Practices of environmental management are under development within some mining companies, in particular European mining companies.

At the European legislative level, the management of mining, quarrying and ore-processing waste is included in the initial Environmental Impact Assessment of industries. These systems do already exist in some countries of European Union.

In addition, there is a strong case for seeking to secure minimum requirements for good practice based on careful review of the most successful aspects of minerals planning in each country. The European Commission is currently following this approach in its initiatives announced in the Communication on the safety of mining activities.

There is a need for a thorough assessment to be made of the impact of sustainable development policies relevant to minerals, possibly leading to the formulation of a European policy on sustainable exploitation and consumption of minerals.[31][32]

The European legislation has vocation to be applied to the Central and Eastern European countries, candidate for integration. For some of them, the mining activity plays an important social and economic role. During the time of the planned economy, the environmental management was practically non-existent. Putting into practice the European standards in the field of the mining activity should follow an appropriate timetable.[33]

3.3. MAIN OUTCOMES

According to the above, the recommendations are:

1. To validate this inventory study of the sites of mining waste deposit in each European country, by detailed study carried out by a homogeneous multi-disciplinary team, especially for abandoned and closed mines,
2. To get information for each site, on solid composition but also on the nature of the leachates resulting from specific and representative mining waste samples (according normalised European leaching and long term tests),
3. To evaluate different evolution forms of legislation (based on BAT),
4. To define basic criteria for mine closure plans, on the base of European contaminated lands approach,
5. To organise meetings and exchanges of information between industrials and researchers of the Member States (as the task forces after Spanish and Roman accidents),
6. To start research and development programs on sets of themes, specific to the various methods of mining waste management, including an improvement of recycling techniques. The themes that have to be studied are related to main generic issues :
    - **Design of tailing and waste rock facilities**,
    - **Waste management** (characterisation of the reactivity of specific mining waste by different ways leaching test, long term column test and normalised tests of the Landfill Directive, improvement of recycling technique of mining waste and assessment of current after-care practices),
    - **Dam stability** (study of influence of exceptional meteorological conditions on the stability of dams),
    - **Water management** (study of the behaviour of heavy metals coming from mining waste in the subjacent geologic layers and the prediction of their becoming by tools like geochemical and solute-transport modelling),
    - **Closure Plan**

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