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Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries

in accordance with Directive 2006/21/EC

Elena Garbarino, Glenn Orveillon, Hans G. M. Saveyn, Pascal Barthe, Peter Eder

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Joint Research Centre

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Title Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries

Abstract This document, Best Available Techniques Reference Document for the Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC, abbreviated as MWEI BREF, is a review of the Reference Document for Management of Tailings and Waste-Rock in Mining Activities (MTWR BREF). This review is the result of an exchange of information between experts from EU Member States, industries concerned, non-governmental organisations promoting environmental protection and the European Commission. The reviewed document presents up-dated data and information on the management of waste from extractive industries, including information on BAT, associated monitoring, and developments in them. It is published by the European Commission pursuant Article 21(3) of Directive 2006/21/EC on the management of waste from extractive industries. This document presents data and information on the following:

- General information and key figures on extractive industries in Europe, extractive waste generation, extractive waste facilities and key environmental issues (Chapter 1).
- Applied processes and techniques for the management of extractive waste (Chapter 2).
- Emission and consumption levels resulting from the management of extractive waste (Chapter 3).
- Techniques to consider in the determination of Best Available Techniques (Chapter 4). This includes generic management and waste hierarchy techniques, risk-specific techniques to ensure safety, techniques for the prevention or minimisation of water status deterioration, techniques for the prevention or minimisation of air and soil pollution and other risk-specific techniques.
- Best available techniques conclusions (Chapter 5).
- Emerging techniques (Chapter 6). This includes techniques that were reported at different levels of technology readiness.
- Remarks and recommendations for future work (Chapter 7).

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This report was produced by the Circular Economy and Industrial Leadership unit at the European Commission's Joint Research Centre (JRC) – Directorate B: Growth and Innovation under the supervision of Peter Eder and Luis Delgado Sancho (Head of the Circular Economy and Industrial Leadership unit). It was drawn up within the framework of the implementation of the Directive on the management of waste from extractive industries (2006/21/EC) and is the result of the exchange of information provided for in Article 21(3) of the Directive.

The authors of this BREF were Elena Garbarino, Glenn Orveillon, Hans Saveyn and Pascal Barthe.

Colleagues from the European Integrated Pollution Prevention and Control Bureau (EIPPCB), and in particular Serge Roudier (head of the EIPPCB), Michele Canova, Benoit Zerger, Antoine Pinasseau and Jože Roth (Waste Treatment BREF team) as well as Anna Atkinson (proofreader), Rick Nowfer & Carmen Ramirez (editors), Soledad Donaque, Carmen Morón Martín & Sabine Naimer (secretariat support) are gratefully acknowledged for providing support with regard to the Sevilla process and peer reviewing.

The information exchange process centred on contributions shared by members of a Technical Working Group (TWG) consisting of experts representing European industry associations, environmental non-governmental organisations, EU Member States and Norway (EFTA).

Major overall contributors to this information exchange process were industry associations EUROMINES (European Association of Mining Industries, Metal Ores & Industrial Minerals), UEPG (European Aggregates Association), EUROMETAUX (The European Association of Non-Ferrous Metals Producers, Transformers and Recyclers), IOGP (International Association of Oil and Gas Producers), environmental non-governmental organisation EEB (European Environmental Bureau) and EU Member States Finland, Sweden, Spain, Ireland and France.

Information was also provided by industry associations EURACOAL (European Association for Coal and Lignite), IMA-EUROPE (The Industrial Minerals Association – Europe), ORGALIME (European Engineering Industries Association), EAA (European Aluminium Association), and by EU Member States Austria, Croatia, Cyprus, the Czech Republic, Germany, Estonia, Italy, Poland, Portugal, Romania, and the United Kingdom, as well as by Norway.

The JRC would also like to thank the countless other people and organisations that have contributed in one way or another to the drawing up of this document, including (but not limited to) operators who filled out questionnaires, experts who provided feedback through the BATIS shadow groups and the various people who participated in the different meetings, webinars and site visits.

PREFACE

1. Status of this document

The original reference document on Best Available Techniques (BAT) on the management of tailings and waste-rock in mining activities, abbreviated as MTWR BREF, was mainly drafted in the period 2001-2004 and published by the European Commission in January 2009 pursuant to Article 21(3) of Directive 2006/21/EC on the management of waste from extractive industries[1]. The original BREF was therefore drawn up before the adoption of Directive 2006/21/EC. The starting point for this document was the Communication from the European Commission COM(2000)664 on the Safe Operation of Mining Activities[2].

This document, the Best Available Techniques Reference Document for the Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC, now abbreviated as MWEI BREF, originates from a review of the original MTWR BREF. This review centred on an exchange of information between experts from EU Member States, industries concerned, non-governmental organisations promoting environmental protection and the European Commission. The reviewed document presents updated data and information on the management of waste from extractive industries, including information on BAT, associated monitoring and developments in them. It is published by the European Commission pursuant to Article 21(3) of Directive 2006/21/EC on the management of waste from extractive industries[1].

In this context, Chapter 5 of this document, the BAT Conclusions, provides key information and data on BAT.

The role and proper use of BAT is explained in the Extractive Waste Directive[1]:

- Member States shall ensure that operators responsible for the management of extractive waste take all measures necessary to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of extractive waste. These measures shall be based, *inter alia*, on the best available techniques without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the waste facility, its geographical location and the local environmental conditions.
- Member States shall take the necessary measures to ensure that competent authorities periodically reconsider and, where necessary, update permit conditions in light of the information exchange on substantial changes in best available techniques.

This document does not provide legal interpretation, nor should it be used to such purpose. It aims to provide technical information related to BAT referring to a broad range of materials and processes. Reference to extractive waste in this document does not imply a legal interpretation of the status of this material as either extractive waste or not extractive waste.

The MWEI BREF, and more specifically the BAT Conclusions, should therefore be seen as a reference aiming at:

- providing extractive industries, competent authorities and other relevant stakeholders with up-to-date information and data on the management of extractive waste;
- supporting decision makers by providing a list of identified BAT to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of extractive waste, duly taking into account that the techniques listed and described in this chapter are neither prescriptive nor exhaustive and that other techniques may be used that ensure at least an equivalent level of environmental protection.

[1] OJL 102 (11/04/2006) p.15.
[2] COM(2000) 664 final (23/10/2000).

2. Participants in the information exchange

Technical experts forming part of the TWG were nominated by the Industrial Emissions Directive (IED) Article 13 Forum members and the Technical Adaptation Committee (TAC) of Directive 2006/21/EC. The TWG consisted of representatives from Member States, the industries concerned and non-governmental organisations promoting environmental protection.

The TWG was the main source of information for drafting this document. The work of the TWG was led and coordinated by the Circular Economy and Industrial Leadership unit of the Joint Research Centre's (JRC) Directorate B (Growth and Innovation) in Seville (Spain).

3. Structure and contents of this document

Chapter 1 provides general information on the extractive industries sector with key figures and environmental issues related to the management of extractive waste.

Chapter 2 gives a general overview of the different techniques for managing extractive waste.

Chapter 3 contains data and information on the environmental performance of extractive waste management sites that participated in the exchange of information. This chapter presents a number of environmental performance indicators.

Chapter 4 describes in more detail techniques to prevent or reduce as far as possible the impact on and the potential risk to the environment or/and human health of the management of extractive waste. It includes procedures and monitoring techniques. Techniques described in this chapter are considered to be most relevant for determining BAT.

Chapter 5, the BAT Conclusions, presents the BAT as defined in Article 3(18) of Directive 2006/21/EC.

In view of the site-specific conditions of extractive waste management activities, Chapter 5 presents conclusions on two distinct groups of BAT:

- generic BAT, which are generally applicable, unless otherwise stated;
- risk-specific BAT, which are applicable to sites where specific risks of adverse effects on the environment or human health are identified through a proper Environmental Risk and Impact Evaluation.

Generic BAT focus on:

- corporate management;
- information and data management (including the site-specific information and the evaluation of environmental risks and impacts);
- waste hierarchy.

Risk-specific BAT comprise BAT identified to prevent or reduce as far as possible specific risks that are identified by a proper Environmental Risk and Impact Evaluation, duly considering the relevant site-specific information:

- BAT on safety are relevant for sites where a risk of a major accident and/or risk of pollutant leaching/release is identified. These comprise BAT related to:
  - the structural stability of the extractive waste deposition area;
  - the physical and chemical stability of the extractive waste.
- BAT on the prevention or minimisation of water status deterioration and air and soil pollution are relevant for sites where a risk of water, air and/or soil pollution is identified. These comprise BAT related to:
  - prevention or minimisation of groundwater status deterioration and soil pollution;
  - prevention or minimisation of surface water status deterioration;
  - prevention or minimisation of air pollution.
- Other risk-specific BAT are relevant for sites where other environmental or human health risks are identified. These comprise BAT related to:

- prevention or minimisation of noise emissions from the management of extractive waste;
- prevention or minimisation of odour nuisance from the management of extractive waste;
- prevention or minimisation of visual and footprint impacts from the management of extractive waste;
- management of extractive waste containing Naturally Occurring Radioactive Materials (NORMs).

The following processes and activities are covered in Chapter 5:

- the management of waste from on-shore extractive activities;
- the handling/transport of extractive waste (e.g. loading, unloading and on-site transport);
- the treatment of extractive waste:
  - physical and mechanical treatment (e.g. sorting, blending, dewatering, thickening);
  - chemical treatment (e.g. desulphurisation, cyanide detoxification);
  - biological treatment (e.g. biological sulphide reduction);
- the deposition of extractive waste:
  - temporary deposition;
  - permanent deposition;
- the activities directly associated with the management of extractive waste:
  - treatment of Extractive Waste Influenced Water (EWIW);
  - preparation of extractive waste to be placed back into excavation voids.

Chapter 6 gives an overview on "emerging techniques" as defined in Section 2.3.9 of Commission Decision 2012/119/EU.

Finally, in Chapter 7, concluding remarks and recommendations for future work are presented.

4. Information sources and derivation of BAT

This document is based on information collected from a number of sources, in particular through the TWG that was established specifically for the exchange of information under Article 21(3) of Directive 2006/21/EC. The information has been collated and assessed by the JRC's B.5 unit who led the work on determining BAT, guided by the principles of technical expertise, transparency and neutrality. The work of the TWG and all other contributors is gratefully acknowledged.

The BAT Conclusions have been established through an iterative process involving the following steps:

- identification of the key environmental issues for the sector;
- examination of the techniques most relevant to address these key issues;
- identification of the environmental performance levels achievable, on the basis of the available data in the European Union and worldwide;
- examination of the conditions under which these environmental performance levels were achieved, such as costs, cross-media effects, and the main driving forces involved in the implementation of the techniques;
- selection of the BAT.

Expert judgement by the JRC's B.5 unit and the TWG has played a key role in each of these steps and the way in which the information is presented here.

Where available, economic data have been given together with the descriptions of the candidate techniques presented in Chapter 4. These data give a rough indication of the magnitude of the costs and benefits. However, the actual costs and benefits of applying a technique may depend greatly on the specific situation of the installation concerned, which cannot be evaluated fully in this document. In the absence of data concerning costs, conclusions on the economic viability of techniques are drawn from observations on existing facilities.

5. Review of BREF

BAT is a dynamic concept and so the review of BREFs is an ongoing process. For example, new measures and techniques may emerge, science and technologies are continuously developing and new or emerging processes are being successfully introduced into the sector. In order to reflect such changes and their consequences for BAT, this document will be periodically reviewed and, when necessary, updated accordingly.

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Best Available Techniques Reference Document for the Management of Waste from Extractive Industries

in accordance with Directive 2006/21/EC

List of figures

List of tables

SCOPE

At the Kick-off Meeting for the review of the MTWR BREF in May 2014 in Seville, the following was agreed with the TWG:

> *To ensure that the MWEI BREF scope reflects the scope of Directive 2006/21/EC to the greatest possible extent and to align the BREF's objectives with the general requirements defined in Article 4 of Directive 2006/21/EC. However, for practical reasons, to address in the MWEI BREF only activities with current relevance in the EU and for which extractive waste may pose a potential environmental or human health concern including major accidents.*

It was also discussed that *current relevance* should mean that, at the least, prospecting is already ongoing.

The aforementioned Article 4 of Directive 2006/21/EC states that:

> *[…] Member States shall ensure that the operator takes all measures necessary to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of extractive waste. […] The measures […] shall be based, inter alia, on the best available techniques […].*

Article 2 of Directive 2006/21/EC develops the Directive's scope. This article not only describes activities and wastes included in and excluded from the scope of the Directive altogether, but it also provides exemptions from certain articles in the Directive for certain types of residues. Nonetheless, it is important to note that this scope-related article does not provide any exemptions from Article 4 of the Directive for inert wastes and unpolluted soils resulting from the prospecting, extraction, treatment and storage of mineral resources, including peat, or the working of quarries. At the Kick-off Meeting, it was decided to exclude from the scope of the MWEI BREF unpolluted soils which are not classified as waste. In other words, to identify best available techniques for the management of *all* types of extractive wastes covered by the scope of Directive 2006/21/EC.

Taking this into account, an analysis of the different recitals and articles of Directive 2006/21/EC allows the determination of the boundaries of the scope of the MWEI BREF, in particular the extractive industries and extractive wastes to be included in the exchange of information on Best Available Techniques (BAT) for the management of waste from extractive industries.

The following is covered by the scope of this document:

- Wastes resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries (Article 2 of Directive 2006/21/EC):
  This relates to activities and extractive wastes already largely covered in the MTWR BREF:
  - the management of extractive waste from surface or underground extraction of mineral resources, organic or inorganic substances such as energy fuels, metal ores, industrial minerals and construction minerals;
  - the management of waste from mineral resource treatment, treatment being defined in Article 3(8) of Directive 2006/21/EC as a mechanical, physical, biological, thermal or chemical process or combination of processes carried out on mineral resources such as size change, classification, separation, leaching and re-processing of previously discarded waste.

  This also includes the following mainly new activities and materials:
  - the management of extractive waste from onshore oil and gas extraction, including drilling muds, flowback water and well completion fluids;
  - the management of extractive waste from quarrying;
  - the management of extractive waste from peat extraction;
  - other forms of extractive waste besides extractive waste from mineral processing and extractive waste from excavation, such as sludge from decantation processes applied in the management of extractive waste.

The following is excluded from the scope of this document:

- the management of products resulting from the prospecting, extraction, treatment and storage of mineral resources and working of quarries;
- the management of extractive waste generated at a prospecting, extraction or treatment site and *transported* to a designated waste treatment installation or facility not in the scope of Directive 2006/21/EC;
- the management of waste which does *not directly* result from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries (Article 2 of Directive 2006/21/EC);
- the management of extractive waste from *offshore* prospecting, extraction and treatment of mineral resources (Article 2 of Directive 2006/21/EC);
- *injection* of water and reinjection of pumped groundwater as defined in the first and second indents of Article 11(3)(j) of Directive 2000/60/EC, to the extent authorised by that Article (Article 2 of Directive 2006/21/EC);
- the management of extractive waste from the extraction of *water* (Article 3(5) of Directive 2006/21/EC);
- the management of waste from *smelting, thermal manufacturing processes* (other than the burning of limestone) and *metallurgical processes* performed on mineral resources (Article 3(8) of Directive 2006/21/EC);
- abandoned extractive waste facilities, i.e. extractive waste facilities left by the operator and not properly closed.

The term *waste* in this document is defined by Article 3(1) of Directive 2008/98/EC on waste as any substance or object which the holder discards or intends or is required to discard.

The following facilities for the management of extractive waste have been included in the scope of this document:

- Waste facilities: i.e. any area designated for the accumulation or deposit of extractive waste, whether in solid or liquid state or in solution or suspension, for the following time period (in accordance with Article 3(15) of Directive 2006/21/EC):
    - no time period for Category A waste facilities and facilities for waste characterised as hazardous in the waste management plan;
    - a period of more than six months for facilities for hazardous waste generated unexpectedly;
    - a period of more than one year for facilities for non-hazardous non-inert waste;
    - a period of more than three years for facilities for unpolluted soil, non-hazardous prospecting waste, waste resulting from extraction, treatment and storage of peat and inert waste.

  Such facilities for the management of extractive wastes include pond-type facilities such as ponds containing extractive waste from mineral processing and/or heap-type facilities such as heaps of extractive waste from excavation or heaps of dry stacked extractive waste from mineral processing.
- Facilities for treatment (active or passive) of water from extractive waste facilities.
- Facilities preparing extractive waste prior to placing it back into the excavation voids (when existing).
- Facilities where waste (pre)treatment takes place (when existing).

Figure S.1 provides a schematic overview of the scope of this document:

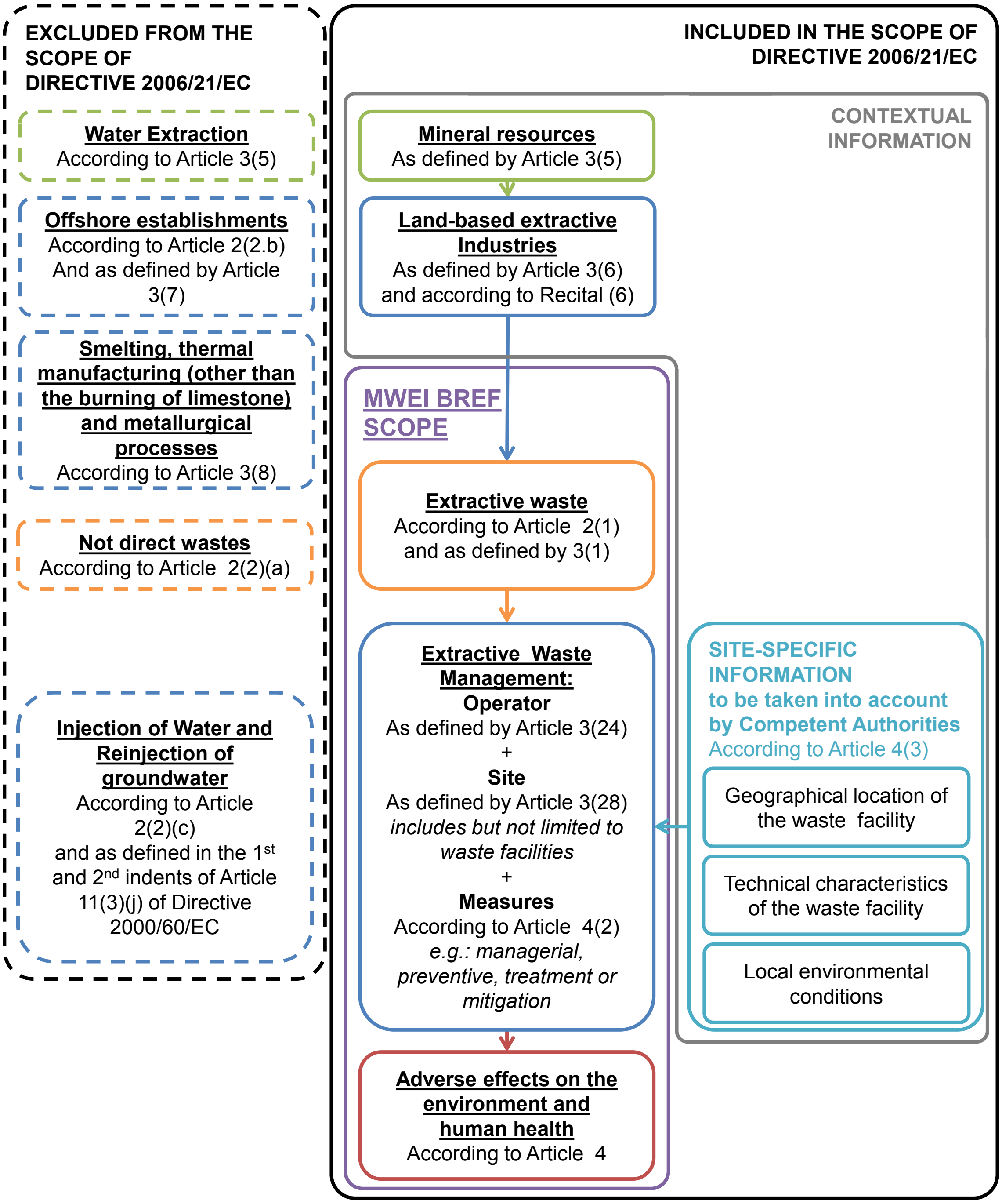


Figure S.1: General schematic illustration of the scope of the MWEI BREF, aligned to the scope of Directive 2006/21/EC

1 GENERAL INFORMATION AND KEY FIGURES

1.1 Introduction

Mineral resources extraction is one of mankind's oldest industries. Extraction of mineral resources has been undertaken by many civilisations and has in many areas been a source of wealth and importance. Different prehistorical and historical periods refer directly to extractive activities: Stone Age (30 000 BC), Copper Age (3000 BC), Iron Age (1000 BC), Coal Age (1600 AC), and, more recently, the Oil Age (1800-1900) and Atomic Age (since 1945).

In Europe, the extraction of mineral resources played a central role in the shaping of the European Union and its predecessor, the European Coal and Steel Community.

Extractive industries are the very first link of a long supply chain. Extraction of raw materials as feedstock materials for downstream industries contributes as such to technological development. The extractive industry as a whole plays a crucial role in the economic and societal development of our nations. As the demand for raw materials is increasing, there has been a growing interest in extraction of mineral resources in Europe in the last decade, in order to meet as much of this demand as possible and rely less on imports. Many prospecting projects and new extraction sites are underway: e.g. gold mines in the Iberian Peninsula, polymetallic mines in the Scandinavian countries, and boron and lithium prospecting in the Balkans. Moreover, oil and gas hydrocarbon exploration is also ongoing in several European countries to investigate the potential of so-called unconventional hydrocarbon resources discovered across Europe.

The extraction of mineral resources may generate varying amounts of extractive waste, which will require appropriate management. Extractive waste is accumulated and deposited in Extractive Waste Facilities (EWFs) (e.g. ponds and/or heaps) designed for perpetuity. The costs related to design, construction, maintenance, closure and rehabilitation of these extractive waste facilities may be significant. Lessons learned from the past show that, while extractive projects are synonymous with economic growth and jobs, they may also raise concerns among local communities due to the possible negative impacts on the environment and human health that might be generated by such activities, especially those related to EWFs. In some extreme cases, failures and accidents may be a cause of environmental devastation and human health deterioration, including casualties (WISE 2016). For this reason, local communities might, at times, be reluctant to accept mineral resources extraction projects. It is therefore of the utmost importance to earn the trust of the local population by reducing the environmental impact of such projects.

Many efforts have been made in the last few decades by the extractive industries to prevent, reduce and minimise as far as possible the negative impacts brought about as a result of the management of extractive waste and the extraction activities. Learning from the past, extractive waste management strategies and techniques have evolved considerably to achieve these objectives. Resources used for these objectives will yield positive returns, not only on the environment but also on the social perception and acceptance of new mineral resources extraction projects. Furthermore, minimising the environmental impacts contributes to making the extraction of mineral resources more environmentally responsible.

This chapter gives an overview of the extractive industry sector at the time of writing this document (2018), providing overview figures on extraction activities in Europe along with the key environmental issues arising from the management of extractive waste.

The figures presented in this chapter mainly originate from Eurostat, the British Geological Survey, the U.S. Geological Survey, the U.S. Energy Information Administration, the Material Flows database and the information provided by the Technical Working Group. Where appropriate, the figures were revised by the TWG experts.

1.2 Key figures and data

In this document, the wording "extractive industries" refers to the industries extracting mineral resources, i.e. naturally occurring deposits in the earth's crust of an organic or inorganic substance such as energy fuels, metal ores, industrial and construction minerals, but excludes the extraction of water.

These resources are generally categorised according to their end use. They are commonly grouped into three broad categories:

- fossil fuels: this category usually includes liquid and gaseous hydrocarbons, and coal and lignite (e.g. hard coal/anthracite, soft/bituminous coal, brown coal/lignite); peat may also be included in this category when extracted for energy and not for use in horticulture and agriculture (e.g. soil improvers or growing media);
- metalliferous ores or metal ores: metal-bearing ores or metals used as feedstock for the primary production of metals; and
- industrial and construction minerals: mineral resources used as feedstock for the industry sector, e.g. ceramics or glass manufacturing, for the chemicals and fertilisers industry, or for the construction industry such as aggregates, ornamental and dimension stones or minerals for the cement industry.

1.2.1 Economic indicators of the extractive sector

From an economic viewpoint, the extractive sector generates a substantial contribution in the EU-28. Data presented here were extracted from Eurostat's Structural Business Statistics (SBS) database when available. In general, statistical data on the sector at EU level may differ from source to source; however, Eurostat's SBS database was selected as the most comprehensible one. The database groups the extractive industries into four main categories (NACE activities):

- B05 Mining of coal and lignite;
- B06 Extraction of crude petroleum and natural gas;
- B07 Mining of metal ores;
- B08 Other mining and quarrying.

Based on the SBS database (Eurostat 2015c), Figure 1.1 summarises some key economic indicators on extractive industries in the 2011-2015 time period. In this period, the extractive industries represented the following:

- **Enterprises**:
  ~ 17 000-18 000 enterprises carrying out extraction of mineral resources (on average):
  - industrial and construction minerals extraction comprised ~ 16 500 enterprises (NACE code B08), 95 % of the total;
  - ~ 550 enterprises extracting fossil fuels were registered (NACE codes B05 and B06), 3 % of the total:
    - 41 % in the coal and lignite sector;
    - 59 % in the oil and gas sector;
  - ~ 300 enterprises extracting metalliferous ores were registered (NACE code B07), 2 % of the total.
- **Human resources**:
  ~ 520 000 persons employed (on average), of which:
  - ~ 200 000 in the extraction of industrial and construction minerals, 39 %;
  - ~ 270 000 persons in the extraction of fossil fuels, 52 %:
    - ~ 190 000 for extraction of coal and lignite (71 % of the fossil fuels);
    - ~ 80 000 for extraction of oil and gas (29 % of the fossil fuels);
  - ~ 50 000 persons in the extraction of metalliferous ores, 9 %;
- **Turnover**:
  ~ EUR 221 billion turnover (on average):
  - industrial and construction minerals: ~ EUR 36 billion (16 %);

- fossil fuels: ~ EUR 174 billion (79 % of the extractive sector), of which:
  - ~ EUR 160 billion for the oil and gas sector;
  - ~ EUR 14 billion for the coal and lignite sector;
- metalliferous ores: ~ EUR 11 billion (5 % of the extractive industries).

- **Added value**:
  ~ EUR 70 billion of value added (on average):
  - industrial and construction minerals: ~ EUR 12 billion (17 %);
  - fossil fuels: ~ EUR 52 billion (74 %), of which:
    - ~ EUR 44 billion for the oil and gas sector (84 % of the fossil fuels);
    - ~ EUR 8 billion for the coal and lignite (~ 16 % of the fossil fuels);
  - metalliferous ores: ~ EUR 6 billion (9 %).

Note that, for the fossil fuels sector, the figures encompass onshore and offshore oil and gas extraction although the offshore extraction of mineral resources is not within the scope of this document.

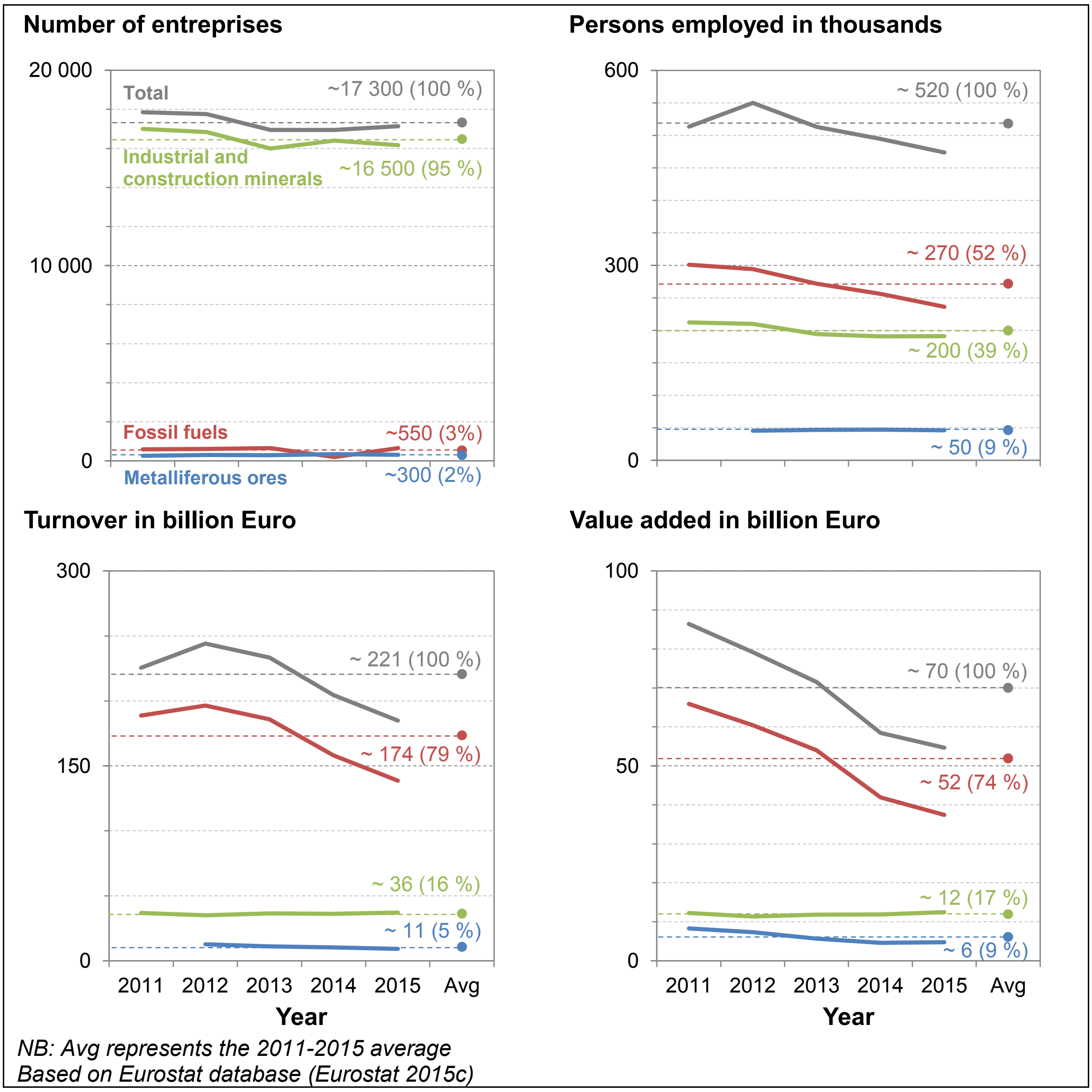


Figure 1.1: Key economic indicators for the extractive industries' economic sectors, 2011-2015

Extractive waste management costs are very site-specific and vary depending on the selected waste management options, the amount of extractive waste to be managed, the extractive waste characteristics, and the site location. According to information provided in various extractive industries, this cost can vary from less than 1 % to several percent (3-4 %) of the total mineral resources extraction costs (EC-DG ENV 2001).

The operational costs of the management of extractive waste from mineral processing vary from less than one euro per tonne of managed extractive waste (< EUR 1/t) to EUR 10-20/t (Caldwell 2013; EC-DG ENV 2001; UC CMM 2014).

1.2.2 Deposits of mineral resources in Europe

In order to provide the reader with an idea of the main European regions where extraction of mineral resources is carried out, and thus the management of mineral resources, two main tables were compiled:

- Table 1.1 presenting an estimate of the number of mines in the EU-28, Norway and Turkey, compiled using different comprehensible databases and sources of information:
  - the BRGM database on mineral resources deposits (Cassard *et al.* 2015);
  - the UEPG database on aggregates extraction sites (UEPG 2012); and
  - the comments and data provided by the TWG.

  Dimension stones are included in the sector labelled industrial and construction minerals, as no specific database at EU level was available.
- Table 1.2 summarises the leading countries in the extraction of some mineral resources based on the BGS database (BGS 2014).

The estimated number of mineral resources extraction sites in the EU-28 is presented in Table 1.1.

Poland, Finland, Spain, Germany, France, the United Kingdom, Italy, Sweden, Austria and Romania were the 10 countries within the EU with more than 1 000 extraction sites reported.

In 2012, Poland and Germany had the highest estimated number of aggregates extraction sites in the EU-28: 4 088 and 3 145 extraction sites, respectively.

The UK and Spain had the highest number of extraction sites for industrial and construction minerals, with 1 196 and 763 sites, respectively.

Greece was the leading country for extraction of bauxite and other light metal ores with 28 extraction sites.

Poland and Bulgaria had the highest estimated number of base metal extraction sites (copper, nickel, lead, tin and zinc mines): 9 and 11 extraction sites, respectively.

Hungary, Poland and Portugal had 3 extraction sites for the extraction of iron and steel alloying elements such as tungsten.

Finland was the leader in precious metals extraction sites with 10 mines for gold, silver or platinum extraction in 2012.

Poland and the UK also had the highest number of coal and lignite extraction sites, 63 and 50, respectively.

Peat extraction was carried out only in Finland, the UK and Ireland, with 1 060, 86 and 79 sites, respectively.

Based on the data exchange, Poland and the Czech Republic showed the highest number of onshore oil and gas extraction sites, with 274 and 128, respectively.

The Czech Republic also reported 2 uranium ores extraction sites.

Table 1.1: Estimates of mineral resources extraction sites in the EU-28 in 2012

Member State	Mineral resources extraction sites in the EU-28												Estimated number of extraction sites
	Aggregates[a]	Industrial and other construction minerals[b]	Peat[b]	Bauxite, alumina, magnesite, ilmenite[b,c]	Cu, Ni, Pb, Sn, Zn ores[b]	Fe, Co, Cr, Mn, Mo, V, W ores[b]	Ag, Au, Pt ores[b]	Uranium ores[b]	Other metalliferous ores[b]	Coal and lignite[b]	Hydrocarbons[b]	Oil shale[b]	
AT*	1 362	13		2		3			2	7			**1 389**
BE	112	1											**113**
BG	295	44			11	2	3			9	1		**365**
CY	24												**24**
CZ**		440						2		45	128		**615**
DE	3 145	9		1	2	1				14	1		**3 173**
DK	364												**364**
EE**	516	27	121									16	**680**
EL	189	15		28	4								**236**
ES**	2 392	763		1	4	2	1			35	11		**3 209**
FI**	2 730	34	1 060		5	2	10		1				**3 842**
FR**	2 572	1039		1			85		1	0	57		**3 755**
HR	250	3									2		**255**
HU	788	35		5		3				12			**843**
IE**	450	1	79		3					1	1		**535**
IT	1 800	5				2							**1 807**
LT	307												**307**
LU	10												**10**
LV	25												**25**
MT	16												**16**
NL	215												**215**
PL**	4 088	480			9					63	274		**4 914**
PT	279	7			1	3			2				**292**
RO	1 210	21		1	5	1	5	1		11			**1 255**
SE	1 391	6			7	2	2						**1 408**
SI	40	4								1	1		**46**
SK	299	14		7	1	1			1	2			**325**
UK**	871	1196	86	1	7	1	2			50	81		**2 295**
EU-28	**25 740**	**4 157**	**1 346**	**47**	**59**	**23**	**108**	**3**	**7**	**250**	**557**	**16**	**32 313**

Estimates based on different sources:
[a] Initial data taken from UEPG database (UEPG 2012).
[b] Initial data taken from BRGM database (Cassard et al. 2015).
[c] Extraction sites for aluminium-bearing ores encompass alumina refining installations.
** Data corrected by Industry TWG representatives.*
*** Data corrected by Member States TWG representatives.*

Obviously, having an important number of extraction sites does not necessarily mean that the production is high.

Hence, Table 1.2 summarises the major producers of mineral commodities in the EU-28 in 2012 based on the data collected from the British Geological Survey (BGS 2012, 2014).

Based on 2012 data, Germany was also the largest producer of aggregates, barytes, coal and lignite, and kaolin, as well as potash and salt.

When comparing the data presented in Table 1.2 with data presented in Table 1.1, it is clear that Germany, which had the second highest number of aggregates extraction sites, had the highest production, whereas for coal and lignite, although it had less extraction sites than the UK, its production was in 2012 the biggest in the EU.

Other countries with a high number of extraction mines, e.g. Poland and Finland, are also among the biggest producers of mineral commodities.

Poland was the biggest producer of copper, lead and zinc in the EU-28 in 2012 and Finland was the leading country in the production of chromium (as it is the only producing country in the EU-28), gold, and platinum group metals (PGMs).

Other leading producers of certain commodities are:

- Denmark for diatomite;
- Greece for bauxite, bentonite, nickel and perlite;
- Hungary for manganese;
- France for mica and talc; based on the data provided by TWG experts, France was also reported to be a major producer of andalusite and silica sand;
- Ireland for alumina production from bauxite and zinc concentrate production;
- Italy for feldspar quarrying;
- Portugal for tungsten and lithium production;
- Spain for fluorspar, fuller's earth, gypsum, strontium minerals and tin production;
- Sweden is the absolute producer of iron; and
- the UK is the leading producer of oil and gas when counting both onshore and offshore oil and gas.

An overview of the total production is presented in the next section: 1.2.3 Extraction of mineral resources.

Table 1.2: Leading countries in the EU-28 in 2012 based on commodity production

Country	Major mineral commodity production in the EU
Austria	Magnesite
Denmark	Diatomite
Germany	Aggregates, barytes, coal and lignite, kaolin, potash and salt
Greece	Bauxite, bentonite, nickel and perlite
Hungary	Manganese
Finland	Chromium, gold and platinum group metals (PGMs)
France	Mica and talc
Ireland	Alumina and zinc
Italy	Feldspar
Poland	Lead, copper and zinc
Portugal	Lithium and tungsten
Spain	Fluorspar, fuller's earth, gypsum, strontium minerals and tin
Sweden	Iron
U.K.	Oil and gas

Based on the BGS database (BGS 2014)

1.2.3 Extraction of mineral resources

1.2.3.1 The position of Europe and the EU-28 in the world

Extraction of mineral resources is a process in which valuable mineral resources are extracted from the rock/ore as a raw material.

The "run-of-mine", also called "gross ore" or "crude ore", can be used to estimate the extraction of raw materials. Run-of-mine can be estimated using a Material Flow Accounting (MFA) database which contains data on "used extraction", corresponding to the "run-of-mine" ore.

The global material flow database for material extraction (SERI and WU 2014) created by the Sustainable Europe Research Institute (SERI) and Vienna University (WU) was selected to show trends in the extraction of mineral resources from the past few decades. The database provides global data on used extraction of mineral resources (or run-of-mine) per country, per year (since 1980) and per category of mineral resources (fossil fuels, industrial and construction minerals including construction rocks, and metalliferous ores).

Figure 1.2 represents the total run-of-mine of the EU-28, Europe and the world, expressed in million tonnes and plotted for the last three decades.

The European extraction represents the total run-of-mine of all the countries of the European continent without Turkey and the Russian Federation.

The total run-of-mine is the sum of used extraction for the three categories of mineral resources: fossil fuels, industrial and construction minerals, and metalliferous ores as reported in the database.

According to these data, over the last decades, the extraction of mineral resources increased globally in order to meet the market's requirements.

However, in Europe the data indicate an almost constant activity in the last three decades in terms of tonnage: ~ 5 000 Mt (million tonnes) of run-of-mine were excavated every year in Europe.

Therefore, while the worldwide extraction increased by almost 200 % over the last three decades (from 22 280 Mt (10^6 t) in 1980 to 61 730 Mt in 2013), the European contribution at the global level dropped from ~ 23 % in 1980 to ~ 8 % in 2013.

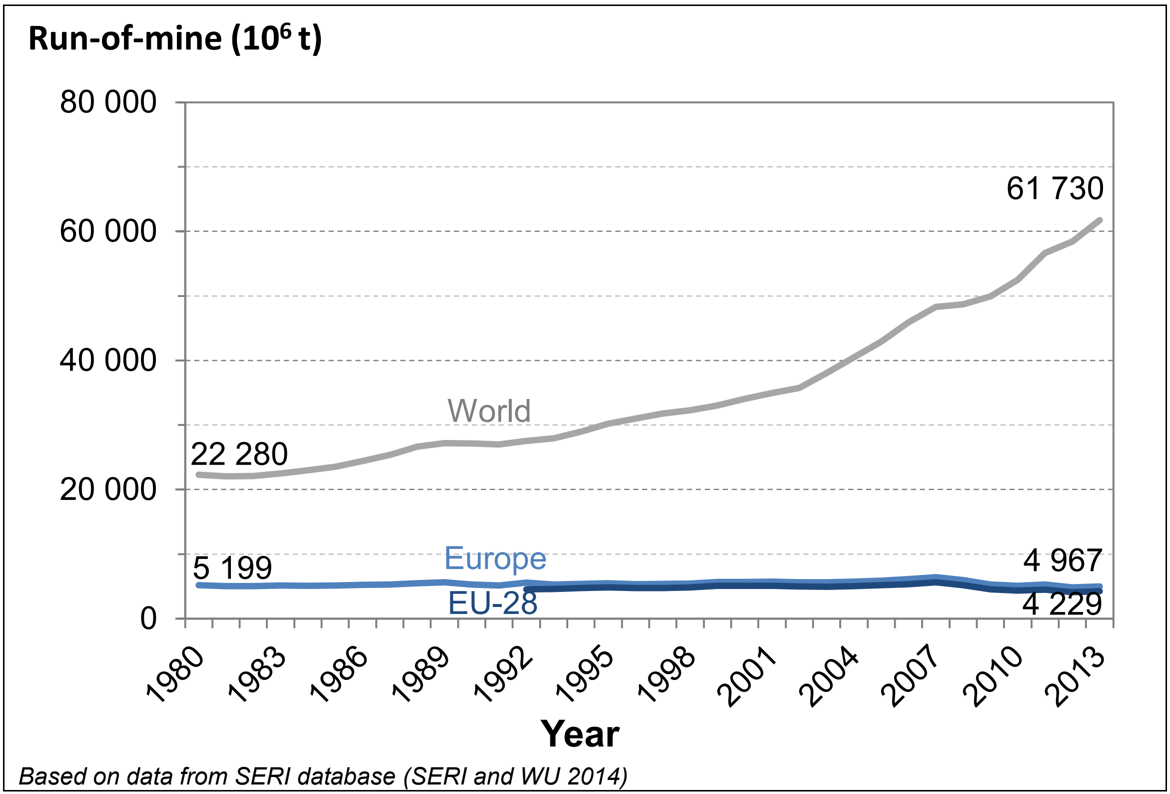


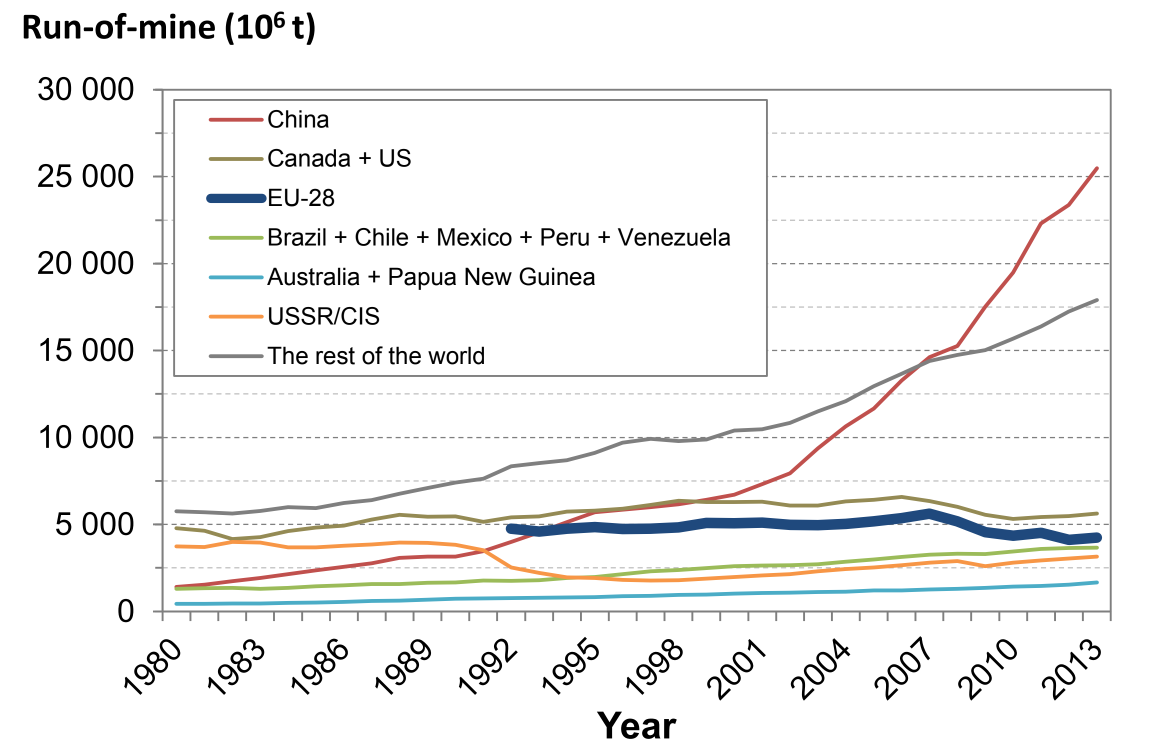
Figure 1.2: Mineral resources extraction in the world, Europe and the EU-28, 1980-2013

In order to have a better idea of the EU-28 position in the global economy compared to other major regions or countries where extraction of mineral resources takes place, the previous data on run-of-mine can be broken down into major producing countries/regions.

The yearly run-of-mine output of these regions in the past three decades is presented in Figure 1.3. In 2013, it represented more than 70% of the total output.

This graphical plot makes two points clearly visible:

- the EU-28, with its ~ 4 200 Mt of run-of-mine in 2013, is an important player in the extractive sector at the global level;
- China, the current world leader with ~ 25 500 Mt of run-of-mine, increased its extraction by ~ 300 % since 2000 and by ~ 1 700 % since 1980. China will most probably continue to be the absolute leader in the extractive sector in terms of extracted tonnage in the coming decade.



Based on data from SERI database (SERI and WU 2014)

Figure 1.3: Mineral resources extraction in leading regions and countries, 1980-2013

In order to have a better idea of the relative share of different categories of mineral resources in the total run-of-mine, as well as the contribution of the EU-28, the previous data can be broken down into the three main categories of mineral resources: fossil fuels, industrial and construction minerals and rocks, and metalliferous ores.

For that purpose, both the Eurostat database on Material Flow Accounts (Eurostat 2015b) and the global database (SERI and WU 2014) have been used.

Table 1.3 shows that industrial and construction minerals represented the majority of the total extraction of mineral resources in the world in 2013 (38 623 Mt or > 60 %). In the EU-28, industrial and construction minerals represented 76 % (3 060 Mt) of the total extraction of mineral resources in 2013 (4 013 Mt), while the contribution of fossil fuels at the global level was ~ 23 % (14 481 Mt) and the extraction of metalliferous ores ~ 1 % (8 626 Mt).

Table 1.3: Estimated run-of-mine in the world, in Europe and in the EU-28 in 2013

	World	Europe*	EU-28	
	(Mt)	(Mt)	(Mt)	(% of world)**
Mineral resources extraction	61 730	4 968	4 013	6.5
Fossil fuels (onshore and offshore)	14 481	1 050	758	5.2
Industrial and construction minerals	38 623	3 629	3 060	7.9
Metalliferous ores	8 626	289	195	2.3

** Europe includes all the European countries but not the Russian Federation and Turkey.*
*** Indicates the EU-28 share in the total world extraction.*
Based on data from SERI database (SERI and WU 2014), and Eurostat (Eurostat 2015b)

1.2.3.2 The mineral resources extracted in Europe and the EU-28

Figure 1.4 shows that the relative shares of each category of mineral resources in the total run-of-mine have remained more or less constant in the EU-28 over the past decade:

- the industrial and construction minerals represented 75-81 % of the total run-of-mine (78% on average);
- the fossil fuels contributed 17-21 % (19% on average); and
- the metalliferous ores share was 3-5 % (3% on average).

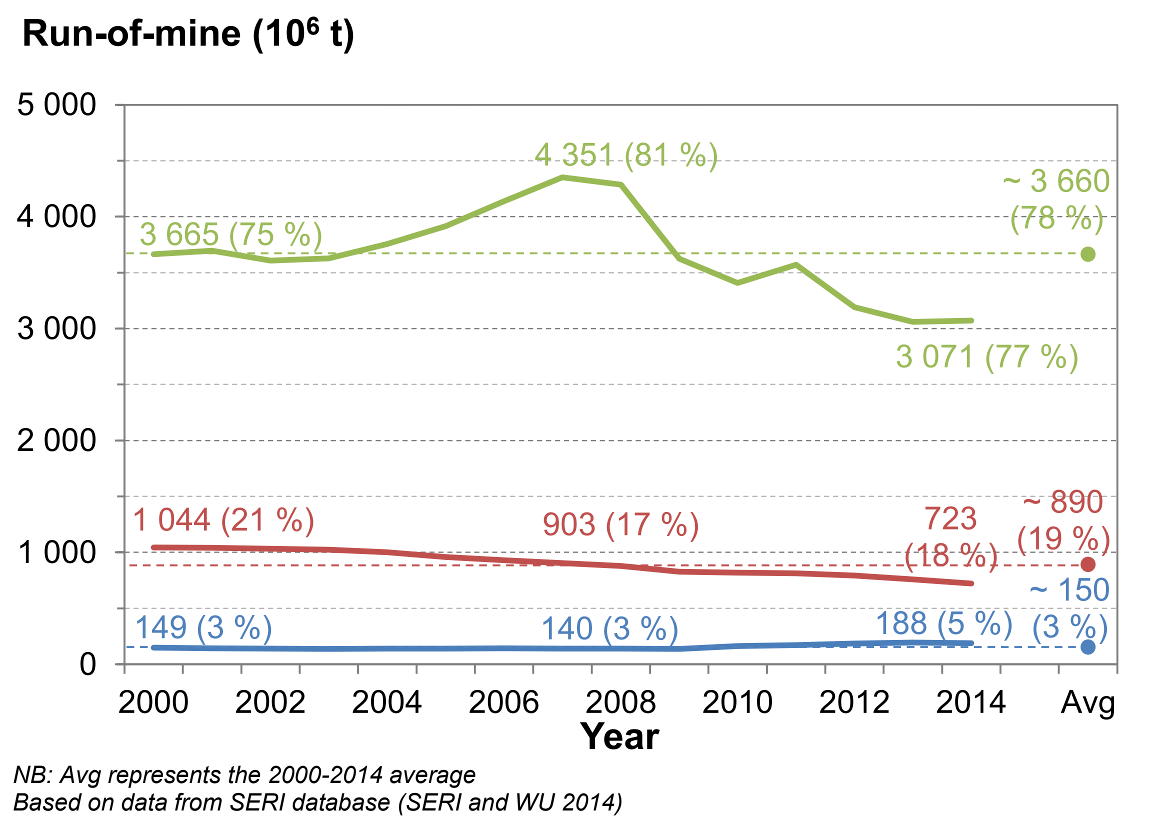
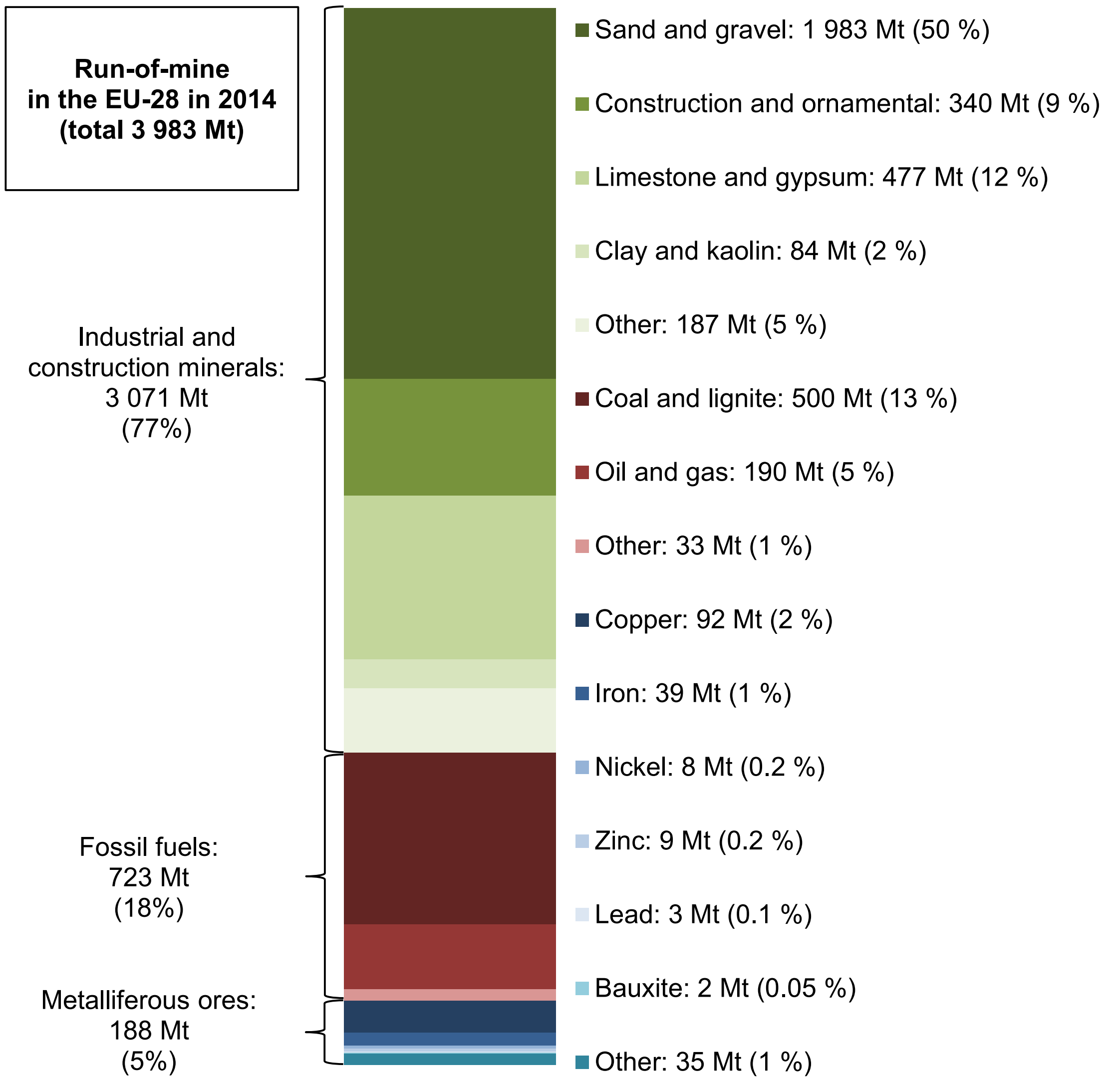


Figure 1.4: Run-of-mine by sector in the EU-28, 2000-2014

A more detailed breakdown showing the run-of-mine per main commodity extracted in the EU-28 in 2014 is presented in Figure 1.5.

This chart indicates the run-of-mine in million tonnes (Mt) and the relative share (in %) of some of the main mineral resources extracted in the EU-28:

- Sand and gravel represented the most important extracted mineral resource in terms of tonnage in 2014: ~ 2 000 Mt according to Eurostat, comprising as such 50 % of the extraction of mineral resources in the EU-28. The total EU-28 production of aggregates reported by the European Aggregates Association (UEPG), which includes sand and gravel production, was estimated to be ~ 2 500 Mt.
- Coal and lignite represented the second largest run-of-mine in the EU-28 in 2014 (13 % of the total EU extraction, 500 Mt). The total EU-28 production of coal and lignite reported by the European Association for Coal and Lignite was 507 Mt.
- Finally, among metalliferous ores, copper ores led in terms of tonnage with 92 Mt of ores processed in 2014 according to Eurostat.



Based on data from Eurostat (Eurostat 2015b) – Data aggregation is based on NACE codes.

Figure 1.5: Estimated run-of-mine of the most extracted mineral resources in the EU-28 in 2014

At the time of writing, the EU-28 was a world-leading producer of some commodities. Data from the Geological Surveys databases, British Geological Survey (BGS 2014) and US Geological Survey (USGS 2015) indicate that the EU-28 was the world leader in kaolin and perlite extraction. The EU-28 was the second largest producer of salt, limestone, gypsum, feldspar, magnesite, bentonite, talc, fuller's earth and strontium minerals. Finally, in the extraction of aggregates, diatomite and mica, the EU-28 ranked third. The data indicate that the EU-28 is an important producer of industrial and construction minerals.

It is important to stress that some European countries other than the EU-28 Member States are major producers of mineral commodities at the global and European levels: mainly Norway and Turkey according to the British Geological Survey.

Norway extracts mainly titanium oxides (7 % of global production in 2012 and not extracted in the EU-28); natural gas (3 % of global production) and liquid hydrocarbons (2.5 % of global production and more than the EU-28 total extraction).

Turkey extracts mainly borates (45 % of global production in 2012 and not extracted in the EU-28), feldspar (32 %), kaolin (5 %), magnesite (4 %), barytes (3 %), bentonite (2 %), coal (1 %), chromium ores (9 %), zinc ores (1.5 %), lead ores (1 %), and gold (1 %).

1.2.3.3 The geographical distribution of the mineral resources extraction across the EU-28 and Europe

Commodities for which the EU-28 ranks among the top 10 producers worldwide are listed in Table 1.4. Some additional mineral commodities of interest such as precious metals or crude petroleum, for which the EU-28 is not among the leading producers in the world but still has a significant production, are also listed.

Commodities have been ranked according to the EU-28's global rank, starting with commodities for which the EU-28 is the world leader (1st position).

The share of the EU-28 expressed as a percentage of total world extraction is low for fossil fuels and metalliferous ores. It is less than 5 % for most of these commodities. These low global shares for the EU-28 contrast with the high position the EU-28 holds for many industrial and construction minerals. For the latter group, the EU-28 extraction accounts for 10 % to 30 % of the total world extraction for most of the commodities.

The fifth column in Table 1.4 indicates the top producers along with their relative contribution (in %) to the total EU-28 extraction. The leading producers for each commodity are in bold and correspond to the ones presented in Table 1.2.

Table 1.4 shows that the extraction of industrial and construction minerals is, in general, more evenly spread across Europe than the extraction of metalliferous ores, which is usually concentrated in a few countries:

- for industrial and construction minerals such as aggregates, limestone, gypsum and magnesite, but with the exception of perlite, fuller's earth and strontium minerals, 75 % or more of the EU-28 production originates from three to nine Member States;
- for metalliferous ores, e.g. lithium, chromium, iron, bauxite, cobalt and platinum group metals (PGMs), 75 % or more of the EU-28 production originates from one to three Member States.

Table 1.4: Mineral commodities production in the EU-28 and the world in 2012

Commodity	EU-28 extraction (10^3 t/*10^6 m^3*)	% of world extraction	EU rank at global level	Leading producer in EU-28 (% of total EU-28 extraction)
Kaolin	8 031	31	1	**DE**(55); UK(14); CZ (8)
Perlite	838	23	1	**GR**(81)
Sodium chloride (brine and rock salt-halite)	57 539	21	2	**DE**(33); NL(11); UK(11); FR(11); PL(7); ES(7)
Limestone (lime production)	27 970	8	2	**DE**(24); IT(22); FR(14); BE(9); PL(7)
Gypsum	19 222	13	2	**ES**(34); FR(13); DE(10); UK(9); IT(8)
Feldspar	7 304	29	2	**IT**(64); FR(8); ES(5)
Magnesite	2 772	11	2	**AT**(28); ES(23); SK(22); GR(13)
Bentonite	2 683	17	2	**GR**(48); DE(14); CZ(8); SK(7)
Talc	1 076	14	2	**FR**(37); FI(37); AT(13)
Fuller's earth	772	22	2	**ES**(100)
Strontium minerals	84	10	2	**ES**(100)
Aggregates	2 277 000	8	3	**DE**(20); FR(14); PL(11); IT(9); UK(6); ES(5); RO(4); AT(4); FI(4)
Diatomite	292	15	3	**DK**(38); FR(26); ES(21)
Mica	34	11	3	**FR**(54); FI(36)
Coal and lignite	564 087	7	4	**DE**(35); PL(26); GR(11); CZ(10); BG(6)
Alumina (Al_2O_3 content)[a]	5 548	6	4	**IE**(35); ES(20); DE(18); GR(9)
Potash	4 033	13	4	**DE**(55); UK(14); ES(10)
Gas hydrocarbons[b] (10^6 m^3)	*167*	*5*	*4*	***UK**(60); DK(13); IT(7)*
Tungsten (W content)	2	3	4	**PT**(38); AT(35); ES(25)
Zinc (Zn content)	755	6	5	**IE**(45); SE(25); PL(10)
Fluorspar	237	3	5	**ES**(48); BG(29)
Lead (Pb content)	226	4	5	**PL**(32); SE(28); IE(21)
Copper (Cu content)	836	5	6	**PL**(51); BG(14); ES(12)
Lithium (Li content)[c]	0.6	2	6	**PT**(100)
Chromium ores	452	2	8	**FI**(100)
Barytes	107	1	9	**DE**(49); UK(28)
Liquid hydrocarbons[d]	75 344	2	> 10	**UK**(60); DK(13); IT(7)
Iron ore	29 019	1	> 10	**SE**(91)
Bauxite	2 141	1	> 10	**GR**(85)
Manganese ore	99	< 1	> 10	**HU**(52); BG(39)
Nickel (Ni content)	44	2	> 10	**GR**(50); FI(45)
Silver (Ag content)	1.8	7	> 10	**PL**(65); SE(18)
Cobalt (Co content)	1.4	1	> 10	**FI**(100)
Tin (Sn content)	0.1	< 1	> 10	**ES**(62); PT(38)
Gold (Au content)	0.03	1	> 10	**FI**(39); BG(25); SE(22)
PGMs (metal content)	< 0.001	< 1	> 10	**FI**(94)

[a] Produced from mainly imported bauxite.
[b] Offshore production accounts for 50-60 % of this figure (EC 2011).
[c] USGS data (USGS 2015).
[d] Mostly produced offshore (80-90 %) (EC-JRC and EU Offshore Authorities Group 2015; EC 2011).
Based on BGS database (BGS 2012, 2014) except otherwise specified

1.2.3.4 Investment trends in the extractive industries

More recently, a growing interest in critical raw materials (EC-DG ENTR 2014) and the development of new projects related to sustainable extraction of mineral resources and geological data acquisition has been observed across Europe.

Since 2004, new metalliferous ore extraction sites have opened across Europe – 4 copper mines, 4 gold mines, 2 zinc mines and 2 nickel mines (Hebestreit 2014).

Figure 1.6 shows the annual global investment in extractive projects from 2007 to 2013. These data reveal steadily growing investment in mineral resources extraction projects in Europe between 2011 and 2013, but also in North America and Latin America, whereas investments were levelling off in Africa, Asia and Oceania.

Investments in mineral resources extraction projects in Europe increased fourfold (+325%) from EUR 18 billion in 2007 up to EUR 78 billion in 2013. This investment growth in Europe was roughly twice higher than the growth in investment at the global level, where investments grew by a factor of 2.6 between 2007 and 2013 (+165%).

This growth is likely to contribute to Europe increasing its share of the global extractive industry in the coming years.

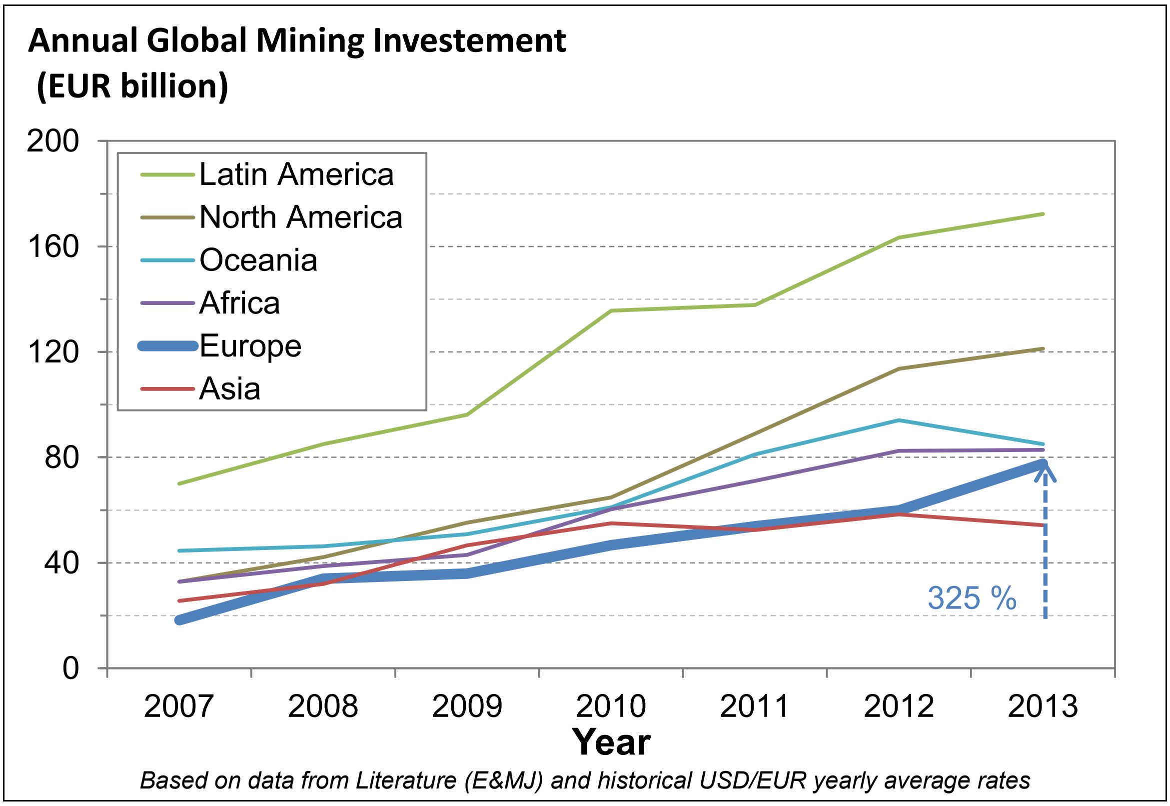


Figure 1.6: Annual investments in the mineral resources extraction sector by region, 2007-2013

1.2.4 Generation of extractive residues

In order to access and extract the targeted mineral resources, important amounts of materials have to be moved. The part of the co-excavated materials or co-processed materials which is not sold or further processed will constitute an extractive residue. The remaining part will be either sold or used in further industrial processes as a product. A residue-to-product ratio can therefore be defined, which will reflect the relative amount of residues generated during the extraction process in order to extract one unit of mineral product.

Residues generated during excavation of mineral resources

Common extractive residues generated during excavation include topsoil, overburden, interburden or waste-rock.

The relative amount of extractive residues generated during excavation of mineral resources can be estimated using the strip or stripping ratio which generally refers to the units of materials it is necessary to remove to extract one unit of ore in open-pit or open-cast surface extraction.

Typically, for surface extraction of base-metal-bearing ores, this ratio varies from 2:1 to 8:1, depending primarily on the geometry of the deposit. In most cases, this ratio will vary significantly over the life of the mine.

However, when extracted below the surface (underground extraction), this ratio will usually be less than 0.5:1 (World Bank 1998).

In Finland, for example, the ratio for metalliferous ore extraction was on average 1.7:1 (ranging from < 0.1:1 to 6:1) in 2011, based on data provided by a Finnish representative for 12 sites (FI TUKES 2011)

For the extraction of industrial minerals, the stripping ratio varies from 1:1 to 2:1 (Evans 1993).

In Finland, for example, the ratio for carbonate minerals extraction was on average 0.2:1 (ranging from < 0.01:1 to 0.9:1) in 2011, based on data provided by a Finnish representative for 17 sites (FI TUKES 2011).

For other industrial minerals extraction, the strip ratio was on average 1:1 with a maximum of 2:1 (FI TUKES 2011).

In the extraction of aggregates and construction/dimension rocks, the stripping ratio also varies from site to site and is on average lower than 0.1:1 (World Bank 1998).

In Finland, for example, the ratio for stones extraction was on average 7:1 in 2011, based on data provided by a Finnish representative for 6 sites (FI TUKES 2011).

Residues generated during mineral processing

Common extractive residues generated during mineral processing include powdery or slurried materials such as tailings.

The relative amount of extractive residues generated during mineral processing is usually closely linked to the type of mineral resources processed, the mineral processing and the ore grade.

Typical minimum ore grades for commercial exploitation (cut-off grades) can vary from 0.0004 % (w/w) for geochemically scarce elements like gold and PGMs to some 10-30 % (w/w) for geochemically abundant elements such as manganese, aluminium or iron (BRGM 2001; Spitz and Trudinger 2008).

Therefore, the relative amount of residues generated during the treatment of minerals can vary by several orders of magnitude. The mineral treatment residues-to-product ratio (ratio between tonnes of residues generated and tonnes of products such as concentrates) can be used to estimate the relative amount of residues generated during the mineral processing.

This ratio ranges from a few units for extraction of alumina from bauxite (1:1 to 2:1) to a few hundred for nickel (500:1) and surpasses 900 000:1 in the case of gold and PGMs (BRGM 2001; Spitz and Trudinger 2008).

Total residues generated during the extraction of mineral resources

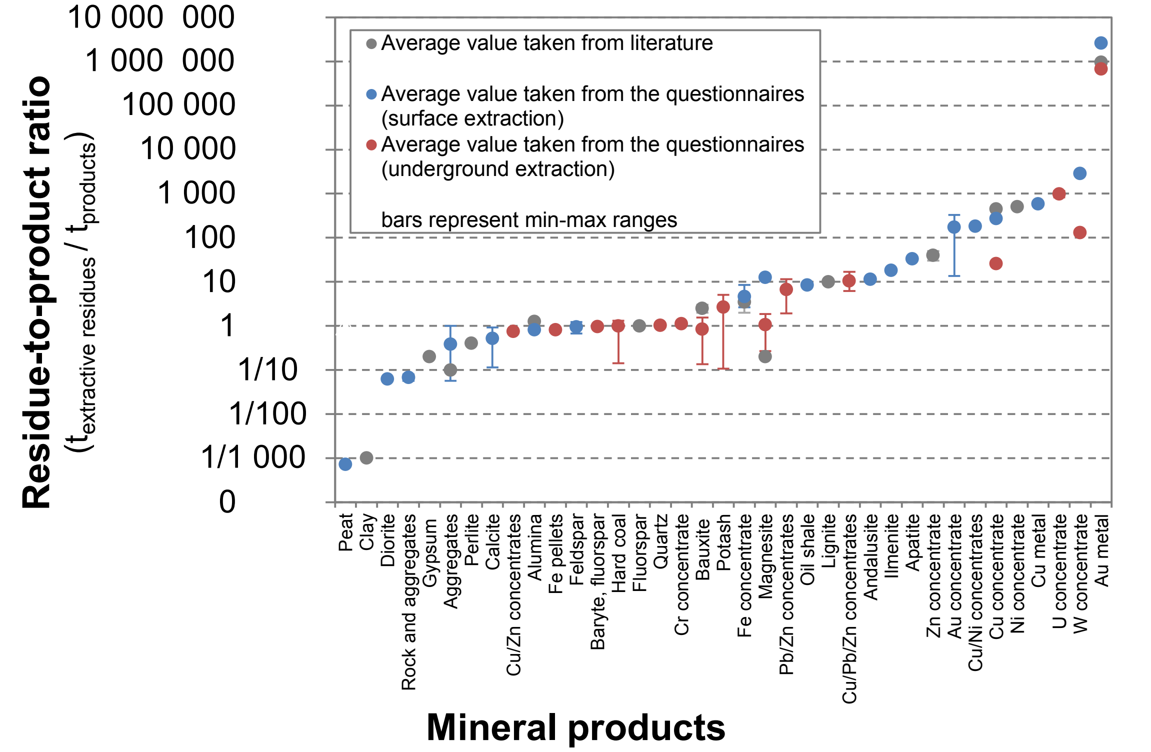
The total amount of extractive residues generated during the extraction of mineral resources can be defined as the sum of all the extractive residues generated during the different extractive processes.

The relative amounts vary from one unit per unit of final product (1:1) to several hundred thousand units per unit of product (> 100 000:1) depending on the extracted commodity, the extraction method and the site-specific local conditions (e.g. deposit type, deposit size, ore grade).

The ratio between the total amount of extractive residues generated and the total production can be defined as the residue-to-product ratio.

Some average ratios generally accepted in literature (BRGM 2001; Spitz and Trudinger 2008) are presented in Figure 1.7 for a selected number of mineral products (commodities).

Data from literature were complemented with data reported by the operators via the questionnaire that was used for the collection of site-specific information and data from operators responsible for the management of extractive waste. Operators had the opportunity to report various data and information on the extractive waste (e.g. extractive industry origin, type of waste, amounts, composition and properties), the extractive waste facilities and other site-specific information.



Based on different sources of literature data (BRGM 2001; EC-JRC 2009; IAI 2015; Spitz and Trudinger 2008) and the questionnaires.

Figure 1.7: Average extractive residue-to-product ratios taken from literature and the site-specific data reported by operators via the questionnaires

<u>Residues generated during exploration and production of oil and gas</u>

Common extractive residues generated during exploration and production of oil and gas include sands, drill cuttings, drilling muds, flowback and produced water.

A part of these residues is generated during the drilling process: e.g. drill cuttings and drilling muds.

Drilling muds are complex colloidal mixtures. The two main categories of drilling fluids are water-based muds (which can be dispersed or non-dispersed) and non-aqueous muds (oil-based muds and synthetic-based muds). Oil-based muds, in general, make up less than 20 % of all drilling muds used.

The main functions of drilling fluids include:
- providing hydrostatic pressure to prevent formation fluids from entering the wellbore;
- keeping the drill bit cool and clean during drilling;
- removing drill cuttings to the surface; and
- keeping the drill cuttings in suspension while drilling is paused and when the drilling assembly is brought in and out of the hole.

The drilling fluid used for a particular operation is selected to avoid formation damage and to limit corrosion.

The drill cuttings are crushed rocks, sand, silt and clay removed from the ground when drilling the wellbore.

In the oil and gas industry, volumes of materials moved during the drilling can be estimated using a similar concept to the stripping ratio: the total residues-to-hole volume ratio. The final volume of residues generated during extraction depends on a number of factors: solids control efficiency, retention factor (in some cases fluids remain underground or are lost during the process – fluid losses), and geological specificities. Nevertheless, it mainly depends on the size of the well: the volume of the hole. The total residue (TR)-to-hole volume ratio is used to estimate the volume of material moved during oil and gas drilling activities. Typically, the TR:HV ratio varies from a few units (2:1 to 3:1 in the best cases) to several tens (> 30-40:1) (ASME 2005)

Usually, only a portion of the drilling muds, sometimes very little, will remain underground after the well drilling.

Another part of the residues is generated during well completion operations, including well stimulation: e.g. flowback resulting from hydraulic fracturing, residuals/transformation products of hydraulic fracturing fluids and/or produced water.

Finally, during the production some residues such as sands can also be generated.

1.2.5 Extractive waste prevention

As previously stated, a certain amount of extractive residues may be generated in order to access and extract valuable mineral resources.Operators may plan to use these residues for internal or external purposes, in which case these extractive materials, in principle, qualify as by-products or products.

Examples of internal or external use of such materials are:
- site rehabilitation (extraction site or waste management site);
- construction (such as means of access for machinery, ramps, safety barricades, berms, dams, etc.); and/or
- production of solidified/paste fill that is placed back into excavation voids as an integral part of the extraction process (e.g. for safety and/or further mining purposes).

The relative amount of used materials in the extractive residues can be estimated using the by-products/residues ratio. Based on the site-specific data provided by operators, some examples of by-products/residues ratios, expressed as a percentage (%), are presented in Figure 1.8.

This ratio can vary from < 1 % for extraction of ilmenite to 91-99 % for extraction of feldspar or quartz, meaning that for the latter almost all the residues are used and only a small part (1-9 %) is discarded as extractive waste. In most cases, the by-products represent 10 % to 50 % of the extractive residues.

Obviously, the use of the extractive residues is not always possible and varies greatly among the different sites. It depends on different factors such as:
- site-specific conditions, e.g.:
    - the residue characteristics (e.g. mineralogy, particle size distribution and chemical properties);
    - the mineral resources extraction method (e.g. underground, surface);
    - the possibility to use the residues for other purposes such as construction and rehabilitation purposes including placing residues back into the excavation voids;
- economic aspects, e.g.:
    - the market demand for such residues;
    - the market location;
    - the price;
    - the transportation cost.

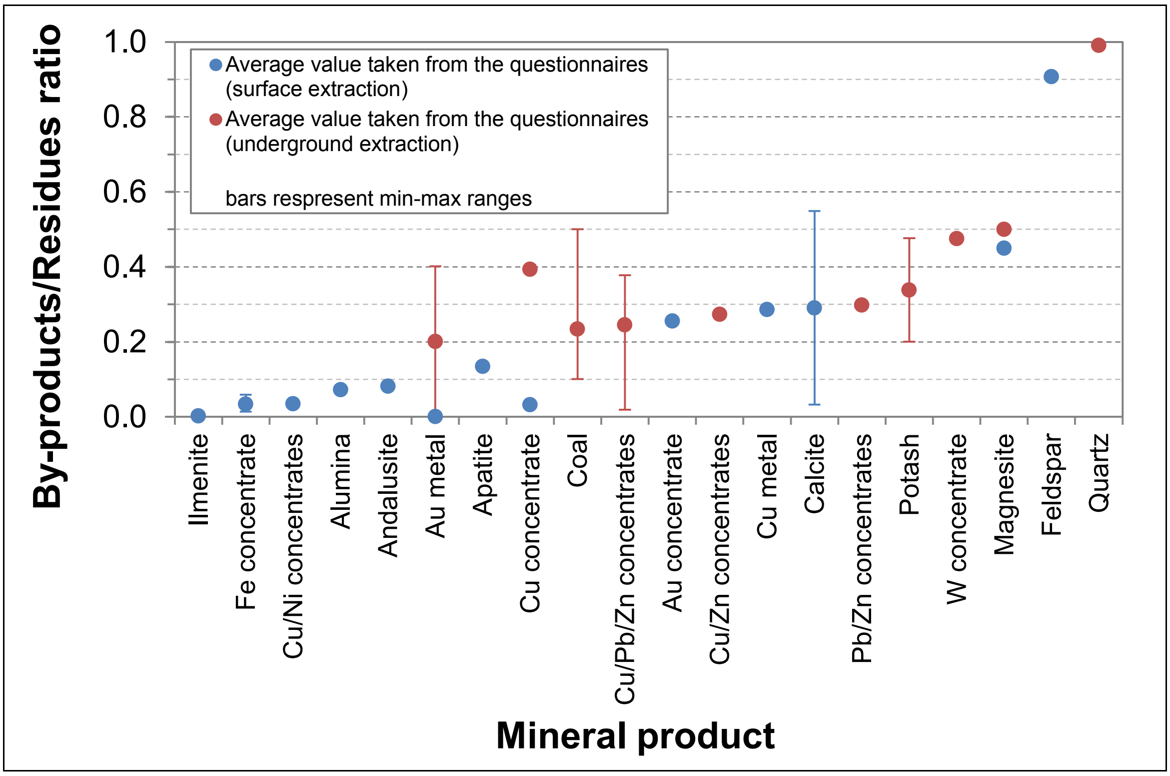


Figure 1.8: Site-specific extractive by-products/residues ratio based on the data provided by operators in the questionnaires

Examples of reported internal or external use of extractive materials are presented in Figure 1.9. This figure summarises the different uses of extractive materials that in principle qualify as by-products/products reported by the 87 operators which contributed to the review of this document by completing the questionnaire.

At most sites, operators reported using these materials for construction purposes: more than 40 sites. Extractive residues from excavation (e.g. waste-rock) and mineral processing (e.g. tailings) were the main materials used for such a purpose.

Placing tailings and waste-rock, which in principle qualify as by-products/products, back into excavation voids was reported by 21 operators.

Site rehabilitation using extractive materials that in principle qualify as by-products/products is carried out at 11 sites. Valuable soil (e.g. topsoil, till) is mainly used for such a purpose.

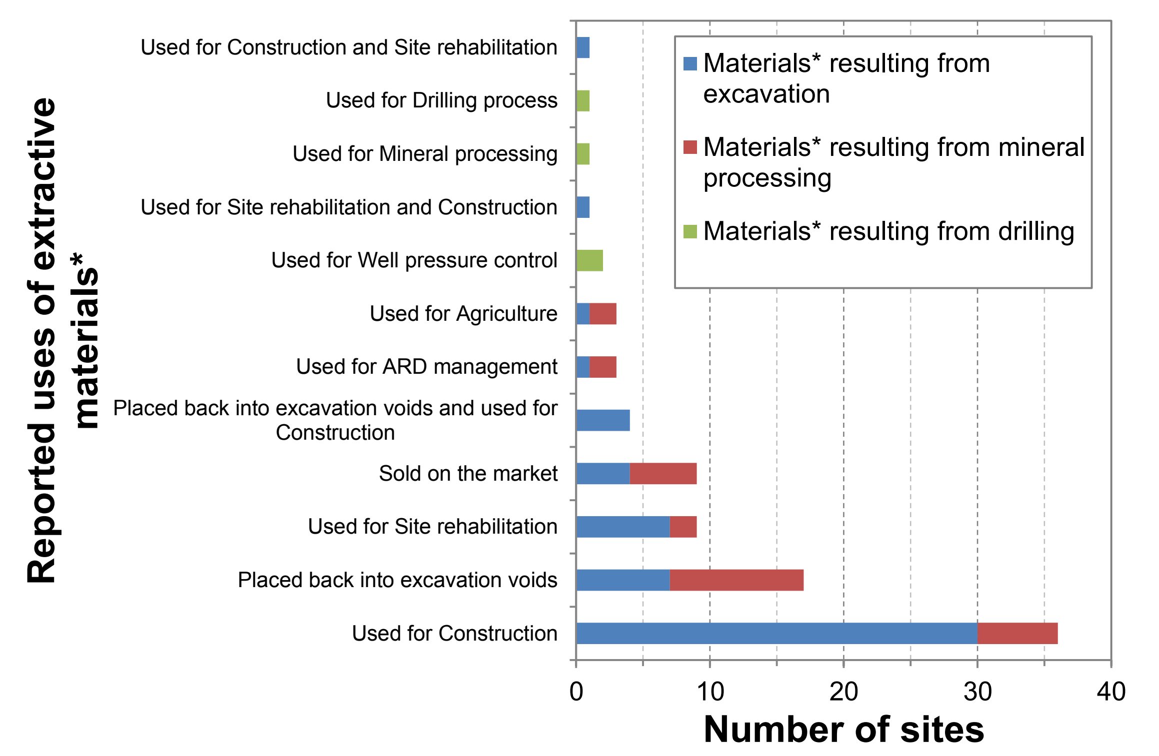
Nine operators reported selling secondary materials.

In some Member States, like France, the aggregates extractive industries have adopted a compromise for the recovery of the by-products of the extraction.

Extractive materials with alkaline properties, such as dolomitic materials, were mainly reported to be used as buffer materials for the management of Acid Rock Drainage (ARD) (see Section 1.3).

Materials which can be used as soil improvers were reported to be used for agricultural purposes.

Water and water-based extractive materials were reported to be re-used in the extractive process (e.g. drilling process, processing of minerals). One operator reported reinjection of water-based by-products.



Extractive materials that in principle qualify as by-products/products.

Figure 1.9: Reported site-specific uses of extractive materials that in principle qualify as by-products/products based on the information provided by operators via the questionnaires

1.2.6 Generation of extractive waste

In the extraction process, a part of the extractive residues will eventually be discarded and classified as extractive waste. Across the EU-28, different interpretations of Directive 2006/21/EC have been observed, resulting in different classifications of the same materials across the EU-28. However, issues relating to implementation or interpretation of legislation are outside the scope of this work.

This document addresses extractive residues that are classified as extractive waste according to the provisions of Directive 2006/21/EC.

Three main categories of extractive waste can be defined:

a) Extractive waste resulting from excavation of mineral resources: e.g. waste-rock, overburden, or interburden, classified as extractive waste according to the provisions of Directive 2006/21/EC.

   These are rock and soil (sometimes mixed with water) that have to be removed to access the ore. For open-pit extraction sites, the amount of extractive waste generated is usually much more significant than for underground extraction sites.

   Unpolluted topsoil will usually be used for site rehabilitation and is thus not considered waste material. Nevertheless, if discarded, topsoil may be classified as extractive waste and may be included in the waste management plan according to Article 2(3), Article 3(3) and Article 5 of Directive 2006/21/EC.

b) Extractive waste resulting from the mineral processing of mineral resources: e.g. tailings, wastes from washing and cleaning of minerals, wastes from stone cutting and sawing, waste sand, waste gravel or crushed rocks classified as extractive waste according to the provisions of Directive 2006/21/EC.

c) Extractive waste resulting from the exploration and production of oil and gas: e.g. fresh water, oil-containing, baryte-containing, or chloride-containing drilling muds and/or other materials classified as extractive waste according to the provisions of Directive 2006/21/EC. This may also include fluids such as flowback and produced water when classified as extractive waste.

To estimate the amount of extractive waste generated annually in the EU-28, in the period from 2004 to 2014, Eurostat's database was used. The database does not provide an "extractive waste" category; however, it does contain the waste generated and reported by the extractive industries (NACE code "mining and quarrying"). The different wastes reported by operators are then divided into different categories. To estimate the amount of extractive waste, only two categories were considered:

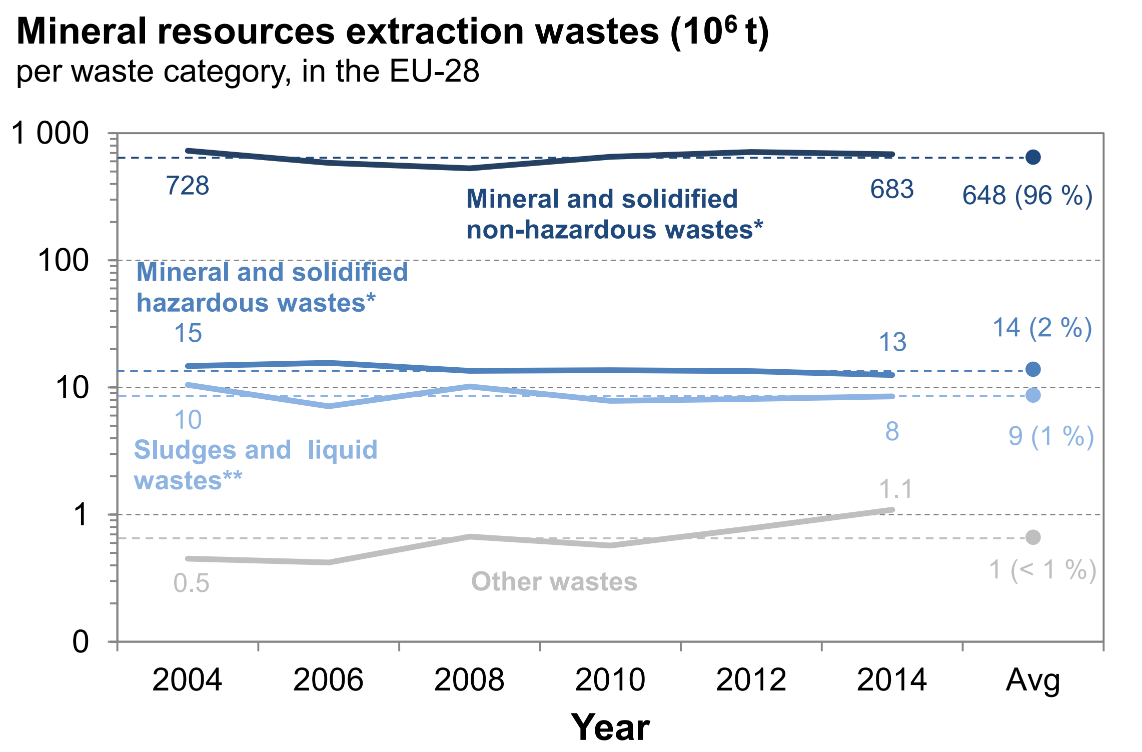
- sludge and liquid wastes (codes W032+W033): this encompasses industrial effluent sludge and sludge and liquid wastes from waste treatment in the extractive sector;
- mineral and solidified wastes excluding mineral waste from construction and demolition and combustion wastes (codes W12-13 excluding W121 and W124).

The amount of waste produced annually by the extractive industries and reported to Eurostat from 2004 to 2014 is presented in Figure 1.10.

According to these data (Eurostat 2015a), the total EU-28 waste produced by the extractive industries ranged from ~ 550 Mt to ~ 750 Mt annually, in the 2004-2014 period.

The mineral and solidified wastes, excluding mineral waste from construction and demolition, along with sludge and liquid wastes represented more than 99 % of the total waste produced by the mineral resources extraction activity. The remaining, less than 1 %, includes all the other waste streams.

Mineral and solidified hazardous wastes, excluding construction and demolition, and combustion wastes, represented only a minor part of the total wastes (2 %) whereas sludges and liquid wastes represented 1 %.

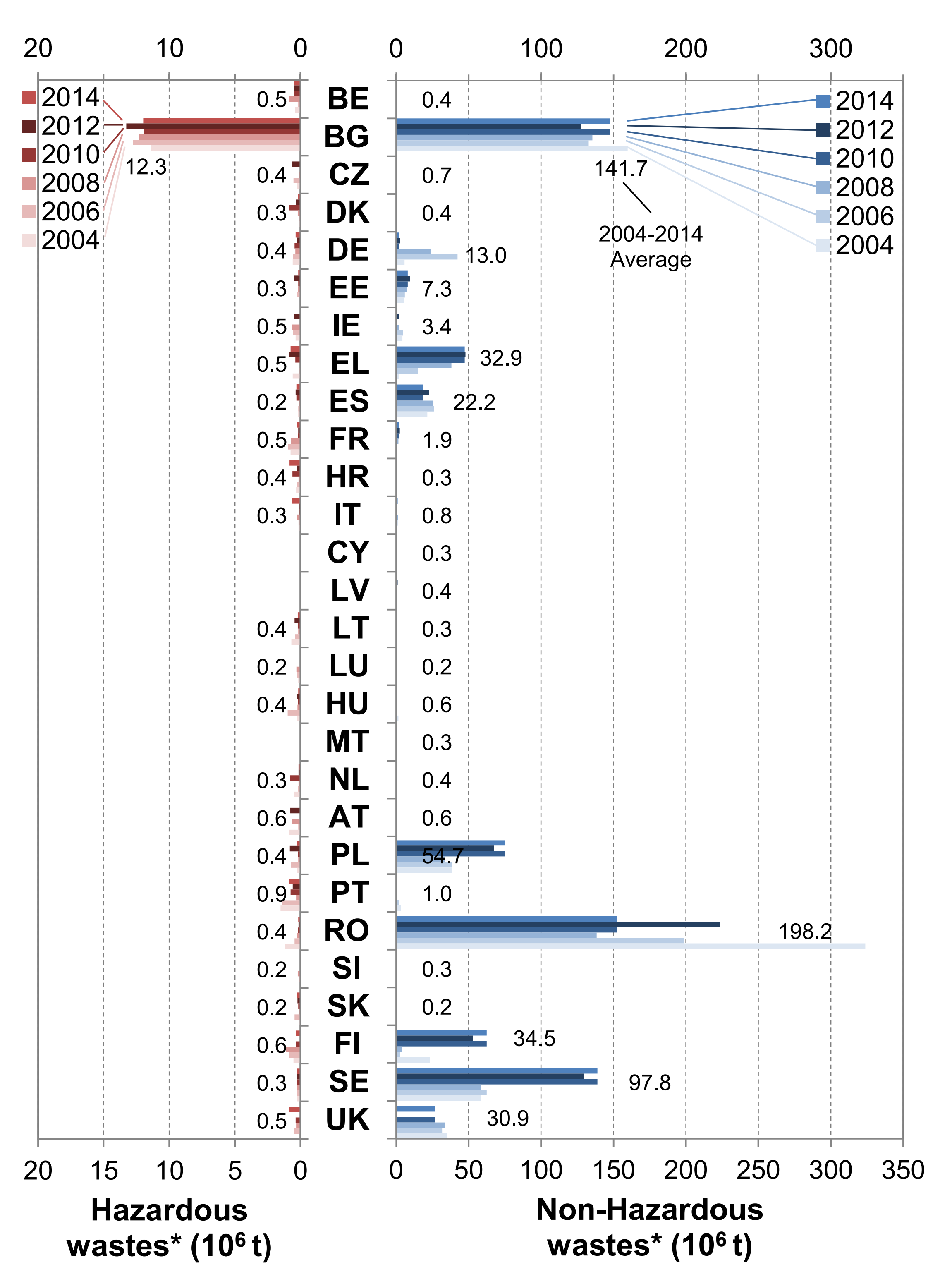


NB: Avg represents the 2004-2014 average
** Excluding solid wastes from construction and demolition and combustion wastes*
*** Industrial effluent sludge, sludge and liquid wastes from waste treatment*
Based on Eurostat database (Eurostat 2015a)

Figure 1.10: Wastes produced by the extractive industries, 2004-2014

The distribution per country of the production of hazardous and non-hazardous sludge and liquid wastes, along with both mineral and solidified wastes, excluding construction and demolition and combustion wastes is presented in Figure 1.11.

The figure presents the data reported by Member States to Eurostat for the time period 2004 to 2014.



** Industrial effluent sludge, sludge and liquid wastes from waste treatment and mineral and solidified wastes excluding solid wastes from construction and demolition and combustion wastes.*
Based on Eurostat database (Eurostat 2015a)

Figure 1.11: Distribution per country of hazardous and non-hazardous liquid and mineral wastes produced by the extractive industries in the EU-28, 2004-2014

According to Eurostat, the main countries in the EU-28 generating mineral and solidified wastes are Romania, Bulgaria and Sweden, which are together responsible for 67 % of the extractive waste in the EU-28.

Bulgaria also reported the largest amount of hazardous wastes from industrial effluent sludge and liquid wastes from treatment, and mineral and solidified wastes excluding solid wastes from construction and demolition in the extractive waste sector (NACE label "mining and quarrying").

In order to put into perspective the total waste produced by the extractive industries, by comparing it with the total waste produced by all the economic activities in the EU-28, Figure 1.12 summarises the share and contributions of the three main waste-producing economic sectors (based on Eurostat's NACE classification and data) in the EU-28 from 2004 to 2014.

As reported in Figure 1.12, the extractive industries are the second largest sectoral contributor to waste production in the EU-28 with a relative share of ~ 30 % in the total EU waste production over the 2004-2014 period.

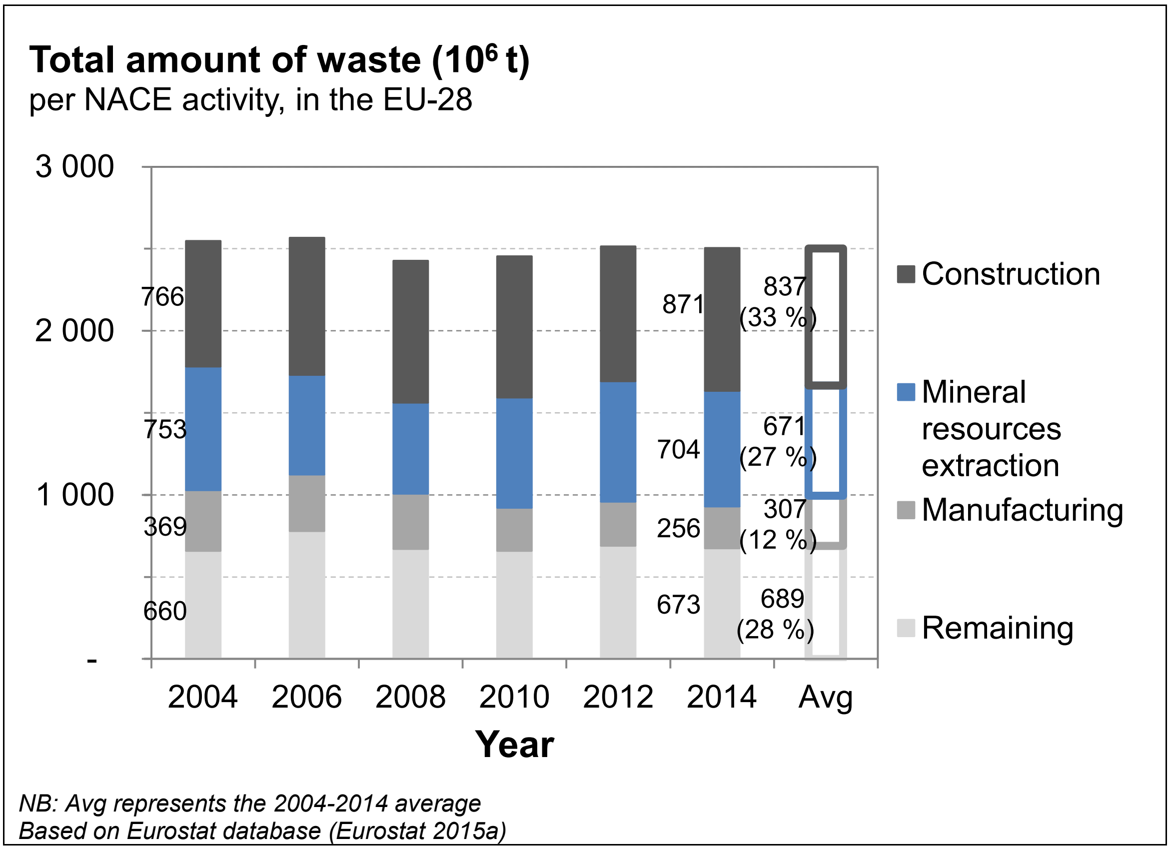


Figure 1.12: Main economic sectors producing waste in the EU-28, 2004-2014

1.2.7 Extractive waste facilities

Operators responsible for the management of extractive waste may also be responsible for the management of EWFs used for the accumulation or deposit of extractive waste, whether in a solid or a liquid state or in solution or in suspension as defined in Article 3(15) of Directive 2006/21/EC.
Table 1.5 summarises the number and the category of the waste facilities reported by Member States to the European Commission in 2014.

Based on the reported data, the EU-28 had more than 2 700 EWFs in operation, i.e. not closed, in the process of being closed, or abandoned.

About 200 EWFs out of the 2 700 were reported to be classified as Category A. This means these facilities:

- contain extractive waste classified as hazardous under Directive 91/689/EEC above a certain threshold; and/or
- a failure of these facilities could give rise to a major accident; and/or
- they contain substances or preparations classified as dangerous under Directives 67/548/EEC or 1999/45/EC above a certain threshold.

Table 1.5: Extractive waste facilities in operation in the EU-28 reported by Member States in 2011-2014

Member State	I - Category A	II.a - Not Category A - Inert	II.b - Not Category A - Non-Hazardous Non-Inert	II - Not Category A (II.a + II.b)	III - Total operating (I + II)
AT	0	NI	NI	33	33
BE	0	3	0	3	3
BG	2	NI	NI	NI	2
CY	1	NI	NI	12	13
CZ*	0	0	11	11	11
DE	2	24	1	25	27
DK	0	0	0	0	0
EE	0	4	0	4	4
EL	1	NI	NI	2 342	2 343
ES	25	NI	NI	1 533	1 558
FI	9	NI	NI	81	90
FR*	1	2 572	1 020	3 592	3 593
HU	6	NI	NI	856	862
HR	NI	NI	NI	NI	NI
IE	2	NI	NI	22	2
IT	126	NI	NI	87	213
LT	0	0	0	0	0
LU	0	0	0	0	0
LV	0	0	0	0	0
MT	0	0	0	0	0
NL	0	0	0	0	0
PL	0	0	1	98	99
PT*	3	5	1	6	9
RO	2	NI	NI	72	74
SK	3	116	0	116	119
SI	NI	NI	NI	NI	NI
SE	15	NI	NI	7	22
UK	4	NI	NI	597	601
EU-28	**202**	**-**	**-**	**9 497**	**9 678**

** 2015 data corrected by TWG MS representatives.*
NI stands for No Information.
Based on data reported by the Member States to the European Commission (EC 2016)

1.3 Key environmental issues

Extractive waste facilities and extractive waste management may vary significantly from one sector to another or from one region to another. The management of extractive waste from oil and gas exploration and production, alumina production or dimension stones extraction represent three very different examples of mineral resources extraction where the operator will have to face different issues and challenges. Additionally, the management of extractive waste in Nordic countries also has different constraints to Mediterranean countries because of the different climates. Nevertheless, all these operators have a same objective: to ensure the short-term and long-term safe deposition of extractive waste, including chemical, physical and mechanical stability over time, in order to prevent any accident and to minimise emissions that could have a negative effect on the environment and/or human health.

Extractive waste management is usually part of the overall ore extraction or oil and gas drilling operation and the treatment of minerals, where applicable.

In practice, the geological characteristics of the deposit will constitute the determining factor in the choice of extraction method. The treatment of minerals will be determined by the geological characteristics of the deposit and, as such, these will influence the management of extractive waste.

The method selected for the management of extractive waste will usually depend on the selected extraction method, the selected mineral processing, the waste characteristics, the technical characteristics of the EWF, its geographical location and the local environmental conditions.

However, in some cases, the operator might adapt the extraction method and the treatment of minerals with respect to its waste management objectives.

1.3.1 Safety and stability

1.3.1.1 Short-term and long-term structural stability of the extractive waste deposition area

When managing extractive wastes (handling, treatment, temporary storage, accumulation and deposition) operators take all the necessary measures to contain and confine the extractive waste in the area designed for that purpose, and to ensure the structural stability of the extractive waste and the confining structure(s).

For example, dams can be built to retain wastes resulting from the treatment of minerals (e.g. slurried extractive waste from mineral processing). Usually, extractive materials are used for their construction (see Section 1.2.5). Such dams have many features in common with water retention dams. Actually, in many cases they are built as water retention dams, particularly where there is a need for the storage of water in order to cover the extractive waste from mineral processing (EC-JRC 2009).

Other examples are heaps which are used to pile up relatively dry extractive waste (e.g. extractive waste from mineral processing or extractive waste from excavation). In that case, operators design and construct the heap structure in order to avoid a possible collapse of the heap.

The dimensions of either type of EWF can be enormous. Dams can be tens of metres high and heaps even more than 100 m. Dams can also be several kilometres long, possibly containing hundreds of millions of cubic metres of extractive waste. At the lower end of the spectrum are ponds the size of a swimming pool or heaps smaller than a townhouse.

The collapse of any type of EWF can have short-term and long-term effects. Typical short-term consequences may include:

- dangerous flow slides;
- release of hazardous substances;
- flooding;
- blanketing/suffocating;
- crushing and destruction;
- cut-off of infrastructure;
- poisoning;
- casualties.

Potential long-term effects may include:

- metal accumulation in plants and animals;
- contamination of soil;
- contamination of groundwater;
- loss of animal life;
- adverse effects on human health.

Guidelines for the design, construction and closure of safe EWFs are available in many publications to prevent or reduce the risk of improper extractive waste design, extractive waste handling or management. The UNECE "Safety guidelines and good practices for tailings management facilities" provide a useful tool in supporting policymakers and the business sector in enhancing awareness and the sharing of experience and good practices among the competent authorities, operators and the public, and for the better harmonisation of the regulations and requirements concerning the safety of extractive waste facilities. If the recommendations given in these guidelines were to be closely followed, the risk of a collapse would be greatly reduced. However, major incidents continue to occur at an average of about two per year (worldwide) (WISE 2016).

An investigation of 18 401 extraction sites and 218 dam accidents has identified the main causes of dam failures. The main causes in recent years were found to be unusual weather, poor management and seepage. Slope instability and structural defects were other less frequent causes of failure (Azam and Li 2010).

The bursts or collapses of dams at operations in Aznalcóllar in Spain and Baia Mare in Romania, as well as the more recent dam failure in Kolontár in Hungary, in 2010, have brought public attention to the management of extractive waste. These events have been reminders that dam collapses can cause severe environmental damage and lead to human casualties, e.g. the Kolontár dam failure resulted in 10 persons being killed, 120 injured, an area of 8 km^2 flooded and the release into the environment of 700 000 m^3 of caustic red mud (WISE 2016), with transboundary consequences.

Improper extractive waste management may have negative economic effects. For example, the clean-up cost of a coal slurry leak of several hundred thousand cubic metres into the Athabasca River in Canada was estimated at ~ EUR 125 million (Lee 2014). Hence, it should be clear that the investments needed to protect the environment and human health will pay off by avoiding the possible costs for remediating the consequences of incidents and accidents, which could be many times higher.

The effective and safe deposition of extractive wastes presents technical and environmental challenges. Each EWF is tailor-made and a sound approach is needed to ensure that the extractive waste management is safe and environmentally sound while also economically viable.

1.3.1.2 Physical and chemical stability of extractive waste

Non-inert extractive waste may undergo significant physical, chemical or biological transformations which, in turn, may have adverse effects on the environment and human health.

The following examples further illustrate the different challenges that non-inert extractive waste may pose:

- Acid Rock Drainage (ARD) or Neutral Rock Drainage (NRD): in the metal ores extractive industries, sulphide ore, in its natural location (i.e. underground and bound in rock mass), is not exposed to an oxidising environment. The finely ground extractive waste of this ore, once discarded in a pond, is much more accessible to water and oxygen. The surface area of accessible sulphides is increased by several orders of magnitude through the mineral separation and size reduction during the treatment of minerals. This implies that, if not managed properly, the rate of weathering, and thereby the mobilisation of weathering products, may be significantly increased. The main consequence of this may be:
  - production of acid and/or acidic extractive waste influenced water (EWIW) stemming from the EWF which may pose a risk of soil and water contamination;
  - leaching of metals (dissolved metals) which may pose a risk of soil, water and groundwater contamination.

- Dissolution: in the potash extractive industries, potash ores consist of potash minerals and rock salt. The deposits are protected from water by impermeable layers, typically clay and gypsum. However, extractive waste of this same ore consists mainly of rock salt (NaCl > 90 %) and is usually piled up in heaps. This salt is accessible to precipitation and is partially washed off over a long period of time. The main consequence of this may be:
  - EWIW stemming from EWFs contain high dissolved salts concentrations which may pose a risk of water contamination.

- Spontaneous combustion: in the coal and lignite or metalliferous ores extractive industries, the self-ignition of extractive waste and then the self-combustion of the extractive waste accumulated and deposited on heaps can occur. In the presence of oxygen, the oxidation of the organic matter contained in the waste or the oxidation of sulphides can generate the heat necessary to trigger the self-combustion process. Different factors will have an influence on the susceptibility of the extractive waste to self-heating. Some examples of parameters which influence this susceptibility are: particle size, presence of oxygen, sulphides content (e.g. pyrite), type and content of organic matter (e.g. presence of gaseous hydrocarbons), water content (moisture) and time (storage time). The main consequences of this may be:
  - danger for human health (and lives);
  - emissions of mercury, arsenic, selenium or other toxic or reactive substances (e.g. CO, NO_x, SO_x);
  - greenhouse gas emissions caused by the uncontrolled combustion process (e.g. CO_2, CH_4);
  - emission of particles.

- Migration of pollutants from the extractive waste: dangerous substances and/or other pollutants contained in the extractive waste may be a source of pollution.

  In extractive industries carrying out mineral processing with chemicals, the substances contained in the extractive waste may adversely affect the environment and human health, for example:
  - free cyanides (CNs) or Weak Acid Dissociable cyanides (WAD CNs) contained in the extractive waste produced during gold extraction aided by leaching with cyanides;
  - caustic soda (NaOH) contained in red mud residues produced during alumina extraction using the Bayer process.

In extractive industries using explosives for excavation works, potentially harmful substances include:

- o residues of explosives (nitrates and nitrogen compounds) contained in the extractive waste.

In the oil and gas extractive industries, drilling wastes such as drilling muds, residuals of fluids used for the well stimulation, e.g. high-volume hydraulic fracturing, and/or production wastes such as sand and/or produced water may have environmental impacts due, for example, to:

- o Total Hydrocarbon Content (THC) in drill cuttings discarded as extractive waste which may pose a risk of soil and water contamination;
- o Volatile Organic Compounds (VOCs) in drilling muds discarded as extractive waste, which may pose a risk of air contamination;
- o Total Dissolved Substances (TDS) in the flowback water produced after high-volume hydraulic fracturing well stimulation, which may pose a risk of water contamination;
- o residuals of fluids remaining in the underground structure during and after the well stimulation which may pose a risk of groundwater contamination; and/or
- o Naturally Occurring Radioactive Materials (NORMs) in the produced water discarded as extractive waste which may pose a danger to human health.

To ensure the environmentally safe management of extractive waste, a good knowledge of the waste and its behaviour over time is of the utmost importance. From an environmental point of view, the main difference between the mineral in the original deposit and the corresponding extractive waste is the increased possibility for physical, chemical and biological processes to affect the waste. This means that through the extraction and handling process certain constituents contained in the original mineral resources might become more accessible in the waste. This can result in possible reactions with the environment or leakage for non-inert waste. Therefore, proper extractive waste characterisation is the basis for successful waste management. It is also important to consider changes that can occur over time (EC-JRC 2009).

The CEN Technical Reports (TR), Specification (TS) and standard (EN) on extractive waste characterisation have been developed with this aim and in particular cover the following:

- CEN/TR 16376: overall guidance document for characterisation of waste from the extractive industries;
- CEN/TR 16365: sampling of waste from extractive industries;
- EN 15875: static test for determination of acid potential and neutralisation of sulphidic waste;
- CEN/TR 16363: kinetic testing for assessing acid generation potential of sulphidic waste from extractive industries;
- CEN/TS 16229: sampling and analysis of weak acid dissociable cyanide discharged into tailing ponds;
- EN 15875: static test for determination of acid potential and neutralisation potential of sulphidic waste.

Initial extractive waste characterisation is the basis for any planning of the management of extractive waste. It may be used for the classification of extractive waste, i.e. inert, non-inert non-hazardous or hazardous. Only if this background work is done properly can the most appropriate management measures be applied.

Further characterisation of the extractive waste is carried out during operation to complement the initial characterisation and to review and update, if necessary, the initial planning based on the initial extractive waste characterisation.

Overall, the extractive waste characteristics that operators generally investigate include:

- mineralogy;
- chemical composition, including the change of chemistry through the treatment of minerals and weathering;

- leaching behaviour;
- physical stability;
- behaviour under pressure;
- erosion stability;
- settling behaviour;
- hard pan behaviour (e.g. crust formation on top of the extractive waste from mineral processing).

To ensure the integrity and stability of the EWF, it is also important to have a complete characterisation of the mechanical and physical properties of the extractive waste including the following:

- Shear strength.
- Particle size distribution (which influences shear strength).
- Density.
- Plasticity.
- Moisture content.
- Saturation rate.
- Permeability. According to their hydraulic conductivity or coefficient of permeability k (in m/s), extractive waste can be classified in five groups according to DIN 18130 part 1:
  - very high permeability: $> 1 \cdot 10^{-2}$
  - high permeability: $1 \cdot 10^{-4}$-$1 \cdot 10^{-2}$
  - permeable: $1 \cdot 10^{-6}$-$1 \cdot 10^{-4}$
  - low permeability: $1 \cdot 10^{-9}$-$1 \cdot 10^{-6}$
  - very low permeability: $< 1 \cdot 10^{-9}$
- Consolidation: the amount and rate of settlement of extractive waste from mineral processing or extractive waste from excavation under loads. In this context, it is also very important to carry out specific site characterisation such as compressibility of quaternary sediments and bedrock topography variation below the sediments which may influence the pore water pressure in the waste.
- Porosity.

The shear strength is the most important characteristic of any extractive waste in the design of a heap or dam. Normally, the appropriate shear strength parameters necessary to carry out a stability analysis are those related to the effective stress, i.e. the effective cohesion and the effective angle of shearing resistance. Comparatively small variations in the shear strength parameters used in the stability analysis may have a significant impact on the safety factor.

1.3.2 Emissions to water, soil and air

The environmentally relevant parameters of EWFs can be subdivided into two categories: (1) normal operating conditions, and (2) other than normal operating conditions such as accidents, leaks, start-up and shutdown operations, momentary stoppages, definitive stoppages, etc.

Prevention and control of emissions to water is of the utmost importance in extractive projects as important volumes of water may be used in the extractive process and for the management of waste. The management of the extraction process, including the treatment of minerals, the management of extractive waste and the management of water are closely linked. During the lifetime of the process, several million cubic metres of excess water may be generated and may require treatment before discharge to comply with the environmental permit requirements and to prevent surface water status deterioration.

For operators responsible for the management of non-inert extractive wastes, prevention and control of diffuse emissions to soil and groundwater may also be of the utmost importance. Extractive waste management activities may cover a considerable surface area (e.g. EWFs may cover several hundred hectares) and contain several hundred thousand tonnes of extractive waste from which uncontrolled seepage may lead to pollution of soil and groundwater for non-inert extractive waste management.

Finally, prevention and control of diffuse emissions to air, including particulate emissions, may occur either during the management of extractive waste (e.g. handling, transport or deposition), or from the EWF itself (e.g. dusting).

1.3.2.1 Particles

Inert and non-inert extractive waste may generate emissions of particles to air (dusting) or to water (e.g. silting) streams. The main examples of such emissions are:
- suspended solids in EWIW – Total Suspended Solids (TSS), e.g. silt and clay particles;
- suspended particles – Total Suspended Particles (TSP), e.g. PM_{10} and/or $PM_{2.5}$ particles in the air or suspended particles of hydrocarbons (oil and grease) in the liquid waste.

1.3.2.2 Dissolved substances

Sources of emissions of dissolved substances which are of particular concern are:
- Acid/Neutral Rock Drainage or Saline Drainage in the management of waste from metalliferous ore extraction and/or coal and lignite extraction;
- seepage and/or discharge of EWIW with a high level of salt content (e.g. chlorides) in the management of waste from potash ore extraction.

As mentioned in the previous section, ARD or NRD but also Saline Drainage (SD) can occur in non-inert extractive waste.

The past two decades have brought a particular and widespread awareness of ARD. Though difficult to reliably predict and quantify, ARD occurs when minerals containing metals (e.g. Pb, Zn, Cu and Au) and sulphur (e.g. sulphides) come into contact with both air and water. While ARD can be generated from sulphide-bearing pit walls, and underground workings (EC-JRC 2009), only extractive waste ARD is considered in this document.

The acid in ARD can leach metals and metalloids from surrounding rocks, causing drainage that has a moderate to high amount of dissolved metals and metalloids, and a high level of sulphates (INAP 2014g).

NRD and SD may also be caused by the oxidation of sulphide minerals (INAP 2014f).

Whereas ARD and SD are usually associated with specific ore deposits, NRD can be generated by a wide variety of ore deposits, depending on the type of alteration and sulphide content (INAP 2014f).

NRD and SD are characterised by a higher pH than ARD. ARD generates EWIW with a pH below 6, whereas NRD and SD usually generate EWIW with a pH ranging between 6 and 9 (INAP 2014e, f).

The main difference between NRD and SD is basically the content of dissolved salts (e.g. sulphate) in the EWIW. According to Chapter 2 of the GARD Guide, the content of sulphate anions in SD is higher than 1 000 mg/l while it is usually less than 1 000 mg/l in NRD (INAP 2014f).

According to the GARD Guide (INAP 2014e) and (INAP 2014f), the main characteristics of ARD, NRD and SD can be summarised as follows:

1. ARD:
    a. $pH < 6$ (acid);

   b. moderate to elevated levels of metals and metalloids, e.g. elevated levels of aluminium, iron but also copper, lead, zinc, cadmium, manganese, cobalt and/or nickel (INAP 2014f);
   c. elevated sulphate levels, e.g. SO_4^{2-} levels ranging from 1 000 mg/l to 10 000 mg/l (INAP 2014f).
2. NRD:
   a. pH > 6 (near neutral to alkaline);
   b. low to moderate levels of metals and metalloids but may have elevated levels of zinc, cadmium, manganese, antimony, arsenic and/or selenium (INAP 2014e); in Finland, nickel, copper, cobalt and chromium may be related to NRD according to the TWG;
   c. low to moderate sulphate levels, e.g. SO_4^{2-} levels < 1 000 mg/l (INAP 2014f).
3. SD:
   a. pH > 6 (near neutral to alkaline);
   b. low levels of metals and metalloids but may have moderate levels of iron (INAP 2014e);
   c. moderate sulphate levels, e.g. SO_4^{2-} levels > 1 000 mg/l (INAP 2014f);
   d. moderate magnesium and calcium levels (INAP 2014e).

The following conditions may increase the ARD/NRD generation potential in extractive wastes containing metal sulphides:
- presence of oxygen (air and water) necessary to oxidise sulphides;
- presence of ferric ions which promote oxidation of sulphides;
- presence of microorganisms which also promote oxidation of sulphides.

The key pollutants in ARD, NRD and SD emissions are:
- dissolved metals and metalloids;
- salt anions such as sulphates, chlorides or bromides;
- alkaline and alkaline earth metals;
- acidity in the case of ARD.

Further information on ARD is provided below.

<u>The basics of ARD</u>
Unless stated otherwise, the following information is from the MTWR BREF (EC-JRC 2009).

When sulphide minerals come into contact with water and oxygen they start to oxidise. This is a slow heat-generating process (kinetically controlled exothermal process) which is promoted by:
- high oxygen concentration;
- high temperature;
- low pH;
- bacterial activity.

The overall reaction rate for a specified quantity of sulphides is also dependent on other parameters, for example the type of sulphides and the particle size, which also governs the exposed surface area. When the sulphides oxidise they produce sulphate, hydrogen ions and dissolved metals.

Extractive wastes consist of the different natural minerals found in the mined rock. In the unextracted rock, often situated below the ground (based on the data and information exchange, the maximum reported depth was on average ~ 700 m with the maximum one reported as being ~ 3 500 m), the reactive minerals are protected from oxidation. In oxygen-free environments, such as in groundwater, the sulphide minerals are thermodynamically stable and have low chemical solubility. Groundwater in mineralised areas, therefore, often has a low metal content. However, when excavated and brought to the surface, the exposure to atmospheric oxygen starts a series of biogeochemical processes that can lead to production of acid rock drainage. Hence, it is not the content of metal sulphides in itself that is the main concern, but the combined effects of the metal sulphide content and the exposure to atmospheric oxygen. The effect of exposure increases with decreasing grain size and, therefore, increased surface area. Hence, the sulphides in the finely ground extractive waste are more prone to oxidation (EC-JRC 2009).

Extractive waste is normally composed of a number of minerals, of which the sulphides only constitute one part, if present at all. Therefore, if sulphide oxidation occurs in extractive waste, the acid produced may be consumed by acid-consuming reactions in varying degrees, depending on the acid-consuming minerals available. If carbonates are present in the extractive waste, on the one hand the pH can be maintained neutral, and on the other hand the dissolved metals precipitate and thus are not transported to the surrounding environment to any significant degree. Other acid-consuming minerals include metal hydroxides, silicates and alumino-silicates. However, the neutralisation potential of alumino-silicates is lower than that of carbonates due to slower reaction kinetics.

The interaction between the acid-producing sulphide oxidation and the acid-consuming dissolution of buffering minerals determines the pH in the pore water and drainage water, which in turn influences the mobility of metals. If the readily available buffering minerals are consumed, the pH may drop and ARD will then occur.

The release of ARD to surface water and groundwater deteriorates the water quality and may cause a number of impacts, such as depletion of alkalinity, acidification, bioaccumulation of metals, accumulation of metals in sediments, effects on habitats, elimination of sensitive species and unstable ecosystems.

Weathering at the field level

ARD may occur where sulphide minerals are exposed to the atmosphere (oxygen and water) and where not enough readily available buffering minerals are present. This could be in, for example, deposits of extractive waste from excavation, marginal ore deposits, and temporary storage piles for the ore, deposits of extractive waste from mineral processing, pit walls, underground workings or in heap leach piles. Historically, sulphide-containing material has also been used for construction purposes at mine sites, e.g. in the construction of roads, dams and industrial yards. However, regardless of where ARD generation occurs, the fundamental processes behind the generation of ARD are the same.

The ARD and metal release will depend primarily on the sulphide oxidation rate, the potential immobilisation/remobilisation reactions along the flow path and the water flow.

At the field level, not only are the temporary variations of material characteristics important for the evolution of the drainage water quality, but the spatial variations will also be a factor to take into account, both depending on the geological context. The resulting drainage water characteristics depend on a number of additional parameters, such as infiltration rate, evaporation rate, oxygen profile in the deposit, height of the deposit, and the construction of the deposit. Heterogeneities in the material characteristics, such as varying mineralogy and degree of compaction, are other parameters that may affect the drainage water quality. Due to the normally long residence time of the infiltrating water in the deposit, the influence of various immobilisation reactions (precipitation and adsorption) may also be significant. The interaction between the extractive waste from mineral processing and/or the extractive waste from excavation and the atmosphere is illustrated schematically in the following figure.

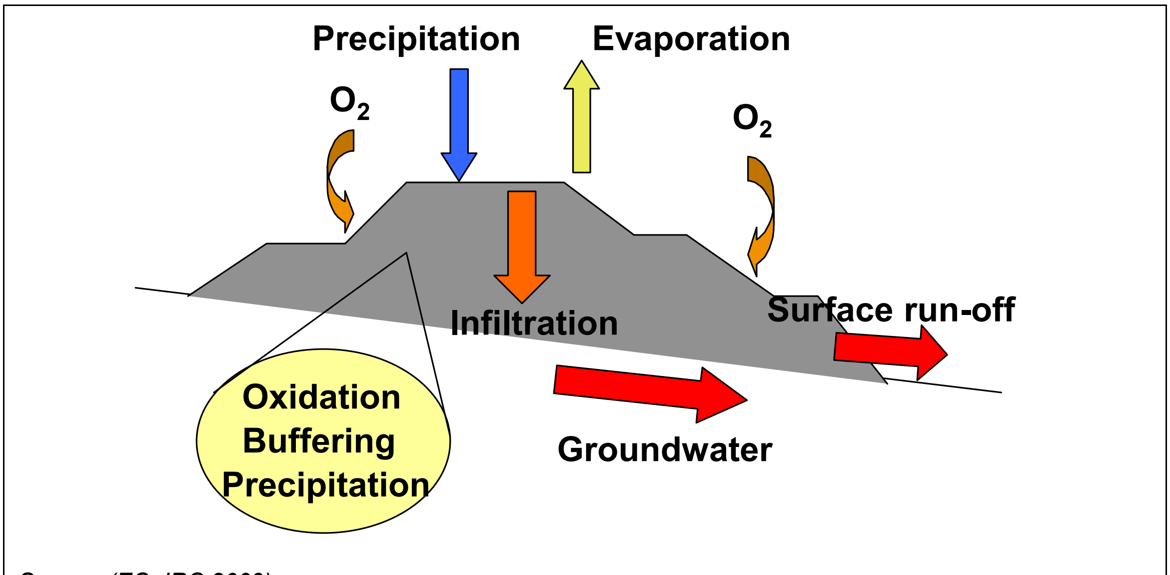


Figure 1.13: Schematic illustration of the extractive waste influenced water (EWIW) generation as a function of the interaction between the extractive waste from mineral processing or the extractive waste from excavation in the EWF and the atmosphere

For a more complete and scientifically correct description of all relevant issues regarding ARD generation, a substantial amount of published literature is available (EC-JRC 2009). A significant number of these publications are the result of research initiatives that have been undertaken during the last 30 years, within large research programmes such as MEND, Post-MEND, AFR, MiMi, MIRO, INAP, PYRAMID and ERMITE. Some of the most active countries carrying out the research so far have been Canada, Australia, the United States, Sweden, Norway and the UK.

1.3.2.3 Dangerous substances and chemical residues

The EWIW may contain chemical residues and dangerous substances used for the mineral processing. Typical contamination may include:

- nitrates and nitrogen-bearing compounds from excavation, e.g. from explosives;
- cyanides from mineral processing, e.g. used in gold extraction;
- xanthates from mineral processing, e.g. used in froth flotation;
- residues of caustic soda, e.g. from the Bayer process.

1.3.2.4 Gas and volatile compounds

As mentioned in Section 1.3.1.2, spontaneous combustion of extractive waste can be a source of gaseous emissions. However, in some cases, the extractive waste itself is also a source of such emissions, e.g. from oil and gas extractive waste or coal and lignite extractive waste.

Examples of gas and volatile compounds emissions generated during the management of extractive waste are:

- greenhouse gas emissions, e.g. CO_2 from controlled (e.g. flaring of gas collected from oil and gas extractive waste) or uncontrolled (e.g. spontaneous) combustion processes, CH_4 from extractive waste itself (e.g. venting);
- volatile compounds emissions, e.g. VOCs or BTEX from oil and gas or coal and lignite extractive wastes;
- other emissions such as combustion products, e.g. NO_X or SO_x resulting from the management of extractive waste but excluding the waste gas emissions resulting from the

transport and handling of extractive waste (excluding exhaust gas from machinery and transport devices).

1.3.3 Other environmental issues

1.3.3.1 Odour and noise

Odour and noise are usually of little concern unless the extractive waste is being transported by truck in the vicinity of residential housing. Transport of flowback and produced water classified as extractive waste from hydrocarbons exploration and production is a good example of this.

1.3.3.2 Visual impact and land use

The visual impact and the land use footprint may be an environmental issue for large sites where significant amounts of extractive waste are managed (several million tonnes) on the land. In that case, sites for the management of extractive waste may cover a sizeable surface area (e.g. up to several hundred hectares for metalliferous ore extractive waste) or lead to important changes in the landscape (e.g. heaps of coal or potash extractive waste several hundred metres high).

1.3.3.3 Usage of water and consumption of reagents, auxiliary materials, feedstock and energy

The usage and consumption of water for transport and management of extractive waste may have a local environmental impact on water availability and quality. Issues raised by water use are very dependent on local climatic conditions and initial water availability.

Consumption of energy and other materials for the management of extractive waste may also have a certain environmental impact.

1.3.3.4 Naturally Occurring Radioactive Materials (NORMs)

Radioactivity is an environmental issue common to some extractive sectors such as uranium extraction, phosphate extraction or oil and gas extraction, where Naturally Occurring Radioactive Materials (NORMs) can be found in the extracted mineral resources and in the extractive waste. Moreover, when these materials undergo processing, Technologically Enhanced NORMs (TE-NORMs) may also be present in the extractive waste. This document does not address the specific environmental issue of radioactive waste management. Nevertheless, it points out the existence of such issues that need to be addressed properly according to the regulations in place in each country. Hence, this document presents some techniques for the management of extractive waste that may be radioactive, without focusing on aspects specific to radioactivity.

1.3.3.5 Vibrations and induced seismicity

Vibrations and induced seismicity have been linked to the management of extractive waste, including but not limited to high-pressure injection of extractive waste in underground EWFs.

1.3.3.6 Biodiversity

Biodiversity can be impacted by the management of extractive waste. The operation (construction, management and maintenance) of EWFs including the management of extractive waste can disturb or destroy the initial natural habitat of local species during the operational phase. For example, when depositing extractive waste in the sea, the local benthic fauna is destroyed during operation; when depositing extractive waste on land, the local flora and fauna are disturbed. In the closure and after-closure phase, operators can introduce new or reintroduce formerly present fauna and flora, by implementing appropriate closure plans and measures (e.g. putting back the topsoil in order to promote revegetation). Emissions from EWFs can also influence the biodiversity at the local level.

2 APPLIED PROCESSES AND TECHNIQUES FOR THE MANAGEMENT OF EXTRACTIVE WASTE

This chapter aims to provide background information, to non-experts, on applied processes and techniques in the management of extractive waste. Techniques related to extraction and treatment of minerals are presented as contextual information in Annexes 9.1 and 9.2.

A comprehensive overview is given of processes and techniques that have been reported as being applied in the sector, including techniques that may not qualify as candidate BAT (see Chapter 4) or BAT (see Chapter 5).

2.1 General principles and life cycle management

Unless stated otherwise, the information reported in the following sections is taken from the MTWR BREF (EC-JRC 2009).

The management of extractive waste, whatever mineral resource is extracted, raises generic and common issues that need to be addressed. Some of the potential impacts on the environment and human health resulting from the management of extractive waste can be reduced substantially by considering the whole life cycle of the EWF and the extraction project from the very beginning, while adhering to the principles of appropriate corporate management systems, Risk Management Systems, Environmental Management Systems, and Information and Data Management Systems.

In addition, the waste hierarchy principles - i.e. the decreasing order of preference given to prevention of extractive waste, followed by reduction of extractive waste generation, followed by the possible re-use of extracted materials, followed by recycling of extractive waste, followed by recovery of extractive waste before considering disposal – form a central element in the context of sustainable development and the transition to a circular economy.

The main life cycle phases of the EWF can be defined as:

- planning and design;
- operational: construction, management and maintenance;
- closure and after-closure.

EWFs are managed by operators in the most suitable way for each phase of their life cycle, in order to reduce risks of negative impacts on the environment and human health.

To achieve this objective, operators apply a so-called design for closure approach, i.e. the EWF is designed from the very beginning considering the closure and after-closure phase and appropriate attention is given to evaluation and quantification of both the short-term and the long-term environmental impacts of the EWF.

Life cycle management, along with the use of a Quality Assurance/Quality Control system, usually implies that at least the information listed in the following subsections has been gathered, considered and archived.

2.1.1 Planning and design phase

The Extractive Waste Management Plan (EWMP) is developed according to Article 5 of Directive 2006/21/EC (and national legislation) and it includes at least:

- the *proposed classification* for the EWF, where applicable;
- <u>*extractive waste characterisation*</u> (according to Annex II to Directive 2006/21/EC and the Annex to Commission Decision 2009/360/EC) including:

  - background information;
  - geological background of the deposit to be exploited;
  - nature of the waste and its intended handling (deposition plan);
  - geotechnical behaviour of the waste;
  - geochemical characteristics and behaviour of the waste.
- a description of the operation generating such extractive waste;
- a description of how the environment and human health may be affected by the deposition of such extractive waste and the preventive measures to be taken;
- the proposed <u>*control and monitoring procedures*</u>;
- the proposed <u>*plan for closure, including rehabilitation, after-closure procedures and monitoring*</u>;
- measures for the prevention of water status deterioration;
- a survey on the conditions of the land to be affected by the EWF.

More detailed information on different studies and plans usually developed by operators is reported below (EC-JRC 2009). It represents a summary of studies and plans which can be developed in the design of an extractive waste deposition area (including an EWF) to an appropriate level of detail relevant for each stage (concept, preliminary and detailed design stages) and then maintained throughout the life cycle phases.

2.1.1.1 Environmental baseline studies

The following is a summary of considerations usually taken into account when collecting and collating environmental baseline information for use in site selection, design and operation. This same baseline information is important for the development of closure plans and environmental monitoring programmes. More comprehensive lists may be found in specific environmental assessment guidelines.

- *Existing resources and land use* - existing resources and land uses within the extractive waste deposition area (including the EWF) and within the greater potential impact area are usually identified, in particular:
  - the boundaries of the greater potential impact area are determined: e.g. area where the impact of the planned activities may change the land, the monetary value of the property or the potential of ecosystem services;
  - evaluation (including monetary value assessment) of the existing potential of ecosystem services in the area of the planned activities and greater potential impact area;
  - land and water (including sea) use:
    - current and historical land uses, including recreational, parks, human habitation, archaeological considerations, extraction, logging, farming and hunting;
    - current and historical water and sea (when relevant) uses, including fishery (fish and shellfish) aquaculture and recreation, drinking water sources and use, as well as aquifers for potential future use;
  - land tenure:
    - establishment of the right to acquire the necessary land for the extractive waste deposition area (including the EWF);
    - identification of land ownership and mineral rights.

- *Baseline scientific data* - baseline environmental scientific data relevant to the extractive waste deposition project area are usually compiled, including the following:
  For land deposition:
  - Physical and chemical:
    - climate (e.g. temperatures, wind, precipitation, evaporation, return period floods);
    - air quality baseline;

    - water (e.g. hydrology, watershed delineation and flow patterns, stream flow, lake bathymetry, subsurface hydrogeology and groundwater quality characteristics, surface water and sediment quality);
    - morphological status of surface water bodies (in accordance with the Water Framework Directive), assessed using the River Habitat Survey, Lake Habitat Survey or similar, locally approved methodology of hydro-morphological survey;
    - landforms;
    - geology and geochemistry (e.g. surface deposits – type, location, density, permeability; stratigraphy, geomorphology, mineralogy, background elemental content; characteristics and chemical composition of soil, quaternary sediments and bedrock);
    - landscape topography (e.g. regional and detailed topographic maps, stereo aerial photography, satellite imagery), including bedrock topography underlying glacial sediments (when relevant);
    - soils (e.g. soils sampling and characterisation);
    - natural hazards (landslides, avalanches, seismic events, flood potential, frost action);
    - information concerning old extraction sites near or below the EWF.
  - Biological:
    - ecosystem identification (usually performed in accordance with the European principles of ecosystem mapping (MAPS), taking into account the CORINE Land Cover classification (CLC); it usually also includes an assessment of the value, including monetary assessment of existing ecosystems, prepared in accordance with local regulations);
    - terrestrial survey (e.g. flora, natural pastures, fauna, endangered and threatened species, migratory species);
    - aquatic survey (e.g. benthos, macro-invertebrates, fish, aquatic plants);
    - evaluation of ecological succession processes in the area covered by the planned activities and its surroundings.

  For sea disposal of extractive waste, which is uncommon practice in the EU but applied in Norway in specific cases after Environmental Risk and Impact Evaluation (see 2.1.1.5):
  - Physical:
    - hydrography (water stratification);
    - current velocity and direction;
    - turbidity;
    - sediment grain size;
    - natural sedimentation rates;
    - bottom topography (slope inclination, stability evaluation, etc.);
    - natural and seasonal variability.
  - Chemical:
    - water chemistry (background concentrations);
    - sediment chemistry and mineralogy;
    - natural and seasonal variability.
  - Biological:
    - ecosystem identification and functioning (water and sediments);
    - endangered and threatened species;
    - levels of metals in bottom fauna;
    - natural and seasonal variability;
    - marine resources.

- *Baseline socio-economic data* - baseline socio-economic data relevant to the extractive waste deposition project area are usually compiled, including:
  - historical background;
  - population;
  - regional economy (e.g. health, education, culture, demography);
  - diagnosis of the area in terms of sensitivity to the effects of climate change;

- identification of socio-economic issues which might arise from the project.

A baseline study is usually established as part of the Environmental Risk and Impact Evaluation and is also essential as a benchmark for monitoring programmes carried out during mining operation and after closure.

2.1.1.2 Initial extractive waste characterisation

Critical for the correct management of extractive waste is the proper characterisation of the waste. The characterisation results will determine how to manage the extractive waste during operation (deposition technique, protective measures, etc.), at closure (closure requirements and techniques) and in the post-closure phase (prediction of long-term behaviour).

Ideally, the extractive wastes are properly characterised before the start of the operation and the results are fully incorporated into the planning and design of the extractive waste management facilities and the management plans. Review and verification of extractive waste characteristics (monitoring) is performed during the operational (construction, management and maintenance) phase and closure and after-closure phase (when relevant).

Further information on waste characterisation can be found in the mandated work developed by the European Committee for Standardization (M/395): "Characterisation of waste from extractive industries", which resulted in four standardised documents (CEN/TR and CEN/TS) and one fully validated European Standard (EN):

- EN 15875:2011 "Characterization of waste - Static test for determination of acid potential and neutralisation potential of sulfidic waste";
- CEN/TR 16363:2012 "Characterization of waste – Kinetic testing for assessing acid generation potential of sulfidic waste from extractive industries";
- CEN/TR 16376:2012 "Characterization of waste – Overall guidance document for characterization of waste from extractive industries";
- CEN/TS 16229:2011 "Characterization of waste – Sampling and analysis of weak acid dissociable cyanide discharged into tailings ponds";
- CEN/TR 16365:2012 "Characterization of waste - Sampling of waste from extractive industries".

2.1.1.3 Identification of extractive waste site options

The very first issue raised by the management of extractive waste is to identify distinct site options where the waste will be accumulated or deposited based on a preliminary characterisation of the sites and the extractive waste.

An ore deposit can only be extracted where it is located but there is some degree of freedom in the choice of extraction method and the exact location of shafts and other infrastructure. Nonetheless, the mineral treatment is typically undertaken as close as possible to the excavation site, due to the often low grade of the ore which implies that the ore value cannot cover high transport costs. However, in some cases the ore is processed many thousands of kilometres away from the excavation site, for instance for the processing of bauxite to produce alumina.

In some cases, extractive waste is pumped or transported many kilometres to an appropriate site for deposition or treatment; however, it is generally preferable to limit or reduce the transportation cost.

For the identification of site options and the selection of the location of the extractive waste deposition area (including the EWF), many factors have to be considered in order to prevent or reduce as far as possible any adverse impacts on the environment and/or human health.

Some of the factors to consider include:

- preferable use of existing geographical formations (e.g. existing pits or slopes) after careful analysis (e.g. of the hydrogeological characteristics and stratigraphy of quaternary sediments);
- need to respect the hydrogeological setting of the surrounding area (ground- and surface water) and characteristics of quaternary overburden and underlying bedrock (e.g. water permeability of glacial/postglacial sediments, potential compaction, and topography, fracture zones and permeability of underlying bedrock);
- adaptation of the extractive waste deposition area (including the EWF) to the surrounding area (e.g. dust, noise and odour control if there is a residential population nearby);
- meteorology (e.g. rainfall data including the possible increase of rainfall over the lifetime of the EWF due to the effects of climate change);
- geotechnical and geological background (e.g. foundation conditions, seismic risk data);
- natural and cultural environment;
- relationship of the extractive waste deposition area (including the EWF) with underground operation;
- topography of long-term construction;
- proximity to surface water;
- proximity to the coast (seawater);
- existing land use;
- local communities;
- biodiversity.

The operator selects a preferred site and prepares a documented rationale for its selection, including an analysis of the alternative sites studied and rejected. Furthermore, public perception issues related to the project (i.e. internal and external stakeholder requirements) are identified. Issues to consider in the site selection process include the following:

- *Environmental considerations:*
    - EWIW treatment requirements;
    - emissions to surface water;
    - emissions to groundwater (hydrogeological containment);
    - historical use of the receiving watershed;
    - background environmental conditions;
    - impact on vegetation, wildlife and aquatic life;
    - natural flora and fauna;
    - archaeological considerations;
    - potential emissions to air;
    - aesthetic considerations;
    - conceptual water balance analysis;
    - the effect of climate change on weather conditions.

- *Planning considerations:*
    - accessibility (road construction);
    - distance from the mineral processing plant;
    - relative elevation from the mineral processing plant;
    - distance from habitation and areas of human activity;
    - topography (including bedrock topography underlying the quaternary sediment bed when relevant);
    - existing land and resource use;
    - property ownership and mineral rights;
    - transportation corridors, power lines, etc.;
    - watershed and surface area considerations;
    - volumetric capacity;
    - pond volume/storage capacity ratio;
    - geology, including potential orebodies;

- construction material availability;
- conflict with mining activity;
- dam foundation conditions;
- basin foundation conditions (including hydrogeological and compressibility properties of quaternary sediments when relevant, and hydrogeological properties, permability and fracture zones of underlying bedrock);
- downstream hazards;
- hydrology;
- groundwater, and contaminant seepage;
- potential impact area;
- human and environmental risk;
- water management scheme and preliminary water balance;
- operational plan;
- deposition plan;
- preliminary containment and water management structures;
- preliminary cost estimate based on preliminary considerations;
- conceptual risk assessment (including assessment of induced seismicity risks);
- health and safety assessment.

- *Decommissioning and rehabilitation considerations:*
  - flood routing requirements;
  - revegetation potential;
  - long-term physical and chemical stability;
  - ease of establishing permanent drainage;
  - reduction and/or control of acid drainage and other contaminants;
  - dust control;
  - long-term maintenance, monitoring and treatment requirements.

- *Cost considerations:*
  - capital cost;
  - cost of extractive waste transport;
  - operating and maintenance costs of the extractive waste deposition area (including the EWF);
  - closure costs;
  - cost per tonne of ore processed.

2.1.1.4 Extractive waste handling/transport, treatment and deposition plan

After identification of extractive waste handling/transport, treatment and deposition options, based on the data and information collected (site options, extractive waste initial characterisation, environmental risk and impact evaluation, risk assessment, etc.), an extractive waste handling/transport, treatment and deposition plan is developed. This plan may allow for the staging of EWF lifts and raises over the life of the mine to accommodate the long-term storage of the extractive waste, to maintain suitable solids storage capacity, and to allow the appropriate polishing of free water during operation of the mine.

An appropriate consideration of future expansion requirements and/or capacity should be considered in the plan. The deposition plan development requires information on the quantity and density of the extractive waste, including extractive waste from mineral processing, when relevant; the water content and production information estimated from the process/mineral processing plant; and the water balance; and should include provisions for estimating uncertainty and contingencies. The basic parameters are validated and updated on a periodic or regular basis.

Equally important are the construction specifications and the recording in detail of the built and extended EWF, which will need geodetic surveying at regular intervals.

2.1.1.5 Environmental Risk and Impact Evaluation

In order to obtain stakeholder and regulatory acceptance for siting a new extractive waste deposition area (including an EWF), it is often necessary to conduct an evaluation of environmental risks and impacts. In some cases, it is also a legal requirement to conduct an Environmental Impact Assessment (EIA). In EU Member States, the EIA is regulated by Directive 2014/52/EU amending EIA Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment (EC 2014). The Directive requires Member States to conduct an EIA for projects listed in Annex I. According to point 19 of Annex I. to the Directive, *quarries and open-cast mining where the surface of the site exceeds 25 hectares, or peat extraction, where the surface of the site exceeds 150 hectares*, are made subject to an assessment in accordance with Articles 5 and 10. An EIA is also required for the *extraction of petroleum and natural gas for commercial purposes where the amount extracted exceeds 500 tonnes/day for petroleum and 500 000 cubic metres/day for gas*. For projects listed in Annex II, Member States are required to assess whether they need an EIA or not. Point 2 of Annex II to the Directive states that it is up to Member States to determine whether projects from one of the following extractive industry activities are made subject to an assessment in accordance with Articles 5 and 10 through a case-by-case examination *or* threshold or criteria set by the Member State:

a. *quarries, open-cast mining and peat extraction (projects not included in Annex I);*
b. *underground mining;*
c. *extraction of minerals by marine or fluvial dredging;*
d. *deep drillings, in particular:*
   i. *geothermal drilling;*
   ii. *drilling for the storage of nuclear waste material;*
   iii. *drilling for water supplies;*
   with the exception of drillings for investigating the stability of the soil;
e. *surface industrial installations for the extraction of coal, petroleum, natural gas and ores, as well as bituminous shale.*

The information the operator has to supply in the EIA report is described in Annex IV to the EIA Directive. Guidance was also provided by Commission services on the application of the EIA Directive to projects related to the exploration and exploitation of unconventional hydrocarbons. In addition, Commission Recommendation 2014/70/EU laying down minimum principles for the exploration and production of hydrocarbons using high-volume hydraulic fracturing (such as shale gas) invites Member States to ensure that an EIA is carried out prior to granting authorisations for exploration and/or production of hydrocarbons which may imply the use of high-volume hydraulic fracturing.

Additional information on the specific aspects of the EIA procedure and the content of baseline studies can be found, for example, in the Guide Environmental Impact Assessment Procedure for mining projects in Finland (Jantunen *et al.* 2015). However, this guide does not reflect the latest amendement of the EIA Directive.

In the specific cases of sea tailings disposal, which is uncommon in the EU, comparisons are made between land disposal alternatives and sea disposal to evaluate the environmental acceptance and the technical feasibility of any relevant alternatives.

Baseline studies analyse the impacts of an extractive waste deposition area (including an EWF) and are aimed at the selection of the most appropriate location and configuration. They determine what the existing conditions are before a new site goes into operation. They therefore provide the basis for any impact identification and assessment that might follow. The level of detail of the baseline study and Environmental Impact Assessment (EIA) is usually defined by a scoping assessment conducted by the permitting authority.

The Environmental Risk and Impact Evaluation process requires integration of knowledge about the project as it is being designed, the natural and social environments in which the project is situated, and community and stakeholder concerns. For the Environmental Risk and Impact Evaluation, the study is generally carried out for both the extractive waste deposition area (including an EWF) and the extraction site (e.g. mine, quarry or oil and gas well) in an integrated manner.

The following is a summary of some significant aspects usually addressed in an Environmental Risk and Impact Evaluation:

- environmental baseline;
- the process: extraction and mineral processing of mineral resources;
- site options identification and site selection for the extractive waste deposition area (including the EWF), with a clearly documented rationale for the selected site;
- concept design of the extractive waste deposition area (including the EWF).

Furthermore, the Environmental Risk and Impact Evaluation examines processes, emissions (e.g. point source emissions and diffuse emissions), exposure scenarios (for humans and biota), and impacts. It is employed to study and compare the environmental (including ecological) and health effects of various options.

The Environmental Risk and Impact Evaluation includes not only the identification of the "risk sources" but also the evaluation of the probabilities of occurrence of accidents (e.g. actual failure), as well as the severity of the likely consequences to follow from such an accident. Thus the risk assessment provides the basis for the development of any risk management strategy and all its consequent action plans and procedures (including communication, contingency, mitigation and emergency response).

The risk is assessed (and managed) through each phase of the life cycle of the extractive waste deposition area (including the EWF). However, the intensity of the assessment will vary at different stages, depending on the objectives of the review, the complexity of the pertinent issue and the extent of information available.

Generally, the Environmental Risk and Impact Evaluation includes the following elements:

- scope and purpose of assessment;
- risk assessment team;
- evaluation criteria;
- methodology;
- potential triggers and failure modes;
- probability of failure;
- consequences of failure;
- reporting.

The Environmental Risk and Impact Evaluation leads to a list of identified and assessed risks. The assessment is followed by the planning of risk reduction measures. In principle, a risk can be managed in two ways: 1) measures to reduce the probability of occurrence, or 2) measures to reduce the consequences of an event. An evaluation of possible risk reduction measures is conducted and a plan, including timelines and responsibilities, is developed. An important component in minimising the consequences of a failure will be the development of an emergency plan.

2.1.1.6 Design criteria for short- and long-term safe disposal of the extractive waste

The following list may not apply to all sites or to all situations and therefore it is up to the operator and the permitting authority to decide which aspects apply. Site-specific conditions may require the use of different or additional criteria. Different criteria resulting in different design values may apply during the operational (short-term) and the closure and after-closure (long-term) phases.

Operators apply an integrated design approach that takes into account all the relevant parameters in order to optimise the overall environmental, human health and safety aspects of a project in the short and long term.

A compilation of examples of common design criteria considered by operators for the integrated design approach are given below.

- *EWF design:*
    - o type of facility (e.g. heap, pond, pond with dam(s), type of dams, dam raising method);
    - o topography;
    - o EWF classification (according to Annex II to Directive 2006/21/EC, the Annex to Commission Decision 2009/360/EC and/or national legislation);
    - o construction plan;
    - o closure considerations;
    - o stability design criteria (hydrology and hydrogeology specific environmental considerations, construction materials, foundations, stability under static and dynamic conditions – failure mode analysis for operational phase, and closure and after-closure phase);
    - o monitoring systems (e.g. piezometers, inclinometers, settlement gauges, drainage water flow monitoring, seepage or leakage detection, temperature, surveillance methods).

- *Hydrology and hydrogeology:*
    - o hydrological and hydrogeological studies;
    - o water balance analysis;
    - o water quality;
    - o flood design criteria;
    - o freeboard requirements;
    - o drought design (i.e. water cover requirement);
    - o catchment run-off and diversion arrangements;
    - o deposition plan;
    - o supernatant (or free) water management (e.g. decant systems, spillways, siphons, pumping stations, natural hazards handling requirements);
    - o drainage water management (e.g. drainage systems, pipes);
    - o seepage management (e.g. filters design, cut-off trench, grout curtain, ditching, dam core design, interception wells, basal structure design);
    - o erosion management plan.

- *Special environmental considerations:*
  Seismic risk, seismic attenuation of foundation strata and construction materials, liquefaction potential of foundation strata and construction materials, and climatic conditions, are assessed and taken into consideration for the design of the EWF. This includes:
    - o extreme values to be expected (flood, earthquakes);
    - o wind and free water wave impacts;
    - o permafrost effects, when relevant;
    - o climate (e.g. frost);

  - fauna and flora (e.g. biodiversity, specific protection measures).

- *Foundations, geology and geotechnical engineering:*
  - geomorphology;
  - regional and local geology, faults;
  - stratigraphy;
  - bedrock and soil characteristics (including bedrock fracture zones and quaternary sediment characteristics in glaciated areas);
  - geotechnical information, including:
    - compressibility;
    - shear strength;
    - angle of friction;
    - grain size;
    - density;
    - plasticity;
    - fractures;
    - liquefaction potential;
    - permeability;
    - erosion potential;
    - hydraulic fracture;
  - foundation preparation prior to construction considering:
    - vegetation removal, including merchantable timber;
    - excavation of organic soils;
    - cut-off walls;
    - groundwater control and containment;
    - bedrock cleaning and slush grouting;
    - high-pressure grouting;
    - diversion wells;
    - diversion channels;
    - dewatering requirements;
    - stability;
    - constructability;
    - other special construction requirements.

- *EWF construction materials:*
  The availability of naturally occurring construction materials is assessed, as are the engineering characteristics of these potential construction materials, tailings, grout/concrete or other potential liner materials (both natural and synthetic), i.e. with regards to:
  - grain size;
  - density;
  - volume;
  - shear strength;
  - permeability;
  - acid-generating potential;
  - chemical reactivity (acid-generating potential, reaction with pond water, thiosalt-generating potential);
  - wind and water erosion potential.

  Potential detrimental effects of extractive waste from mineral processing and/or process water on construction materials are determined. Environmental impacts, stability and rehabilitation requirements related to the use of any construction materials are considered at this stage.

2.1.1.7 Emergency planning

Usually, emergency planning includes the development of a documented emergency plan for critical situations and failure scenarios (internal emergency plans). In some cases, measures to handle emergencies are planned together with the competent authorities (external emergency plans).

Emergency plans state which measures are to be taken in the case of failure events (possible or actual). This plan covers the organigram of the operator, specifying each person's responsibilities and the interfaces with external organisations. In the emergency plan, a plan of action describing operational measures and resources available to limit consequences, as far as possible, is established and documented.

The aim of the emergency planning is:
- to reduce the risk of failure of the EWF structures and prevent harm coming to people or the environment;
- to reduce the need for improvisation in a crisis or failure situation;
- to ensure the optimal utilisation of available resources;
- to identify and pinpoint responsibilities at every level;
- to make sure that everyone within the organisation, as well as the public and authorities concerned, are provided with the necessary information.

2.1.1.8 Control and monitoring procedures in the operational phase

A comprehensive control and monitoring plan is developed, and covers the full site life cycle with regard to control of the emissions and impacts, and their monitoring. It may also include monitoring of extractive waste characteristics and stability. Some examples of important points usually controlled and monitored during the operational phase are listed below.

- *Quality Assurance/Quality Control (QA/QC) system:*
  It is good practice to maintain and have the following elements available throughout the construction, operation and closure phases:
    - construction drawings and as-built construction records, including revisions;
    - test results;
    - meeting minutes;
    - construction photographs;
    - monitoring notes.

- *Construction control:*
  Typical components of a construction management system include:
    - planning and scheduling;
    - survey control (layout, as-built records);
    - grouting monitoring;
    - foundation preparation monitoring;
    - material quality control;
    - compaction control;
    - instrumentation monitoring and data synthesis;
    - record-keeping;
    - construction safety;
    - construction environmental criteria.

- *Dust control:*
  It is necessary to minimise dust releases from the extractive waste deposition area (including the EWF). This may involve keeping the extractive waste wet and/or using short- or long-term chemical or organic covers.

- *Conformance checks of extractive waste deposition areas (including EWFs):*
    - performance monitoring – i.e. visual conformance checks – with a high frequency;
    - groundwater pressure (pore water pressure);
    - seepage;
    - deformation (settlement and stability);
    - weather influence;
    - seismic events;
    - special inspection programmes after major events (earthquakes, hurricanes, spring break-up, floods);
    - indicators of instability:
        - soft zones and boils along the toe;
        - dirty sediment in seepage;
        - increased seepage rates;
        - new areas of seepage;
        - longitudinal and transverse cracking;
        - settlement;
    - areas requiring special attention:
        - spillways;
        - decant structures;
        - drain and pressure relief wells;
        - concrete structures;
        - pipes and conduits through dams;
        - riprap areas;
        - siphons;
        - weirs;
        - trees and animal dens.

- *Physical stability monitoring plan:*
    - location of control stations;
    - scheduling (control periods and conformance checks);
    - type of monitoring (visual conformance checks, measures and parameters);
    - appropriate level of instrumentation (e.g. piezometers) with a clearly identified purpose;
    - conformance check methods, data compilation and evaluation;
    - persons responsible for monitoring;
    - data storage and reporting systems;
    - criteria to assess the monitoring programme.

- *Water management plan:*
    - hydrology:
        - severe storm events and drought events;
        - necessary information and parameters for water management activities;
        - criteria to manage water levels within safe limits, including any required daily or seasonal water level control;
    - water control, ensuring that:
        - safe water management is carried out within the boundaries of the system;
        - water balance analysis is reviewed based on the monitoring findings;
        - damage to all structures is prevented/controlled/repaired;
        - reviews and revision are carried out as required after changes in the design or the construction method and when the pond level exceeds the specified critical elevation, and must be performed after major storm or spring melt events;
    - perimeter seepage:
        - evaluating the potential for seepage from the extractive waste deposition area (including the EWF);
        - defining levels and characteristics of acceptable seepage;
        - preparing action plans to deal with deviations from design seepage;

        - measuring performance including control of seepage within design rates;
        - monitoring and controlling to ensure that systems are performing as per design;
    - hydrogeology and groundwater quality:
        - monitoring and controlling hydrogeology to ensure that systems are performing as per design;
        - monitoring and controlling groundwater quality to ensure that systems are performing as per design.

- *Mass balance of extractive waste:*
  This ensures the efficient use of the capacity and effective closure of the extractive waste deposition area (including the EWF). Short- and long-term scheduling of lifts and raises are also covered in the plan. At preset intervals a schedule for deposition of the extractive waste and a filling curve (volume/elevation graph) are validated against actual field conditions.

2.1.1.9 Planning for closure, including rehabilitation, and after-closure procedures and monitoring

Closure plans and performance criteria are developed in the early stages of EWF design, and then verified and updated periodically throughout the operating life of the EWF in preparation for final decommissioning and closure. Closure is usually covered by regulations, and the following list provides some general considerations applicable to the development of closure plans. In certain circumstances, closure has to be followed by long-term aftercare. This requires similar plans and controls to those used for closure.

- *Elements of a closure planning:*
    - determination of background data, including:
        - history of site;
        - infrastructure;
        - process flow controls;
        - system operations;
        - mineralogy;
        - topography;
        - hydrology/water management;
        - hydrogeology;
        - soil capability;
    - revegetation;
    - environmental risk and impact assessment;
    - long-term maintenance;
    - geotechnical analysis for the closure planning;
    - chemistry and geochemistry;
    - monitoring programme;
    - EWIW management or treatment requirements, where relevant;
    - communications;
    - financial assurance;
    - stakeholder consultation;
    - potential end land use; and
    - closure technology (i.e. dry or wet cover, flooded, wetlands, perpetual treatment, vegetative cover).

- *Aspects of EWF stability relevant for closure plan considerations:*
  Closure plans require a thorough reassessment of the EWF and its stability under closure conditions. All aspects of the EWF and of the physical and chemical stability are reviewed. In particular, the actual performance of the EWF in service, including deformation, seepage, foundation and sidewalls, is checked against design projections, as well as against projected post-closure conditions. Design loads might be different after decommissioning and closure.

Structural monitoring and inspections are continued for all facilities until they are decommissioned, and thereafter as appropriate. Identification and delineation of any requirements for continuing inspection and/or monitoring of remaining structures after closure is carried out.

Action plans are prepared to deal with shortcomings in closure quality and/or difficulties in complying with closure specifications. Examination of the consequences of closure of the facilities on emergency preparedness procedures, and the updating of these plans as appropriate, is also desirable. Continuing availability of design, construction and operating records after closure for structures remaining in place has to be ensured.

In the uncommon case of sea disposal of extractive waste, the closure plan and procedures for closure are to a large extent restricted to removal of pipelines and infrastructure coupled with tailings disposal. No specific rehabilitation is put in place as natural sedimentation is considered for the capping of the extractive waste deposition site. Norwegian authorities set as a prerequisite for the sea disposal permit monitoring of the disposal site and its surroundings during operation as well as after closure.

2.1.2 Operational phase (construction, management and maintenance)

For some EWFs, the distinction between construction and operational phases is not so clear, because construction activity may also take place during operation (e.g. raising of the dam). Construction of the EWF is well documented and follows the construction plan established in the design phase. As-built documentation is provided, highlighting any changes compared to the construction plan.

In the construction of the EWF:
- construction is supervised by an *independent qualified engineering*/geotechnical specialist;
- *records of the results of test work* (e.g. compaction) carried out for and during construction are properly maintained.
- *"as-built" drawings and actual procedure records* are maintained, recording any *variation or change* from the original design and, if necessary, revisiting the design criteria;

Based on the database on failures of EWFs for the management of extractive waste from mineral processing (Newland Bowker 2017), which contains data on 295 accidents that occurred from 1915 to 2017, the main causes of EWF incidents have been found to be:
- overtopping in 49 cases;
- slope instability or static failure in 47 cases;
- earthquakes or seismic instability in 42 cases;
- seepage and internal erosion in 25 cases;
- structural and foundation conditions or foundations with insufficient investigations in 23 cases;
- structural inadequacies, or inadequate or failed decants in 21 cases;
- erosion or external erosion in 11 cases;
- mine subsidence in 1 case; and
- unknown in 76 cases.

In the unknown cases, a general lack of understanding of the features that control safe operations may be included.

This indicates that more rigorous investigations and engineering in the planning and design phase, along with better control during the operational phase, are the key factors in safe EWF management.

Geotechnical engineering has advanced far enough to design sound and safe dams, which means that present-day disasters often result from improper management of the EWF.

The following measures are frequently taken to avoid incidents:
- monitoring of the phreatic surface;
- planned provisions for diverting discharge of water and extractive waste from mineral processing away from the pond in the event of difficulties;
- providing an alternative discharge option, possibly into another pond;
- providing emergency overflow facilities and/or standby pump barges for emergencies;
- measuring ground movements with deep inclinometers and having a knowledge of pore pressure conditions;
- providing suitable drainage;
- maintaining records of design and construction and recording any updates/changes in design/construction;
- educating and training staff;
- providing continuity in the engineering of the dam;
- independent audits of the dam with a sign-off by the third-party auditor.

The operation of the EWF should follow the EWMP, the operational instructions and the monitoring plan for the facility. Any deviations from these documents need to be recorded and evaluated. Monitoring data are evaluated on a regular basis and followed up where necessary. Internal and external reviews (audits) are performed in some cases.

The following measures are taken to ensure sound operation:
- the generation of extractive wastes receives the same level of management attention as the production of saleable product;
- effective operational control and monitoring is maintained;
- there are systems for keeping records of the generated quantities and characteristics of extractive wastes;
- accountabilities and responsibilities for extractive waste management are clearly defined with appropriately qualified personnel;
- management facilities are routinely inspected by a qualified professional engineer experienced in extractive waste management and signed off to confirm that all significant risks have been identified and are adequately managed in the continued operation of the facilities;
- operating instructions are prepared in the language of the operators and followed; these instructions include all the monitoring requirements;
- operating records, such as rise in levels, tonnes contained, seepage quantities, water consumption (including possible meteorological data), etc. are stored and properly maintained;
- operating conditions which occur beyond the boundaries identified by the design are immediately reported to the engineer or checked by a qualified technician;
- appropriate training of operational personnel is provided, including on incipient fault diagnosis;
- special attention is given to the follow-up of the water management plan;
- effective mechanisms for the reporting of faults are established and maintained;
- effective emergency response plans are maintained and further developed.

2.1.2.1 Operation Supervision and Maintenance (OSM) manuals

Several operators use dam safety manuals. These manuals are known as OSM manuals (Operation, Supervision and Maintenance). An example of such an OSM manual covers the following:
- dam safety organisation;

- emergency preparedness plan;
- classification according to the consequences of the dam failure;
- dam construction;
- hydrology;
- environment;
- operation;
- monitoring;
- permits;
- reports.

2.1.2.2 Auditing

Conformance checks (with or without third party) and internal and external (independent) audits cover all aspects that can affect the overall EWF safety, e.g. as-built and design changes documentation, conformity/non-conformity reports, monitoring reports, documented corrective measures and results, adequacy of the OMS manual, overall water balance of the EWF, surveillance performed according to applicable standards, risk assessment, incidents, uncontrolled seepage, emergency plans, decommissioning plan, etc.

The independent auditing of an EWF consists of the evaluation of the performance and safety of a facility on a regular basis by a qualified and experienced expert, who has never been associated with the design or operation of the EWF.

2.1.3 Closure and after-closure phase

Typically, an EWF might be in operation for up to a few decades. However, the deposited extractive waste will remain in place long after the cessation of the extractive activity. Therefore, special attention is given to the proper closure, rehabilitation and aftercare of the EWF. Generally, the major issues to be considered for the closure and after-closure phases include the long-term safeguarding of:

- physical stability of constructions (e.g. dams) and extractive waste (e.g. heaps);
- chemical stability of extractive waste;
- biological stability of extractive waste;
- successive land use (the rehabilitation of a site usually aims to turn the area into something that is useful to the local community).

Sometimes the extractive wastes do not contain any substances that are harmful to the environment. In these cases, the operator will ensure that the water is drained from the EWF during the closure phase to safeguard the physical stability. Afterwards, the dams will be flattened to allow access for machinery. Ponds and heaps will be prepared for subsequent use, which in most cases means covering the ponds and heaps with soil and vegetating them. Some sites can be handed over to the subsequent user after a relatively simple rehabilitation, e.g. after reshaping, covering and revegetation.

However, in other cases closure and after-closure require more elaborate planning. Usually, the plan for this step is already part of the first permit issued. By the time of its actual execution, the plan will have undergone regular updates, depending on changes in the operation and on negotiations with the permit issuers, competent authorities and other stakeholders. Usually, the aim is to leave a footprint as small as possible. In that context, progressive rehabilitation of the site can help to minimise both the visual and the environmental impact of the EWF during operations. Nevertheless, a complete change of landscape may be aimed for in some cases. The concept of "design for closure" implies that the closure of the EWF is already taken into account in the feasibility study of a new EWF and closure planning is then continuously updated during the life cycle of the EWF taking into consideration the monitoring findings. In all cases, the aim is to minimise any possible negative environmental and/or human health impacts, in particular with regard to physical instability.

In that context, the following three classes of failure mechanisms are considered for the physical stability of the EWF and safe disposal of the extractive waste:

- slope failures in the foundation or the management facility itself;
- extreme events such as floods, earthquakes and high winds;
- slow deterioration, e.g. through water and wind erosion, frost and ice forces, weathering of fill materials and intrusion of vegetation and animals.

It should be noted that the OSM manuals, mentioned in the previous section, are also applied throughout the closure and aftercare phase.

When the closure of EWFs occurs simultaneously with the closure of a mine, an integrated closure and aftercare plan is usually developed and carried out.

The following issues are included in the previous life cycle phases, but are considered again in order to adjust the closure plans according to the *as-built situation* at the site:

- closure costs are included in the assessment of alternatives;
- closure plans adopt a risk assessment approach;
- closure plans are maintained throughout the active life of the EWF and are routinely updated taking into account any modifications to the design during the operational phase (construction, management and maintenance);
- facilities are designed to facilitate premature closure if necessary;
- aftercare design minimises the need for active management.

An important part of developing a closure plan is to develop a post-extraction land use. A successful subsequent utilisation of an extractive waste location is facilitated by a balanced consideration of the ecological, environmental, recreational and economic aspects.

The following table summarises the fundamental criteria for closure processes, from initial planning through to actual implementation.

Table 2.1: Fundamental criteria for closure processes, from initial planning through to actual implementation

Issue	Closure objectives
Physical stability	All remaining anthropogenic structures are physically stable in the long term.
Chemical stability	Physical structures remaining after closure are chemically stable in the long term.
Biological stability	The biological environment is restored to a natural, balanced ecosystem typical of the area, or is left in such a state so as to encourage and enable the natural rehabilitation and/or reintroduction of a biologically diverse, stable environment.
Hydrological and hydrogeological environment	Closure aims at preventing physical or chemical pollutants from entering and subsequently degrading the downstream environment - including surface and groundwater.
Geographical and climatic influences	Closure is appropriate to the demands and specifications of the location of the site in terms of climatic (e.g. rainfall, storm events, seasonal extremes) and geographic factors (e.g. proximity to human habitations, topography, accessibility of the mine).
Local sensitivities and opportunities	Closure optimises the opportunities for restoring the land and the upgrade of land use is considered whenever appropriate and/or economically feasible.
Land use	Rehabilitation is such that the ultimate land use is optimised and is compatible with the surrounding area and the requirements of the local community.
Funds for closure	Appropriate readily available funds need to be available to ensure implementation of the closure plan.
Socio-economic	Opportunities for local communities whose livelihoods may depend on the

considerations	employment or economic fallout from the extraction activities are taken into consideration. Appropriate measures are made to ensure that the socio-economic benefits of closure are maximised.

Source: (EC-JRC 2009)

Figure 2.1 illustrates an example of a heap closure trial carried out to test the closure and after-closure plan, which includes the capping of the entire heap with a vegetative cover.

Source: Image provided in the questionnaires, with the permission of K+S Kali

Figure 2.1: Example of a heap rehabilitation trial

2.2 Prevention of extractive waste generation

Prevention at the source, in order to minimise and reduce as far as possible the generation of extractive waste, may be performed by implementing appropriate equipment and technology modifications during the extraction of the mineral resources. For example, the pre-sorting of materials can be implemented during extraction in order to maximise alternative uses of extracted materials and minimise and reduce as far as possible the final amount of extractive waste to be deposited.

The total amount of extractive waste generated during mineral resources extraction is the result of the extractive process itself (including for example the mineral processing), technological possibilities and the economic context (the cut-off grade might vary depending on energy price, commodity price, etc.). Operators in charge of extractive waste management might not always have a direct influence on the quantities and properties of extractive waste generated during the extraction process.

Three main options exist to reduce the total amount of extractive waste to be deposited:

<u>Placing back materials into excavation voids:</u>
Placing removed materials back into excavation voids refers to the reinsertion of these materials into the mined-out part(s) of the extraction site for construction and/or rehabilitation purposes. The materials used are typically soil, topsoil, overburden, waste-rock and/or tailings, either alone or in combination with other cementitious binders.

In the oil and gas extractive industries, drill cuttings can be used to fill the voids in between the casing and the well.

In other extractive industries, mined rocks of an uneconomic grade may be placed back into excavation voids or temporarily stored in disused workings. This process is also referred to as *stowing*. Slurried and dry tailings may be used to fill excavation voids in underground mines or abandoned pits or in exhausted portions of active pits.

Commonly, the materials used are produced during the extraction process and, therefore, placing materials back into excavation voids is part of the extraction process. The main purposes of placing materials back into excavation voids are:

- for underground extraction:
  - to assure the ground stability;
  - to prevent stope wall spalling and convergence and reduce surface subsidence;
  - to provide roof support, confining pressure and long-term stability;
  - to increase ore recovery (further parts of the orebody can be extracted);
  - to increase safety;
  - to prevent surface subsidence;
  - to improve ventilation.
- for surface extraction:
  - to enable rehabilitation (decommissioning/landscaping reasons);
  - to increase safety, particularly for openings in relatively weak rocks;
  - to minimise the footprint (e.g. as opposed to building ponds or heaps);
  - to minimise risk of collapses by filling the pit instead of building a new pond or heap.

Besides the benefits for the extraction operation itself (see list above), placing extractive materials back into excavation voids also decreases the above-ground surface disturbance and the total amount of extractive waste to be deposited. Excavation and size reduction operations transform massive rock into a granular material with pores, resulting in an increase of the overall volume. As a consequence, only a maximum of ~ 50 % w/w of extracted materials can be placed back into excavation voids.

<u>Use of materials for internal purposes:</u>

This option refers to the use of materials within the extractive industry, for example as:

- construction materials, which may include:
  - means of access for machinery;
  - ramps;
  - safety barricades;
  - berms;
  - dams/embankments etc.;
- rehabilitation materials, which may include:
  - cover materials used for the capping of the extractive waste deposition area (including the EWF).

Use of materials for external purposes (e.g. as secondary raw materials):
This option includes, for example, aggregates used in earthworks and infrastructure construction, hydraulic engineering, landfill construction or as products (for example as raw materials in different applications such as cement production, tiles or brick manufacturing, soil amendment), when complying with Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

2.3 The preparing for re-use and recycling of extractive waste and/or extractive waste influenced water

2.3.1 The preparing for re-use

During the extraction of oil and gas, more precisely during the oil and gas drilling process, part of the extracted materials will generally be re-used if possible, e.g. drilling muds can be used in a closed loop as long as their properties are suitable.

Flowback and produced water both represent examples of potentially valuable water resources that may be exploited prior to disposal and new water withdrawal. Flowback refers to the approximately 10-80 % of the injected fluids for each fracturing stage that returns to the surface, and which contains heavy metal ions and NORMs disssolved by the water from the formation over geological times (Fakhru'l-Razi *et al.* 2009; Gordalla *et al.* 2013; PGI 2015). Produced water refers to the saline water present in the reservoir before operations and flowing out during the exploration and production stage, mixed with residuals of fracturing chemicals (Gordalla *et al.* 2013; PGI 2015). The flowback contains much fewer dissolved salts in comparison to the produced water, as the fracturing fluid has been in contact with the target formation for only a short period of time, e.g. hours up to days. They may both be re-used where the water quality and quantity matches the requirements for future re-use. For further reference, the specific guidance document on Best Available Techniques for the exploration and production of hydrocarbons, under development at the time of writing this document (Barthe *et al.* 2015) and expected to include the management of oil and gas drilling fluids, may be consulted.

In the extraction of other mineral resources besides oil and gas, the water will generally be re-used. The water used for the management of extractive waste (e.g. water used for the transport of extractive waste to the EWF), the water in contact with the extractive waste and the water collected (e.g. drainage water) often represent valuable sources of water for the operator.

The excess water from the EWF is commonly stored in a pond called a reclaim, sedimentation, settling, clarification, decant, polishing and/or regulation pond. It may be re-used in the mineral processing plant, depending on the water quality and technical requirements.

In this document, the term Extractive Waste Influenced Water (EWIW) is used to refer to any water whose chemical or biological composition has been affected by coming into contact with extractive waste. It includes water contained in or stemming from extractive waste deposition areas (including extractive waste facilities).

2.3.2 Recycling of extractive waste and/or extractive waste influenced water

Extractive waste and/or EWIW may be recycled in several instances.

Examples of recycling of extractive wastes are:

- recycling of materials in the extraction process, e.g.:
  - recycling of drilling muds in the oil and gas drilling process (IOGP 2009);
  - re-mining of the extractive waste;
- recycling of liquid waste for recovery of water (depending on the water quality and applicable legislation), e.g.:
  - recycling of flowback and produced water;
  - recycling of EWIW;
- recycling of extractive waste as secondary raw materials, e.g.:
  - recycling of red muds for production of ceramics and bricks.

2.4 Management of wastes from mineral excavation and treatment of mineral resources

There are many options for managing and depositing extractive waste. The most common methods are:

- temporary deposition of extractive waste, removal and off-site management;
- deposition of slurried extractive waste from mineral processing into pond-type EWFs (with or without dams);
- deposition of thickened or paste extractive waste from mineral processing into subaerial EWFs;
- dry stacking of wet or dry filter cakes of extractive waste from mineral processing into EWFs;
- deposition of relatively dry extractive waste onto heap-type or hillsides EWFs;
- deposition of extractive waste in water bodies (sublacustrine or sea disposal); and
- deposition of fracturing fluids that qualify as extractive waste in underground EWFs.

On a worldwide scale, the vast majority of extractive waste is deposited in land-based EWFs, with less than 15 out of the 2 500 industrial-scale mines worldwide using sea disposal, representing < 0.7 % of the extractive waste from mineral processing (IMO 2013). In some countries, permits are only issued for land-based deposition of extractive waste, because of existing legislation or stringent environmental requirements (e.g. USA, Canada, Australia). This situation is mirrored in Europe, where former sea disposal operations of extractive waste in the EU Member States were reported to have ceased and where active sea disposal activities have only been reported for Norway. The global declining trend in sea disposal of extractive waste is likely to continue, following a resolution signed by more than 50 countries to stop sea disposal of extractive waste (IUCN 2016).

The ways in which the different extractive waste deposition techniques are applied are discussed in this section.

2.4.1 Extractive waste treatment

Extractive waste may be managed on site or off site, prior to deposition.

When sent to external operators, the extractive waste is treated in waste treatment facilities that do not fall under the scope of Directive 2006/21/EC and are therefore excluded from the scope of this document. This may be the case for the excess water collected during oil and gas drilling and production, such as flowback water and produced water, which is usually sent for treatment to external operators. In addition, most drill cuttings are also taken off site for treatment and disposal once they have been separated from the drilling fluid. A specific BAT Reference Document for the treatment of waste in waste treatment installations permitted under Directive 2010/75/EU on industrial emissions exists and is periodically reviewed (EC-JRC 2017).

The common treatment techniques used for the treatment of EWIW encompass a wide range, such as media filtration and membrane filtration (micro-, ultra-, nano-filtration, reverse osmosis), adsorption and absorption techniques (ion exchange), distillation, etc.

The main techniques for the treatment of extractive waste reported by operators are:

- pre-sorting and selective handling;
- physical treatment;
- chemical treatment;
- thermal treatment;
- biological treatment.

2.4.1.1 Pre-sorting and selective handling

Pre-sorting and selective handling methods enable the separation of potentially valuable materials from the waste stream as by-products before the waste itself is sent for treatment and/or disposal.

They may also allow the separation of hazardous and non-inert extractive waste streams from inert extractive waste followed by selective handling of each stream. In the latter case, the main application lies in the selective management of potentially acid-generating and non-acid-generating extractive waste.

2.4.1.2 Physical treatment

Physical treatment methods aim at phase separation: liquid/liquid, liquid/gas or solid/liquid.

Physical treatment methods can be divided into four main types:
- evaporation;
- gravity separation, e.g. tanks, clarifiers, ponds and lagoons;
- centrifugation, e.g. hydro-cycloning and liquid/liquid centrifuging;
- filtration, e.g. filter press.

These methods are described more in detail in Section 4.2.2.1.

Evaporation
Evaporation can be natural or forced.

Natural evaporation is undertaken in ponds and lagoons designed to separate the (suspended) solids from the water-based stream. The sedimentation allows solid particles to settle in the bottom while water evaporates under the sun. Natural evaporation is not appropriate for the treatment of aqueous streams containing VOCs.

Ponds and lagoons are designed and constructed with a proper basal structure, made of synthetic liners when necessary, in order to avoid any contamination of the soil and groundwater.

Evaporation can also be achieved using forced air evaporators, by blowing air in a countercurrent stream of waste water. The process is carried out in a column. The preheating of the waste water stream might be necessary to eliminate the VOCs contained in the waste water and thus control or prevent emissions of VOCs to the air.

The forced air evaporation method is not appropriate for waste water with a high solids content.

Gravity separation
Gravity separation is used to separate solid particles from water or oil from water. Gravity separation is based on the gravity difference between the aqueous and non-aqueous phases. The separation can be enhanced using coalescing or corrugated plate separators.

Gravity separation is not appropriate to treat emulsions. In that case, pretreatment such as heating or addition of chemicals will be necessary to break the emulsion.

Centrifugation
Cyclones, such as hydro-cyclones, and centrifuges can be used to separate the solid particles from the liquid. The principle is similar to gravity settling. Centrifugal forces accelerate the separation of solid particles from the liquid phase.

The technique can also be applied to separate the oil phase from the aqueous phase or to recover valuable coarse particles (e.g. coarse tailings) that can be further used, e.g. for construction purposes.

Filtration

Press or vacuum filters can be used to separate the liquid phase from the solid one using a physical barrier, e.g. a filter cloth. This barrier serves for the initial stages of separation, while the depositing filter cake ensures the further capture and retention of solid particles.

2.4.1.3 Chemical treatment

Chemical treatment methods are based on chemical reactions aiming to reduce the negative environmental impacts of the waste. Chemical treatment methods can be divided into four main types of chemical treatments:

- precipitation and separation;
- neutralisation;
- stabilisation/solidification;
- coagulation and flocculation.

Chemical treatment methods include:

- desulphurisation which allows the partial or full separation of potentially ARDgenerating extractive waste before the final disposal into the EWF;
- blending the extractive waste from mineral processing with buffering materials;
- removing or destroying cyanides used in the cyanide leaching process in metal extraction before discharging extractive waste into the EWF.

Chemical treatment is generally used, for example, to:

- prevent or reduce the generation of ARD;
- prevent or reduce the release of pollutants to soil;
- prevent or reduce groundwater and surface water contamination; and
- remove hazardous substances, such as cyanides.

See also Section 4.2.2 on Physical and chemical stability of extractive waste.

Precipitation and separation

Dangerous substances may be removed by precipitation and separation (removal) of targeted substances. For example, the removal of cyanides can be achieved by means of oxidising the extractive waste from mineral processing with sulphur dioxide and air, or with hydrogen peroxide. The precipitated cyanide complexes are then removed from the extractive waste prior to deposition in EWFs using separation techniques.

Neutralisation

Neutralisation treatment is the addition of an acid or a base to the waste in order to adjust the pH towards a more neutral pH.

Neutralisation is applied when the pH of the extractive waste is outside the range of 6 to 9. Neutralisation can be applied on solid, liquid or slurry extractive waste.

Stabilisation/solidification

This process aims at reducing the mobility of the contaminants.

Stabilisation/solidification of solid extractive waste is usually performed with cement or other binding materials to produce a dry solid monolithic or granular material.

When placing back extractive waste into excavation voids, this may include the use of binders such as the cemented method or paste method (see Section 4.2.2.1.2).

The immobilisation of contaminants is then controlled by a leaching test.

Coagulation and flocculation
This process, which is also used as a water treatment technique, serves to facilitate the dewatering of water-based oil and gas drilling muds for example.

Different chemical reagents are used to lower the repulsive forces between particles in a dispersion (coagulation) and to subsequently cluster the small particles together into bigger flocs (flocculation). These bigger flocs improve the solid/liquid separation kinetics.

Chemical reagents are then used to help remove the solid particles from the water (see also Section 4.3.2.2.2.3).

2.4.1.4 Thermal treatment (usually applied in oil and gas exploration and production)

Thermal treatment methods aim at treating the organic phase contained in the waste stream. Thermal treatment methods can be divided into three main types:
- incineration;
- desorption;
- blending.

Incineration
Incineration is a combustion process in which the organic wastes are oxidised and transformed into gases and solid residues. An example of incineration is flaring. Techniques to prevent and control emissions to air when flaring gas can be found in the specific BAT Reference Document for the Refining of Mineral Oil and Gas (Barthe *et al.* 2015).

Desorption
Desorption consists of the volatilisation of organic matter in a non-oxidising process. Heat/energy is necessary to raise the temperature in order to desorb the organic waste from the solid mineral waste, e.g. in the case of drill cuttings.
Two types of thermal desorption systems are generally in use:
- low-temperature thermal desorption operating at 250-350 °C;
- high-temperature thermal desorption operating at temperatures up to 520 °C.

The heat is provided by burning fuels or the use of electric or electro-magnetic energy.

The gaseous phase can be condensed in order to recover the oil.

The prevention and control of emissions to air is necessary for these treatment methods.

Blending extractive waste from oil and gas exploration and production
Blending is carried out with oil recovered from thermal desorption or other oily wastes.

Blending aims at mixing the oily phases (from condensates and wastes) with produced oil streams in order to reach the required specifications for further use, for example in cement kilns.

This may be an attractive alternative to incineration without energy recovery, as the oily phase is used as an energy carrier.

2.4.1.5 Biological treatment (usually applied in oil and gas exploration and production)

Biological treatment methods are sometimes used in oil and gas exploration and production because of the high content of organic matter in the extractive waste.

Biodegradation of organic matter by microorganisms is generally applied. Land farming, land treatment and composting are the three main biological treatment methods.

Land farming
Land farming is carried out in facilities where the waste is deposited in layers on a soil. The microorganisms present in the soil degrade the hydrocarbons contained in the waste. The facility is periodically tilled to provide oxygen and to mix the soil. Water and nutrients can be added to enhance the degradation process. The degradation is usually carried out in aerobic conditions.

The land farming method is limited by the accumulation of non-biodegradable materials in the soil such as metals and polyaromatic hydrocarbons.

The produced treated residue may be used for construction of roads for example.

Land treatment
Land treatment is usually carried out in facilities which are similar to land farming ones. It encompasses landspreading and biotreatment. The main difference between land farming and land treatment is the deposition frequency. Land farming refers to periodical spreading of waste on a soil surface, whereas land treatment refers to a single deposition of extractive waste. Therefore, land treatmentthe risk of accumulation of non-biodegradable elements is lower in land treatment than in land farming.

Composting
Composting consists of mixing the extractive waste with:

- bulking agents such as woodchips, straw or rice hulls to increase porosity and provide aerobic conditions;
- manure to provide nutrients;
- fertilisers (containing in particular nitrogen and phosphorus) to enhance microbial activity.

Composting is carried out on piles.

2.4.2 Temporary deposition in tanks (usually applied in oil and gas exploration and production)

Temporary storage facilities are meant to be removed after use and the extractive waste is then sent to an external operator for further treatment and management.

For the temporary storage of extractive waste, the following facilities are generally used:

- pits and/or lagoons used for the treatment of extractive waste, including land farming and land treatment facilities;
- tanks for the storage of oil and gas drilling muds and drill cuttings.

Temporary storage facilities are usually designed with retention systems to avoid any accidental spills, and with basal structures made of synthetic liners to avoid any contamination of the soil and/or groundwater.

Tanks used on site are usually steel tanks that can be transported by trucks. Tanks are periodically monitored to prevent or detect any possible leak. The surface of the pad on which the tank and the retention basin are located is generally double- or even triple-lined with synthetic materials in order to prevent seepage and collect spills and water run-off in a sump.

2.4.3 Deposition on land into pond-type extractive waste deposition areas (including EWFs)

Permanent surface storage without dams
Permanent storage facilities are engineered surface facilities constructed for the permanent disposal of extractive waste, usually extractive waste from excavation and/or mineral processing but also extractive waste from oil and gas drilling, i.e. drilling muds and drill cuttings. These surface facilities for the management of extractive waste need to provide safe long-term containment.

The techniques used for the design, construction, maintenance, closure and after-closure of these facilities are similar to the ones described in Section 4.2. The key points to ensure safe long-term containment can be summarised as follows:

- to design the capacity of the EWF taking into consideration possible floods;
- to design and construct a basal structure in order to control and prevent seepage using single or double lining systems composed of compacted clay, synthetic liners, drainage materials and protective layers such as geotextiles;
- to design and construct a leak detection system;
- to design and construct a leachate collection and removal system;
- to design and construct run-off diversion structures in order to avoid contamination of water run-off;
- to implement a closure and aftercare plan.

Permanent surface storage with dams
Surface EWFs used for the management of extractive waste resulting from oil and gas extraction usually do not have any dam structure for the containment of extractive waste. This contrasts with EWFs used for the management of slurried extractive waste from mineral processing, which usually do have a dam structure for the containment of extractive waste. These EWFs are pond-type EWFs.

The following section on pond-type EWFs and dams is mostly gathered from the MTWR BREF (EC-JRC 2009). Other references are mentioned where appropriate.

The vast majority of the extractive waste from mineral processing is managed on land. This entails the selection of a tract of land on which the extractive waste from mineral processing is stored for an extended period while the extractive waste is being generated by the mineral processing plant and, unless reclaimed for further treatment, for an indefinite period thereafter. The deposit must be secure against physical damage from outflow and must not pollute the surrounding area, neighbouring watercourses, the groundwater, or the atmosphere.

Since the extractive waste from mineral processing is conveyed as slurry from the plant, the deposited mass requires confinement to the extent necessary to prevent the flow of the slurry out of the designated area. In most pond-type EWFs, the solids settle out of the slurry after deposition. Therefore, the pond is composed of settled solids and free water. This may be supplemented by natural run-off, inflowing groundwater or direct precipitation. Part of the free water remains in the supernatant pond and may be removed by evaporation, depending on the climatic conditions. Another part of the free water, which is decanted and drained from the pond (the excess water), may be returned to the processing plant for re-use/recycling, or stored in the pond for future use. Part of the water may be lost by underground infiltration. Finally, part of the water, for which there is no further use, may be discharged into surface water bodies (receiving bodies), often after undergoing treatment.

The basic arrangements of pond-type EWFs may be classified as:

- existing pit (with no dam walls);
- (cross) valley site (with one or two dam walls);
- hillside or off-valley site (usually with three dam walls);
- on flat land (usually with four dam walls, often referred to as a paddock, or one circular wall).

An EWF for the management of extractive waste from mineral processing can consist of single or multiple ponds.

The management of extractive waste from mineral processing implies, for each pond, several possible activities, including:

- transport of extractive waste from the mineral processing plant to the EWF;
- selection of pad and dam construction materials;
- deposition of the extractive waste from mineral processing within the pond;
- confinement of extractive waste from mineral processing;
- diversion of natural water run-off around or through the dam;
- evacuation of excess free water (free water management);
- protection of the surrounding area, including underground, from environmental impacts;
- surveillance of the dam by instrumentation and monitoring systems; and
- closure and after-closure monitoring of the EWF and surrounding area.

Some of these activities will be discussed in the following sections. In addition, aspects of seepage flow and design flood considerations will be introduced. These two aspects have an impact on several of the activities listed above.

2.4.3.1 Deposition of extractive waste from mineral processing

The pond capacity is calculated to allow handling of predictable extreme flood events during operation (design flood). This calculation is based on the Probable Maximum Flood (PMF), usually defined as the 10 000-year flood or two or three times the 200-year flood. The PMF is normally based on a series of local assumptions (e.g. snowmelt period, persistent rain during a number of days, the occurrence of an extreme precipitation event) which allow the development of a hydrograph. The hydrograph is a curve of the flow, i.e. the necessary discharge capacity, as a function of time at a certain point of the studied system. As a rule of thumb, it can be stated that the designed discharge capacity is approximately 2.5 times the highest expected flow at any point. More recently, operators have been taking into consideration the effect of climate change on weather conditions when designing the ponds.

<u>Hydraulic deposit</u>
Most extractive waste from mineral processing is pumped into the EWF with ~ 15 % to ~ 50 % solids content (typically 30-40 %). In some applications, particularly where conventional dams are employed, the discharge of extractive waste from mineral processing into the EWF can take the form of a single-pointed open-ended discharge. In other cases, a more controlled deposition method may be desirable. This may incorporate a single discharge point or multiple perimeter discharges (spigots) or the use of hydro-cyclones or liquid/liquid centrifuging. For progressively built dams, the discharge arrangements are dictated by the dam construction method selected.

The increase in density of deposited material is accelerated by the action of drainage and evaporation. Therefore, storage efficiency can be increased by deposition taking place on a beach. The control of the beach, including the slope angle, length and direction, is important for the stability of the dam in the case of upstream and centreline constructed dams.

The transport of slurried extractive waste from the mineral processing plant to the EWF is usually undertaken by pipeline. The pipeline is seldom buried.

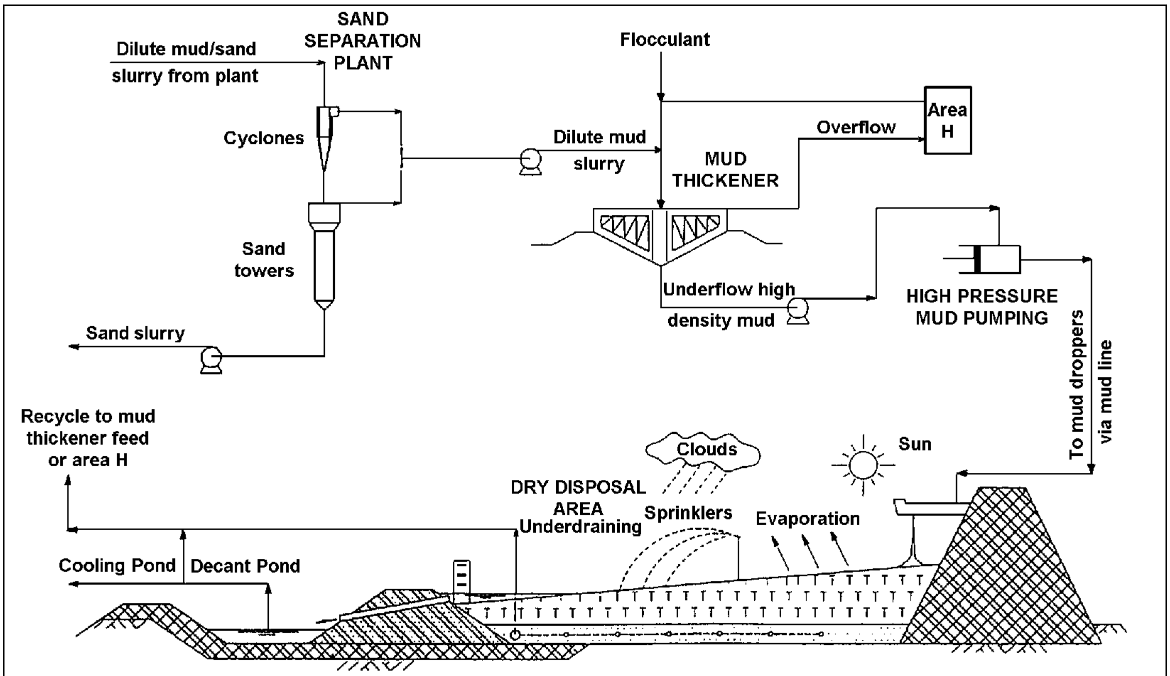
For very fine extractive waste from mineral processing, special deposition techniques may be employed, such as the addition of coarser particles or coagulants/flocculants.

In some cases, it is necessary to deposit extractive waste from mineral processing under water (e.g. extractive waste from mineral processing with ARD potential or severe dust problems) in order to reduce the acid generation potential. This is referred to as subaqueous deposition. It can be accomplished by selecting sufficiently impermeable dam and basal structures in the construction phase and by selecting wet covers in the closure phase. Such wet covers may refer to free water covers, subaqueous in-pit disposal or wetlands.

Thickened/paste deposit

Generally, thickened extractive waste from mineral processing results from a thickening process and presents a solids content of over ~ 50 %, typically from ~ 60 % to 75 %. Thickening may increase the storage efficiency in terms of the storage volume to dam height, since the angle of the deposit increases with the solids content. Equipment used to thicken extractive waste from mineral processing consists of hydro-cyclones, thickeners and lamella clarifiers. Dewatering equipment is described in Section 4.2.2.1.1.

The thickening of extractive waste from mineral processing requires the use of mechanical equipment to dewater the extractive waste to ~ 45-70 % solids. The extractive waste from mineral processing is then spread in layers over the storage area, to allow further dewatering through a combination of drainage and evaporation.



Source: (EC-JRC 2009)

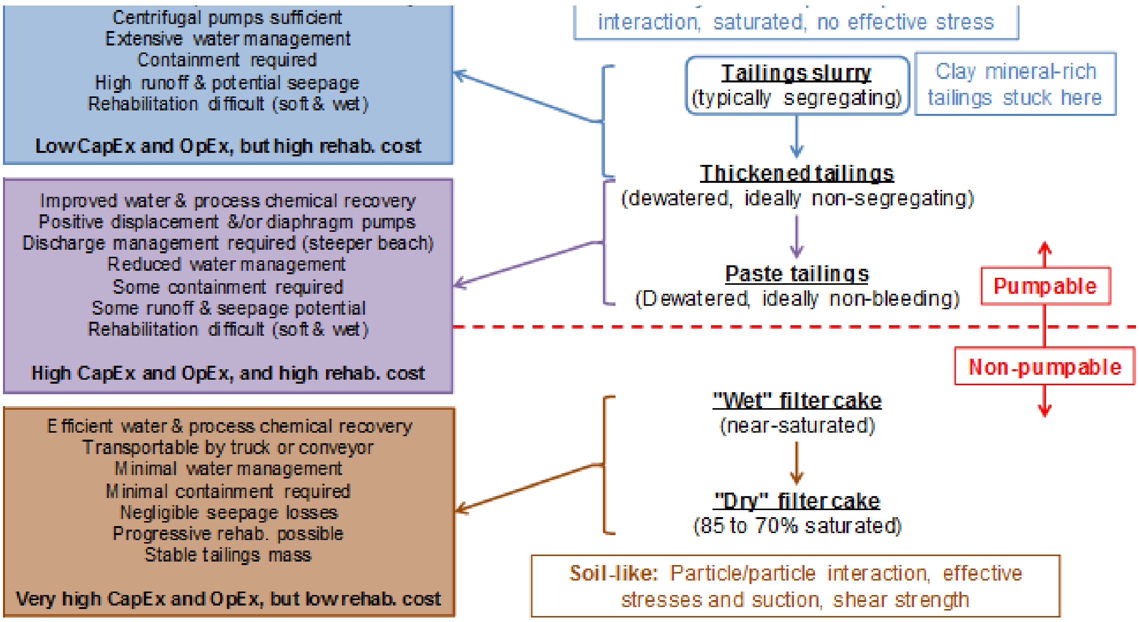
Figure 2.2: Schematic drawing of deposition of thickened extractive waste from mineral processing

Wet or dry filter cake deposit

Wet filter cake is near-saturated while dry filter cake is unsaturated (moisture content typically less than 15 %) with a usual solids content higher than 75 %. The equipment used to dewater extractive waste from mineral processing, by means of a pressure gradient or a centrifugal force, includes filter presses, vacuum filters and centrifuges. This equipment is described in Section 4.2.2.1.1.4. Retention structures (embankment/dams) are built along the perimeter to contain the deposited extractive waste.

Wet or dry filter cakes are transported by conveyors or trucks, put in place and subsequently compacted to form an unsaturated, dense and stable extractive waste deposit usually called a dry stack. It does not require the construction of retention dams.

In Figure 2.3, a scheme of the different dewatered tailings typologies is presented, including consideration of their management, CAPEX and OPEX along the whole EWF life cycle.



Source: Williams 2015, adapted from Davies and Rice 2004, with permission of Prof. Williams

Figure 2.3: The tailings continuum scheme

2.4.3.2 Dam construction

The construction material and methods used for building dams vary widely, reflecting the particular needs of the selected site, the availability of materials and the financial and operating policies of the entire operation.

Typically, dams are subdivided into three parts:
- An upstream section which is capable of retaining the extractive waste from mineral processing without excessive penetration/erosion by the extractive waste itself (e.g. compacted sand).
- A middle section, or core, which provides a passage for drainage water through the structure in a controlled manner and which will not break down or become blocked by fine material (e.g. rock or crushed filter stone).
- And a downstream section which provides toe strength and stability and which will remain dry under all circumstances (e.g. sand compacted to a high density). In some circumstances, it may be necessary to incorporate artificial membranes (geotextile filter fabric) between the main sections of the structure where there is a risk of high seepage and the movement of fine material.

The dam types may be classified as follows:
- Water and solids retention dams:
  - impermeable dams, whose structure (foundations, core, filters and initial shoulders) is completely built before the extractive waste is deposited into the pond. It includes dams constructed in one or various stages raised throughout the lifetime of the dam. Water

and solids retention dams are designed as dams with low-hydraulic-conductivity upstream layers, filters and drainage systems and a dam basal structure to prevent or reduce seepage.

- Total solids retention and partial water retention dams:
  - dam with extractive materials from mineral processing with a low-permeability core;
  - dams with extractive materials from mineral processing in the structural zone.

These types are briefly discussed below.

Note that the term beach, used in combination with the management of slurried extractive waste from mineral processing in a pond-type EWF, means the area of settled extractive waste from mineral processing not covered by free water after deposition of a slurry into the EWF and located between the edge of free water and the crest of the dam.

The purpose of a beach is to establish an area of relatively dry extractive waste from mineral processing against the upstream face of retaining dams, with two important objectives:

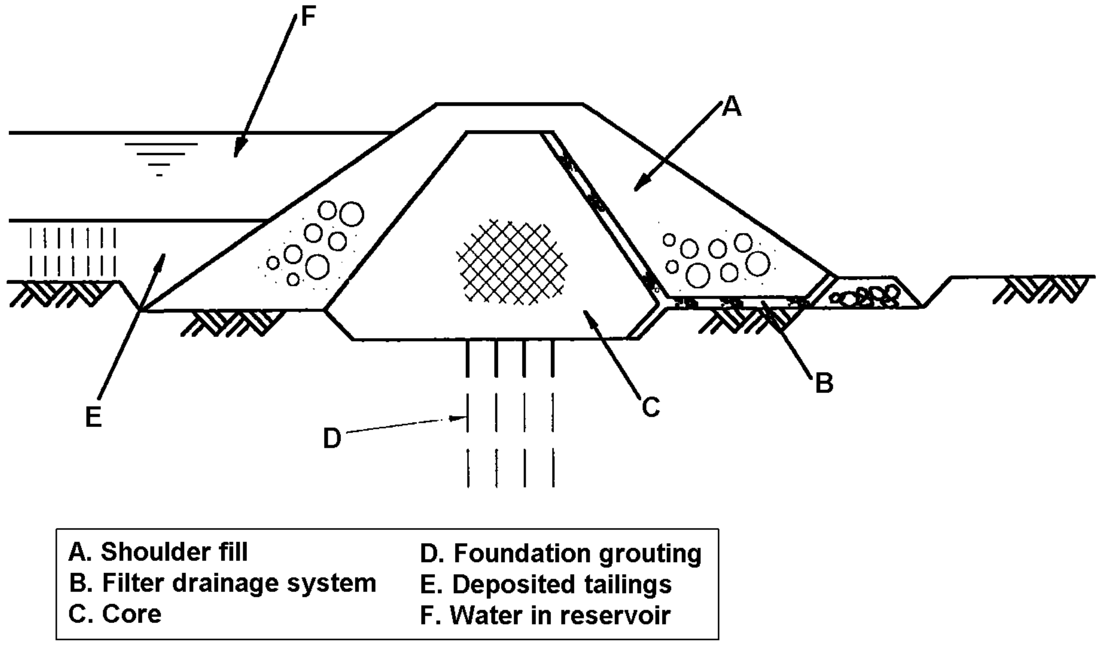
- To prevent water from reaching the crest of the dam where it could cause erosion of the inside face, or more seriously, lead to excessive leakage through the dam with the subsequent risk of "piping" and possible damage/collapse of the structure.
- To allow natural separation of the coarser and finer particles of extractive waste from mineral processing. When extractive waste from mineral processing is deposited into a pond-type EWF in a slurry form, the larger particles tend to settle out more quickly. As these dry out and consolidate, densities will generally increase over time, thereby adding to the overall stability of the structure as a whole.

Figure 2.4 shows an example of a beach at a polymetallic underground mine. The picture is taken from the dam's crest, showing the delivery system and the beach in the foreground and the reclaimed water in the background.

Source: site visit, photo by JRC review team with the permission of Matsa

Figure 2.4: Beach made of extractive waste from mineral processing

Water and solids retention dam constructed in one stage
This type of dam is completely built before deposition of extractive waste from mineral processing in the EWF. Hence, extractive materials from mineral processing cannot be used to build the dam. Conventional dams are constructed where the confinement will take place for both the extractive waste from mineral processing and free water, from the start of the operational phase (deposition start) to the end of the closure phase (deposition end).



Source: (EC-JRC 2009)

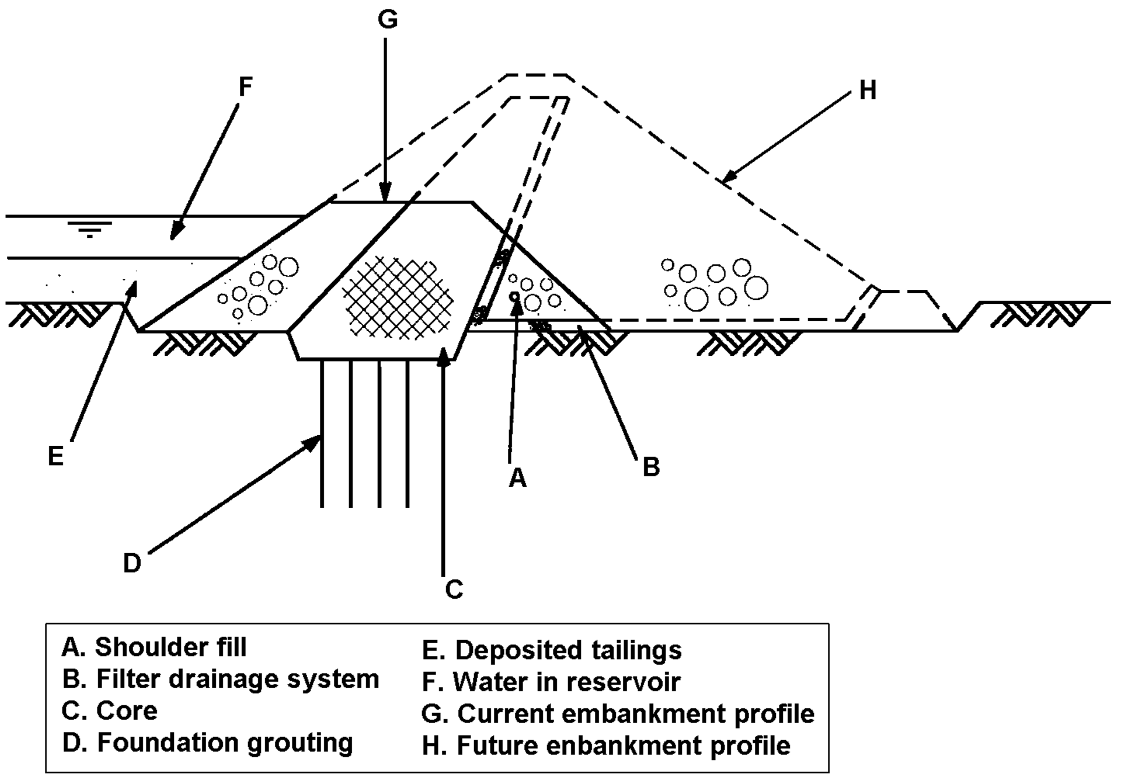
Figure 2.5: Water and solids retention dam constructed in one stage

The purpose of the shoulder fill in a water and solids retention dam is to increase the overall dam strength, but also to protect the core from erosion (wind and water) and from wave action from the free water.

The central core section of such a dam is illustrated in the figure above but the range of options is varied and similar to that for dams designed to confine water alone. In general though, the dam must be capable of:

- controlling the passage of water;
- supporting the loads imposed by the extractive waste from mineral processing and water in the pond;
- transmitting the drainage water effectively and without the passage of solids (filtration system).

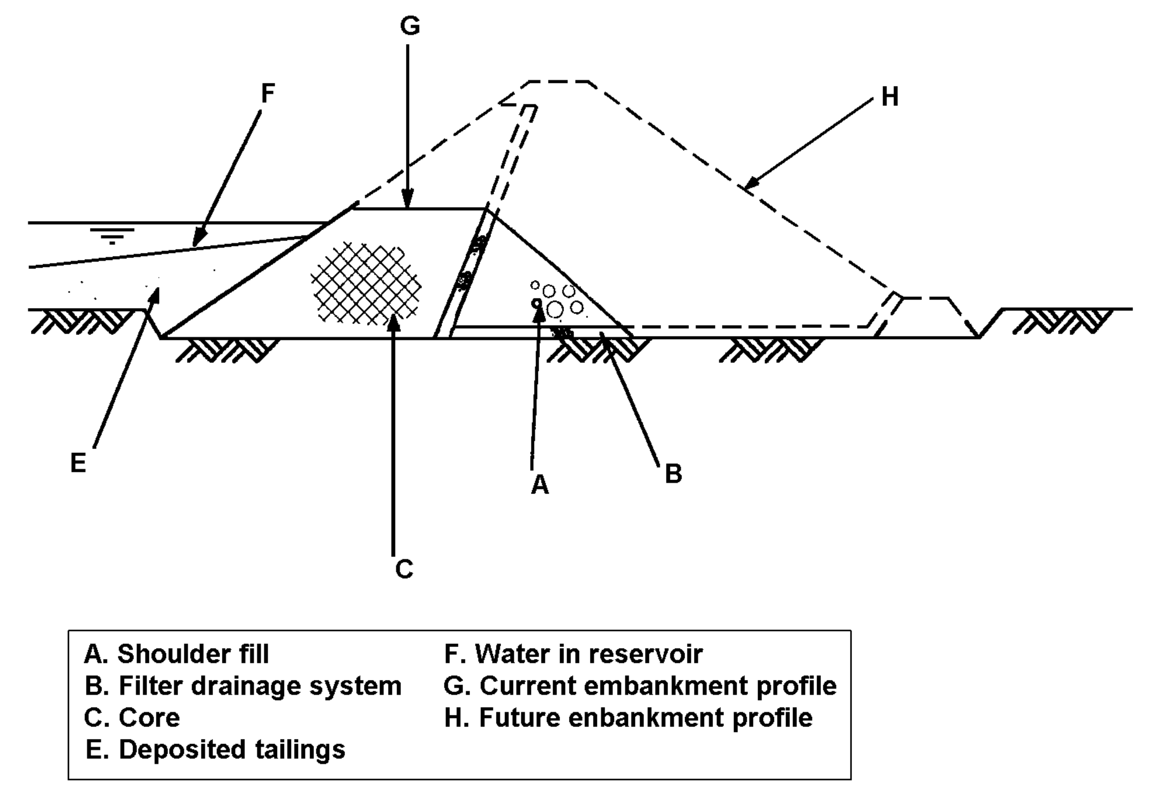
Water and solids retention dam constructed in various stages with an impermeable core
This type of dam is similar to the previous type of dam but has a lower initial capital cost due to the construction being carried out in stages so that the costs are spread more evenly over the period of deposition.



Source: (EC-JRC 2009)

Figure 2.6: Water and solids retention dam constructed in various stages with an impermeable core

<u>Water and solids retention dam with a low-permeability upstream lining structure</u>
If the deposited extractive waste from mineral processing lies close to, or above, the level of the free water in the impoundment, the low-permeability core zone of the dam may be located on its upstream face. This is possible because the core is protected against erosion and wave action by the extractive waste from mineral processing.

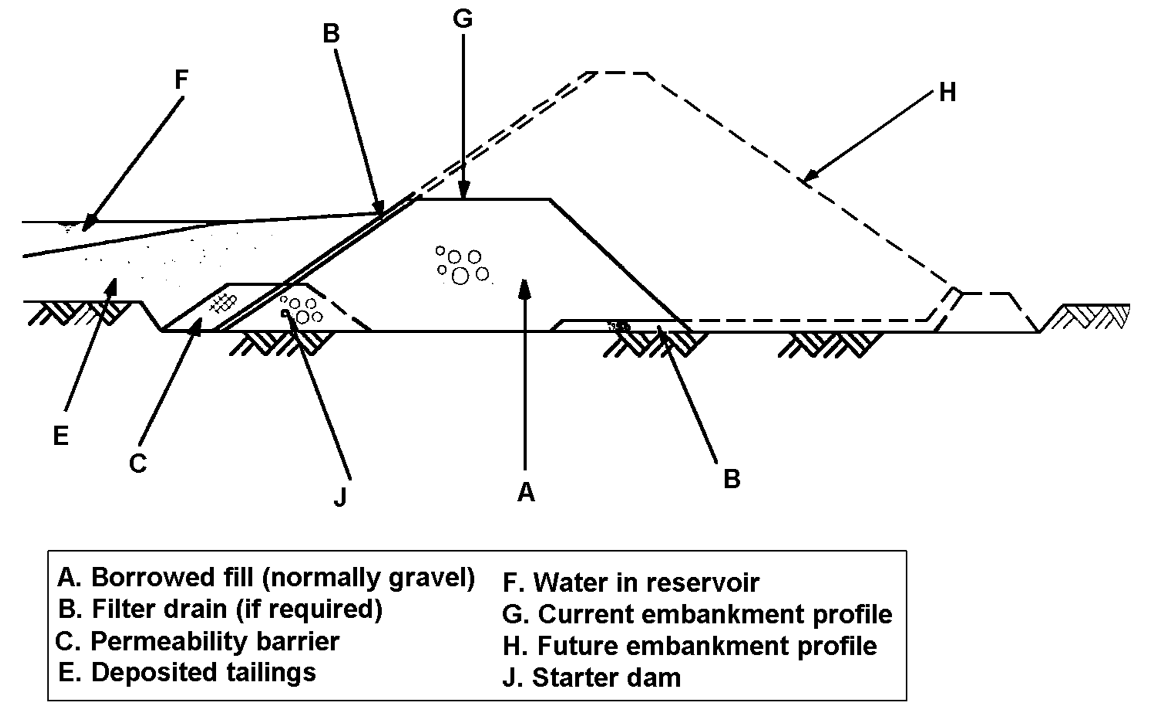


Source: (EC-JRC 2009)

Figure 2.7: Water and solids retention dam with a low-permeability upstream lining structure

<u>Total solids retention and partial water retention dam with a low-permeability core zone constructed with extractive materials from mineral processing</u>

Deposition of extractive waste from mineral processing into a pond may lead to the formation of a beach which may provide a low-permeability core zone.



Source: (EC-JRC 2009)

Figure 2.8: Total solids retention and partial water retention dam with a low-permeability core zone constructed with extractive materials from mineral processing

This arrangement is only possible where the inflow of water will not allow the pond water level to rise above the uppermost level of the beach and, therefore, come into contact with the more pervious dam material. Therefore, continuous monitoring is required in this case.

For this arrangement, it is necessary to build a water-permeable barrier (C in Figure 2.8) into the starter dam, until the beach has developed far enough away from the dam itself.

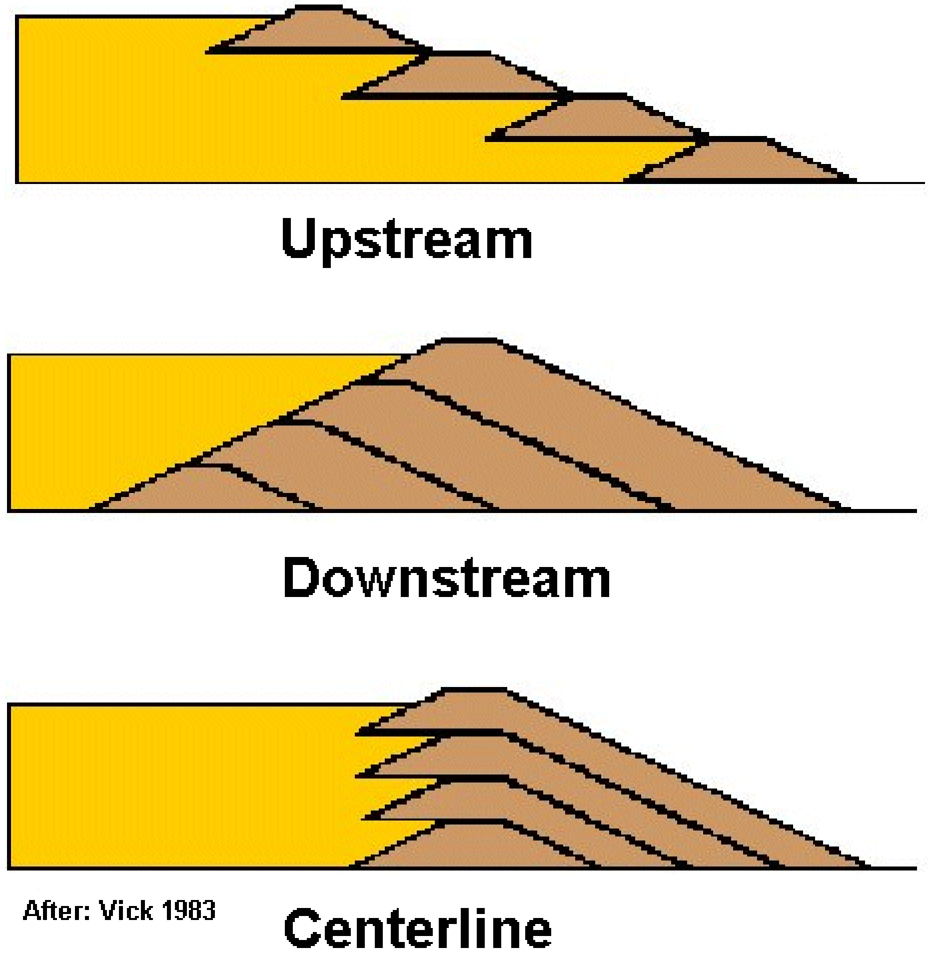
<u>Total solids retention and partial water retention dam constructed with extractive materials from mineral processing in the structural zone</u>

In this arrangement, extractive materials from mineral processing are not only used as a water barrier but also as construction material for the dam. In this case, the coarser hydro-cyclone underflow is typically reserved for the structural zone and the finer hydro-cyclone overflow is deposited into the pond, forming the beach.

There are three main approaches when considering the progressive construction (raising) of this type of dam. These are:

- upstream method;
- downstream method;
- centreline method.

These methods allow for staged construction of the dam, which minimises start-up capital costs. The following figure illustrates these methods.



Source: (EC-JRC 2009)

Figure 2.9: Types of sequentially raised dams with extractive materials from mineral processing in the structural zone

Upstream method using cycloned extractive materials from mineral processing

This method has the advantage of requiring smaller volumes of materials for the raises, which makes this method the most economical raising method of the three (upstream, centreline and downstream).

The following picture shows an example of a dam built using the upstream method. In this example, the dam itself consists of borrow materials (rock-fill).

Source: (EC-JRC 2009)

Figure 2.10: Dam raised using the upstream method at the Aughinish site

Materials used for the raises are placed partially on the previously deposited extractive waste (the beach). Therefore, before each new raise, operators control, among others, the compaction, the consolidation and the stability of the underlying layer. The mechanical, physical and chemical properties of the materials used for the construction are monitored in order to ensure the stability of the dam (e.g. materials used for the construction do not have ARD potential)

The main disadvantage of the upstream method is the risk of physical instability of the dam and its susceptibility to liquefaction. Care is taken in order to control the phreatic surface (e.g. freeboard and wide beach length). This is usually achieved by appropriate drainage. Care is also taken to control the speed at which the dam is raised in order to prevent excessive raising rates and possible instability (e.g. static liquefaction).

This method is called the upstream method because the crest moves upstream as the dam height rises.

<u>Upstream construction using a beach or paddock</u>
This traditional dam construction method uses the natural particle segregation occurring at the beach to sort by size the extractive residues from mineral processing instead of using a hydro-cyclone. This method makes maximum use of the actual extractive residues itself for confinement, and may provide the cheapest system for the management of extractive waste from mineral processing. The system relies on the formation of a satisfactory beach by controlling the deployment of the discharge arrangements and the length of time during which the extractive residues from mineral processing are being discharged from each point.

<u>Downstream method</u>
The coarse fraction of the extractive residues from mineral processing, separated by hydro-cyclones, may be used to form the complete structural portion of the dam or a large part of it. The size of the hydro-cyclones is selected such that a bank of hydro-cyclones operating in

parallel can handle the throughput of extractive residues. The bank of hydro-cyclones is located initially on the crest of the starter dam, the underflow (coarser material) is discharged downstream to form the dam, and the overflow (finer extractive waste) is deposited into the pond.

This method has the advantage of offering greater stability, in particular if the dam is subjected to dynamic loading (i.e. located in areas of seismic activity).

The main disadvantage of this method is that it requires large volumes of borrow materials and consequently construction costs are higher than for the upstream method.

This method is called the downstream method because the crest moves downstream as the dam height rises.

Centreline method

The downstream method entails the use of a considerable volume of coarse extractive materials from mineral processing. Consequently, the proportion of coarse extractive materials separated out by cycloning from the extractive residues may be insufficient to raise the dam. In that case, the use of complementary borrow material is necessary.

In addition, when raising a dam with the downstream method the land use (land footprint) expands with each successive raise. Consequently, operators may face a lack of land availability to further raise the dam.

Therefore, as an alternative to both the upstream and downstream methods, and as a compromise between the advantages and disadvantages of both methods, the centreline method has been developed.

In the centreline method, the upstream portion of the dam is formed by the beach made up of the fine fraction of extractive waste deposited from the crest, whereas the downstream portion of the dam is constructed with borrow materials and/or the coarser fraction of extractive materials separated from the residues.

This method is called the centreline method because the crest moves vertically as the dam height rises.

2.4.3.3 Water-related structures

Water-related structures is a term referring to all the facilities at, or associated with, a site used for the management of EWIW, which includes control, storage, treatment and transport, which may include:

- settling ponds/dams;
- reservoirs;
- system for removing the free water, such as decant towers or decant chute;
- spillways;
- intake structures;
- diversion of water run-off structures;
- drains and drainage layers (including seepage control);
- pipelines;
- culverts;
- pumping stations;
- treatment plants;
- dewatering systems.

A key part of extractive waste management operations is the management of EWIW.

The interaction between water and the EWF is properly analysed by means of a water balance analysis, flood design, drainage system design and free water management design. All this information is included in a water management plan. If the water issue is considered in conjunction with the extraction site with reference to the Acid Mine Drainage (AMD), an integrated water management plan is developed.

2.4.3.3.1 Free water management

The aim throughout the development of the pond is usually to keep the pool of free water (supernatant pond) as low and as small as possible as a means of risk management. The control of the supernatant pond is probably one of the most important procedures in managing extractive waste from mineral processing. Inappropriate pond control can result in overtopping, increase in pore pressures, reduction of freeboard, high seepage rates and embankment settlements. These conditions can lead to instability and a high risk of problematic situations according to the SME Mining Engineering Handbook (Kerr and Ulrich 2011).

However, this risk needs to be balanced against several other objectives, e.g. the amount of time needed by the extractive waste from mineral processing to settle within the pond. In some cases, the water also has to remain in the pond for a certain period of time in order to allow decomposition of the process chemicals. Water saturation of the extractive waste from mineral processing may also be required to avoid dusting.

A clarification pond may provide a good balance between the need to keep the water level in the pond-type EWF low and the contradicting requirements to leave a certain amount of water in the pond. This allows the settling of the fine slimes and decomposition of the process chemicals, whilst the water level in the actual pond containing the settled extractive waste can be kept to a minimum.

The main requirement for successful removal of the water is the provision of an outlet arrangement, the effective level of which can be adjusted throughout the progressively increasing pond level, or of a pump, which can perform a similar function. The removed water is either returned to the mineral processing plant and/or, usually after treatment, discharged into natural watercourses.

The outlet structure for the removal of free water, or decanting system as it is normally termed, is usually composed of two elements:

- an extendible intake; and
- a conduit to convey the discharge away from the dam.

The intake may take the form of a vertical tower, or a sloping chute founded usually in natural ground on a flank of the pond and occasionally on the upstream face of the dam.

The basic alternatives are:

- vertical decant tower;
- decant well;
- decant chute or inclined decant; and
- floating decant system or barge system.

Other options are:

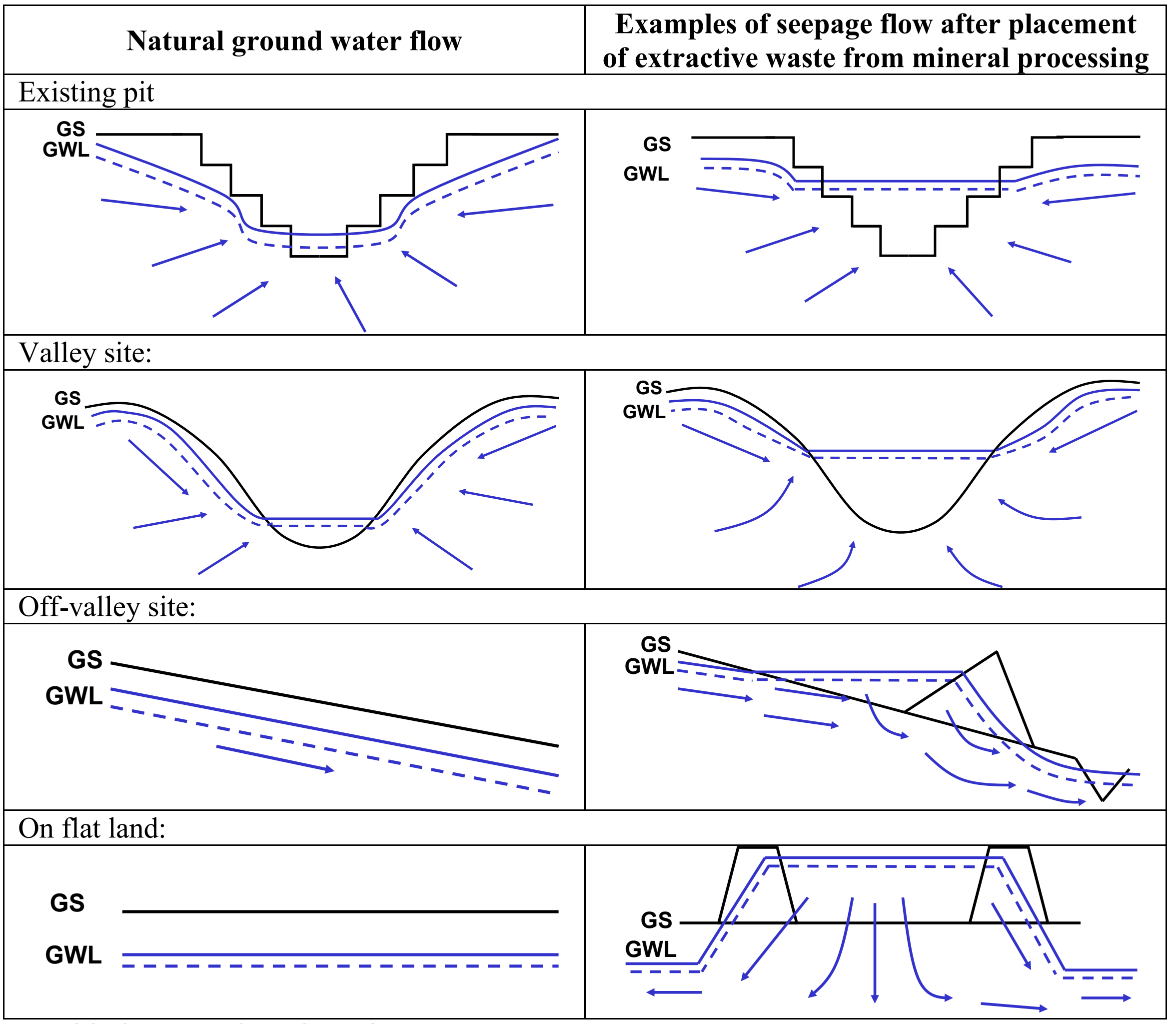
- drained pond; or
- overflow systems:
    - within the dam, or
    - around the dam.

In addition to the regular means of removing the free water, emergency discharge systems are sometimes installed. The idea is that in the event that the regular system fails, the emergency overflow will prevent the dam from collapsing entirely. These outlets are typically overflow systems within or around the dam.

2.4.3.3.2 Groundwater flow management

An EWF will influence the original groundwater flow pattern by introducing a hydraulic gradient (difference in hydraulic head between two points divided by the travel distance between the points). The following figures show schematic examples of seepage flow patterns for original groundwater flow conditions and for the following basic dam types:

- existing pit;
- valley site;
- off-valley site;
- on flat land.



NB: GS=Ground surface; GWL=Groundwater level.
Source: (EC-JRC 2009)

Figure 2.11: Examples of simplified seepage flow scenarios for different types of EWF

It should be noted that these are simplified schematic two-dimensional drawings. In reality, the actual flow pattern will be influenced by factors such as:

- dam properties;
- water level in the dam;
- permeability of the underlying formations;

- ground layering;
- original groundwater flow regime.

Knowledge of the natural hydrogeology of the site (groundwater flows and distribution prior to the construction of the EWF) and evaluation of the influence of the EWF are used in the design of the EWF, the water-related structures, and the water management plan.

2.4.4 Deposition on land onto heap-type extractive waste deposition areas (including EWFs)

Large amounts of extractive waste from excavation generated at open-pit extraction sites are managed on heaps (heap-type EWFs). Certain coarse, paste, wet or dry extractive waste from mineral processing, such as for example the ones resulting from potash, iron and/or coal mineral processing, are also managed on heaps.

Delivery of extractive waste is carried out by a conveyor belt or trucks. The heaps are monitored to ensure the stability of the structure. Water run-off is collected and treated, if necessary, prior to discharge. It may also be diverted into a pond-type EWF or separate water retention basins. The physical stability of heaps has to be analysed in the short and long term. The coarseness of the extractive waste, the actual action of the truck dumping, the spreading and compacting in thin layers using a tracked machine and sometimes a vibrating roller, all help to stabilise the material during and after deposition. Apart from the heap stability itself, the stability of the supporting strata is also considered in the design and operation of heaps.

Dust emissions from heaps can be significant. When discharging from conveyor belts, the operation may have to be interrupted in windy conditions. If the extractive waste is transported by truck, the transport paths may have to be sprayed in dry periods. Progressive rehabilitation, if possible, helps to prevent erosion and dusting.

In the closure phase, extractive waste heaps are usually reshaped to the angle of natural repose, depending on the extractive waste characteristics, and resulting in a geomorphic shape that either in itself or after the placing of a cover, provides long-term stability and adequate protection against wind and water erosion. A slope angle of 3:1 (H:V) is for example considered stable in the long term as such slopes naturally occur in the landscape, according to the MTWR BREF (EC-JRC 2009).

2.4.5 Placing extractive waste back into excavation voids

Extractive waste from excavation and extractive waste from mineral processing can be permanently placed back into excavation voids. According to Article 3(15) of Directive 2006/21/EC, excavation voids into which extractive waste is placed back for rehabilitation and construction purposes are not EWFs (see Section 4.2.2.1.2.).

2.4.6 Deposition in submarine or sublacustrine extractive waste deposition areas (including EWFs)

Deposition in a submarine or sublacustrine extractive waste deposition area is defined as the placement of extractive waste (usually from mineral processing) under water, in a marine or fresh water environment. One of the objectives of deposition under water is to avoid exposing extractive waste from mineral processing to air, causing oxidation of sulphide minerals, and preventing dust problems. Therefore, where extractive waste from mineral processing is likely to cause ARD, deep sea or sea disposal of extractive waste from mineral processing is sometimes used. However, the reason for applying this technique may also be a lack of space for depositing extractive waste from mineral processing on land. Investment costs and operation costs are also lower for sea disposal of extractive waste from mineral processing compared to the costs for a land deposit.

Sublacustrine disposal refers to a technique where extractive waste from mineral processing is disposed of in a deep lake However, the application of this technique has seen a steady global decline due to the environmental impacts on surface waters.

Sea disposal of extractive waste, which includes submarine tailings disposal and Deep Sea Tailings Disposal (DSTD), refers to deposition of extractive waste from mineral processing in the sea at depths varying between 50 m and more than 1000 m.

Extractive waste is transported by pipelines from the processing plant to the sea.

The difference between submarine tailings disposal and DSTD is in general in the depth at which the extractive waste is deposited. It is usually accepted that:

- submarine tailings disposal refers to *disposal of extractive waste from mineral processing through an underwater pipeline at relatively shallow (< 100 m) but submerged water depths in the euphotic zone*;
- DSTD refers to *disposal of extractive waste from mineral processing in relatively deep waters through a submerged pipe below the euphotic zone (point of discharge > 100 m), at the edge of a drop-off; the extractive waste from mineral processing creates a gravity flow that deposits the material on the deep seafloor (usually below 1000 m depth)*.

(Ramirez-Llodra *et al.* 2015)

In the EU, sea disposal of extractive waste has ceased in a number of countries whereas in other countries this method was not reported to be used.

At the time of writing, less than 1 % of the extractive waste from mineral processing is deposited in the sea worldwide (IMO 2013) and several initiatives have been taken to phase out or limit the disposal of extractive waste in the sea.

In Europe, sea disposal is currently actively applied in two countries: Norway (~ 10 sites) and Turkey (1 site).

The effectiveness of sea disposal of extractive waste is mainly based on three mechanisms:

1) reduced oxidation, in particular of sulphides: due to two reasons: (a) the saturated oxygen concentration in water is 25 000 times lower than in air, meaning that very little oxygen is available for oxidation reactions; and (b) the oxygen diffusion coefficient is 10 000 times lower in water than in air, resulting in the slow supply of oxygen;
2) sulphate reduction: at low oxygen concentration levels in the water, sulphate-reducing bacteria consume sulphate and thereby produce hydrogen sulphide, which easily reacts with most dissolved metals and forms a stable precipitate;
3) sediment barriers: after production has stopped, a sediment layer will naturally develop on top of the deposited extractive waste which is reported to be very effective in minimising the interaction between the tailings and the overlaying water.

Slurried extractive waste is transported by pipelines. In order to minimise extractive waste dispersion effects, slurried extractive waste may be:

- thickened in order to remove process water;
- de-aerated to remove air bubbles, which otherwise will lift small particles to the sea surface at the discharge point;
- coagulated by adding chemical flocculants and seawater (Shimmield *et al.* 2010).

Pipes are usually extended as required (in general two or three times a year). However, the main pipe and the buoyancy pipe are assembled on land and then sunk and connected to the existing ones.

The discharge point is located where the slurried extractive waste from the pipeline will form a turbidity plume flowing with minimum dispersion until it reaches the seabed (Shimmield *et al.* 2010). To this aim, pipelines are usually located on slopes greater than 12°. Moreover, steep cones beside the discharge pipe are avoided and slopes with an angle below 10° are targeted (Ramirez-Llodra *et al.* 2015).

The monitoring programme to control the environmental impact within and around the extractive waste deposition area usually covers the following parameters:

- water analyses on solids content (turbidity), salinity, oxygen content and temperature;
- sediment analyses of the content of carbon (or calcium carbonate), grain size (fine particle content), metals, and flotation reagents;
- biological activity of shallow waters with visual documentation (e.g. bottom fauna and flora biodiversity);
- bioaccumulation to analyse potential bioavailability and toxicity to marine organisms (e.g. aquatic and benthic life).

Other measurements (such as sea currents, hydrography, revegetation, etc.) may be taken in order to be able to develop suitable models to predict the dispersion and sedimentation of extractive waste.

Sea disposal of extractive waste may provide certain benefits compared to other land-based deposition methods, e.g.:

- increased physical stability on the seabed: no risk of a dam burst;
- increased chemical stability: extractive waste is less likely to oxidise in the submarine environment, thus reducing the breakdown of minerals releasing toxic metals; in addition, the alkalinity of seawater is understood to decrease the mobilisation of metals (reduced ARD) (Franks *et al.* 2011; Ramirez-Llodra *et al.* 2015);
- reduced dust and odour emissions;
- reduced visual impact;
- reduced investment and operational costs.

In return, sea disposal of extractive waste may have certain disadvantages such as:

- negative environmental impact on the ecosystem: obliteration of the benthic fauna; alteration of the bottom habitat; biological diversity not maintained; impacts on fish stocks;
- negative impact on seawater quality: slow release of flocculants and leaching of metals and metalloids in the sea; turbidity created by underwater slides or other mechanisms;
- larger footprint: the seabed surface affected by sea disposal is larger than for land-based deposition;
- reduced circular economy potential: reduced possibilities for the re-mining of mineral resources from the extractive waste disposed in the sea.

The negative effects on the benthic fauna occur through hyper-sedimentation. The injection of large amounts of fine-grained waste material may create a barren area close to the discharge and is likely to cause the disappearance of species, and changes in the community composition and structure, as well as changes in population abundances. In the longer term, the community composition and structure will reflect the degree of disturbance, with sensitive species disappearing and more tolerant species dominating the new ecosystem (Ramirez-Llodra *et al.* 2015).

Toxic effects of reagents and flotation chemicals, particularly on sessile fauna, are considered in cases where process chemicals are used. Chemicals might also be present in the sediments closest to the discharge points for several years after cessation (Ramirez-Llodra *et al.* 2015).

To minimise possible environmental impacts, the site location and therefore the configuration of the seabed is of utmost importance. Specific site prerequisites include:

- confined area: extractive waste should be effectively contained within a designated area and prevented from migrating (Franks *et al.* 2011): for example, in Norway submarine tailings disposal and DSTD are carried out in fjords;
- depth: extractive waste is deposited below the euphotic zone, pycnocline, and thermocline;
- sediment type: the site selection implies that the natural sediments of the seabed are not coarser than the deposited extractive waste.

The proper selection of the site requires in-depth and specialised studies in order to gather knowledge on:

- the environmental baseline assessment (marine biodiversity, seawater quality);
- the natural conditions of the selected site (bottom topography, stratification of the water, current velocities, sediment properties and natural sedimentation rate);
- the deposition mechanism.

A major issue in the evaluation of the environmental impact from sea disposal of extractive waste appears to be the lack of baseline studies (information on the habitat, environmental conditions, and associated microbial and faunal components that are affected by the discharges) and basic research to understand the functioning of the marine ecosystems and the influence of extractive waste. Although monitoring of sea disposal of extractive waste has been performed for more than 40 years in some areas, there is a lack of published scientific knowledge of the biodiversity patterns and functioning of the marine ecosystems, particularly in the deep sea, including the effects of metals and chemicals on deep-sea biota (Ramirez-Llodra *et al.* 2015).

In addition, the containment of the extractive waste implies, among others, knowledge of the deposition mechanism: the extent and timescale of the extractive waste plume dispersal from the discharge point, which are both dependent upon several factors such as particle size, horizontal dispersion and settling velocity. The deposition rate and containment of extractive waste may also be affected by climate change (e.g. change in currents).

In Norway, comprehensive baseline studies are nowadays compulsory to obtain a permit for discharge of extractive waste into the sea. This is important for several reasons, including to interpret monitoring data related to the impact of extractive waste management operations, which requires an understanding of the natural variability of the data due to seasonal changes. As an example, the turbidity of the water in fjords varies considerably due to changes in river run-off and sediment transfer. An Environmental and Social Impact Assessment is then carried out prior to site selection. In that case, sea disposal and alternative land-based facilities are compared and sea disposal of extractive waste is selected only if it is found to be the best alternative compared to land-based options (in terms of the overall environmental and social risks and impacts).

A five-year research program (NYKOS) has been initiated in Norway to obtain new knowledge about the environmental risks related to the disposal of extractive waste from mineral processing in coastal basins.

According to the Initiative for Responsible Mining Assurance (IRMA 2016), the necessary science to determine the impacts on existing resources is not in place, nor is there any defined programme to collect this information. This, together with the fact that the economic advantage of utilising a natural body of water for extractive waste disposal, over construction of an engineered impoundment for this waste, is so large that it currently distorts the evaluation of the social and environmental factors involved in a waste disposal location decision.These are the main reason for IRMA to only certify land-based disposal at present.

2.4.7 Containment of extractive waste in underground extractive waste deposition areas

Underground extractive waste deposition areas accessed via a wellbore for the accumulation and deposition of extractive waste usually refer to underground structures into which fluids have been injected to stimulate the formation and/or to drill the oil and gas well, but from which not all fluids and fluid components (e.g. chemicals, solid particles) have been recovered after use.

The underground web of fractures and voids might contain the unrecovered fluids, which qualify as extractive waste, and is thus considered an underground extractive waste deposition area.

The main objective for site operators is to ensure that no fluids can leak from the EWF and contaminate nearby aquifers.

To achieve this objective, the design, construction, operation, maintenance and closure of the well are of the utmost importance.

The wells are designed with five to seven casings in general, in order to ensure good isolation of the aquifer from the production tubing.

A quality control and quality assurance process is implemented to ensure that the cement and the cementing works comply with the technical requirements and that no cracks or voids that could lead to a leakage of fluids from the formation are present. Cameras and logs can be used for these purposes. During the production stage, regular monitoring of the well and, when necessary, maintenance are carried out.

Usually, adequate geological studies in the design phase, seismic monitoring during operation and monitoring and control of the wellhead and reservoir pressure are carried out by operators to prevent and control induced seismicity.

Finally, after production, the well is closed by plugging the well below the aquifer level in order to avoid any leak from the underground reservoir to the aquifer or the surface. This operation is called "abandonment" in the oil and gas sector; however, this terminology has not been used in this document to avoid any legal confusion.

As the well represents the pathway from the underground formation to the surface, operators usually plug the well by cementing it below the impermeable strata, which confines the extractive waste in the underground structure.

Regular monitoring is implemented to control any possible leaks from the underground structure after the well closure.

2.5 Management of extractive waste influenced water

Two main streams of EWIW are managed by operators:

- unrecovered water (seepage): prevention or reduction of seepage from non-inert extractive waste deposition areas;
- recovered water (drained water and free water to be re-used, recycled or discharged): this may represent important volumes in some cases.

The most efficient way to prevent seepage into the ground is proper site selection, i.e. an area where a natural impermeable hydraulic barrier is available or where the geohydrological conditions are favourable to avoid seepage.

If this natural barrier is not available, a basal structure is included both for heaps and ponds in order to prevent or reduce seepage to groundwater and the risk of soil and groundwater contamination from non-inert extractive waste. The requirements of the basal structure of the EWF depend on the geochemical characteristics of the extractive waste, the groundwater characteristics below the deposition area, bedrock and soil characteristics (including bedrock fracture zones and quaternary sediment characteristics in glaciated areas) and national legal requirements.

Basal structures can vary from a simple permeable soil barrier, which consists of a permeable soil layer that allows seepage directly into the ground and can be used only for inert extractive waste, to more complex impermeable layered structures. These include:

- impermeable natural soil selectively placed and compacted on site;
- a multilayered system of natural soil and geosynthetics with a very low hydraulic conductivity;
- a reactive basal structure with the addition of alkaline materials and a very low hydraulic conductivity;

Typically, these structures are complex and include drainage and seepage control layers overlying the basal structure.

EWIW may be re-used or recycled (after treatment) for the mineral processing or other extraction activities.

The EWIW stemming from the EWFs, which cannot or will not be further used, is usually discharged by operators, often after treatment, in rivers or seawater bodies in most cases, and/or in lakes in some cases.

The most common environmental impacts of emissions to water are acidification of rivers, emissions of suspended particles and emissions of dissolved substances such as salts and metals.

The management of EWIW, in order to prevent and control emissions, but also as a valuable source of water to be recycled and re-used, is of the utmost importance in any mineral resources extraction project as water plays a key role in most extraction processes.

The water at an extractive site can be divided into two main types of water streams:

- the water which was not in contact with the extractive waste at any stage of the process, e.g. water run-off;
- the EWIW which was in contact with the extractive waste at some stage of the process, e.g. water from the mineral processing, reclaimed water from the EWF, drainage water.

Operators usually try to avoid the contact of water run-off with the mineral resources or extractive waste as the water run-off is seen as a source of fresh water.

Different techniques such as diversion channels and waste covers are used to avoid contact and prevent water contamination.

The EWIW is usually collected and treated. After treatment, water can be re-used, e.g. in the mineral processing. Only the excess water which is not needed, or which can affect the stability of the EWFs, is discharged as a surplus.

For the purpose of this document, the main water-based streams in the extractive industries can be summarised as follows:

- In oil and gas exploration and production:
    - The water that is used in the drilling process to prepare water-based drilling muds.
    - The flowback water that corresponds to the water which flows out at the surface during the next few days after the hydraulic well stimulation. It is mainly the water-based stream containing the technical fluids used for the hydraulic fracturing of the formation, which might also contain heavy metals and NORMs from the underground structure.
    - The produced water that corresponds to the water which flows out at the surface during the production stage of the well. It is mainly the geological water which might contain residuals of technical fluids such as fracturing fluids.
- In the excavation and treatment of mineral resources:
    - The mine water that is the geological water resulting from the dewatering of the extraction site (surface or underground mine).
    - The process water that is the water used during the mineral processing stages such as grinding or froth flotation.
    - The reclaimed water that is the decanted water collected from a tailings pond, a polishing pond or a clarification pond.
    - The drainage water that is the water that infiltrates extractive waste and percolates through or out of the solid extractive waste or the mine and is collected by means of drainage systems.
    - The seepage that corresponds to the water that infiltrates extractive waste and percolates through or out of the solid extractive waste but is not collected.

Although these water streams can at some point be mixed together, e.g. prior to treatment, recycling or discharge, at many sites, operators try to keep the different water streams separate, as this facilitates the water treatment and reduces the required size of the treatment plants.

The treatment of water prior to discharge aims to prevent and control any negative environmental impacts.

In some cases, e.g. for smaller EWIW volumes, the treatment of water may be carried out in specialised water treatment facilities (off site). Off-site treatment is common for the management of EWIW resulting from the extraction of oil and gas. However, for larger volumes of EWIW, the treatment is carried out on site. On-site treatment is common for the management of EWIW resulting from the extraction of mineral resources other than hydrocarbons (oil and gas).

The techniques implemented to prevent and control emissions to water will depend from site to site.

In general, the different techniques used for the management of EWIW can be divided into two categories:

- active techniques, i.e. requiring energy input;
- passive techniques, i.e. not requiring energy input.

Active techniques will also require more maintenance than passive techniques.

Moreover, the different treatment techniques can be grouped into three broad categories, according to the intended purpose:

- the separation of phases;
- the removal of dissolved substances;
- the neutralisation of EWIW.

For each of these categories, operators reported the implementation of several techniques.

In order to reduce the level of suspended solids or liquid particles in the EWIW, operators reported implementing one or a combination of the following techniques:

- gravity separation: based on the principle of natural gravity sedimentation;
- clarification in tanks: based on the gravity settling principle enhanced by a mechanical system to remove solids being deposited by sedimentation;
- coagulation and flocculation: based on the use of chemicals to enhance the sedimentation;
- air flotation: based on the capturing of solid particles in a froth;
- media filtration: based on the size exclusion of particles and/or capture of particles;
- membrane filtration: based on size exclusion (pore size).

In order to reduce the level of dissolved substances in the EWIW, operators reported implementing one or a combination of the following techniques based on the following:

- The oxidation and/or aeration principle:
    - Aeration of the water stream and/or addition of oxidants in order to promote the oxidation and precipitation of dissolved substances, mainly dissolved metals.
    - Active aerobic biological oxidation or implementation of passive aerobic wetlands where the biological activity of microorganisms promotes the oxidation and precipitation of dissolved substances.
- The reduction principle:
    - Anaerobic wetlands or anoxic BioChemical Reactors (BCRs) can be used to promote the reduction and precipitation of dissolved substances.
- The neutralisation/precipitation principle:
    - Hydroxide and carbonate precipitation is implemented to precipitate dissolved metals into a hydroxide or carbonate complex. This is performed by adding alkaline reagents to the EWIW, which leads to a pH rise and the precipitation of dissolved metals.
    - Sulphide precipitation is implemented to precipitate dissolved metals into a sulphide complex by adding sulphide reagents to the EWIW, which leads to the precipitation of dissolved metals.
- The adsorption principle:
    - Adsorption of dissolved substances on inorganic or organic media, based on the surface properties of the media and the liquid-solid interactions, can be used to remove the dissolved substances, e.g. active carbon adsorption or ion exchange.
- The size exclusion principle:
    - Nanofiltration and reverse osmosis.

Finally, in order to adjust the pH of EWIW, operators reported implementing one or a combination of the following techniques:

- active neutralisation based on the addition of basic or alkaline reagents;
- passive treatment based on the passive dissolution of alkaline reagents:
    - Oxic Limestone Drains (OLDs), Open Limestone Channels (OLCs);
    - Anoxic Limestone Drains (ALDs);
    - Successive Alkalinity-Producing Systems (SAPS).

2.6 Summary of reported processes in the management of extractive waste

Through questionnaires developed and distributed for the purpose of the BREF review, several operators responsible for the management of extractive waste provided information on processes used in the management of extractive waste.

Table 2.2 contains a summary of the information, listed by site, relating to the extraction activities, the mineral processing, the type of waste facilities used for the management of extractive waste, the extractive waste treatment implemented, the physical characteristics of the extractive waste and the implemented or planned closure for the EWF.

Table 2.2: Summary of the data and information on the management of extractive waste reported by operators that participated in the questionnaire exercise

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
33	Energy fuels	Coal and lignite	Surface	Washing	0									
53	Energy fuels	Coal and lignite	Underground	Gravity separation + Flotation	30	Heaps + Ponds	109	Centreline						
54	Energy fuels	Coal and lignite	Underground	Gravity separation + Flotation	30	Heaps + Ponds	63			Tailings	5			Landscaping and progressive rehabilitation with a dry cover and a vegetative cover
59	Energy fuels	Coal and lignite	Underground	Gravity separation + Flotation	30	Heaps + Ponds	109			Tailings	5			Landscaping and progressive rehabilitation with a dry cover and a vegetative cover
81	Energy fuels	Coal and lignite	Underground		1	Heaps	6			Tailings	18			Landscaping and capping with a vegetative cover
32	Energy fuels	Coal and lignite	Unknown		1	Heaps	180							
1	Energy fuels	Oil and gas	O&G drilling		1	Surface								
2	Energy fuels	Oil and gas	O&G drilling		0									
3	Energy fuels	Oil and gas	O&G drilling		0		0.1							Decommissioning of the pits, removal of the temporarily stored extractive waste
4	Energy fuels	Oil and gas	O&G drilling		1	Surface	0.3		Vibrating screen	Drill muds	84			Removal of the tanks, backfilling of the cuttings, area covered with gravel
5	Energy fuels	Oil and gas	O&G drilling		6	Surface + Underground	10		Neutralisation + Sedimentation + Solidification + Desorption					Capping with organic cover
6	Energy fuels	Oil and gas	O&G drilling		1	Surface	27							
7	Energy fuels	Oil and gas	O&G drilling		1	Surface	0.1							Area covered with gravel
9	Energy fuels	Oil and gas	O&G drilling		4	Surface + Underground	0.1							
22	Energy fuels	Oil and gas	O&G drilling		0		1							
24	Energy fuels	Oil and gas	O&G drilling		1	Surface	1		Shale shakers + Centrifuge	Drill muds	100			

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
34	Energy fuels	Oil and gas	Unknown		0									
30	Energy fuels	Oil shale	Surface		0									
28	Energy fuels	Oil shale	Underground	Gravity separation + Washing + Heavy media separation with magnetite	2	Heaps + Ponds	273			Waste-rock	6			Capping with a vegetative cover
29	Energy fuels	Oil shale	Underground	Gravity separation + Washing	1	Heaps								
50	Energy fuels	Peat	Surface		1	Heaps	10							Removal of the silt waste from the pond and backfilling with peat
11	Energy fuels	Uranium	Underground	Tank leaching	1	Ponds	68	Combination		Tailings	37		70	Capping with a vegetative cover
79	Energy fuels	Uranium	Underground		7	Heaps	10			Waste-rock		70-95	1	Landscaping and capping with a vegetative cover
80	Energy fuels	Uranium	Unknown	Tank leaching + Ion exchange process	1	Ponds	60	Upstream		Tailings	22		93	Sealing and capping with a dry cover and a vegetative cover

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
73	Industrial and construction minerals and rocks	Construction rocks and aggregates	Surface	Dewatering + Magnetic separation + Washing + Flotation + Optical sorting	3	Heaps + Ponds	100	Centreline		Tailings	8	0.028-0.200		Landscaping and capping with a dry cover and a vegetative cover
31	Industrial and construction minerals and rocks	Construction rocks and aggregates	Surface	Dewatering	1	Heaps	30			Tailings	5		4	Backfilling of a part of the waste
56	Industrial and construction minerals and rocks	Construction rocks and aggregates	Surface	Washing	1	Ponds	0.3							
57	Industrial and construction minerals and rocks	Construction rocks and aggregates	Surface	Washing	1	Ponds	4							Capping with a dry cover and a vegetative cover
58	Industrial and construction minerals and rocks	Construction rocks and aggregates	Surface	Physical classification + Washing	1	Ponds	2							Capping with a dry cover and a vegetative cover
82	Industrial and construction minerals and rocks	Construction rocks and aggregates	Surface		1	Heaps	0.1							Capping with a vegetative cover
75	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Flotation	10	Heaps + Ponds	1 302	Downstream		Tailings	55			Landscaping and capping of heaps with a dry cover and a vegetative cover
35	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Physical classification + Gravity separation + Magnetic separation + Washing	3	Heaps + Ponds	10	Upstream	Thickening	Tailings Waste-rock	65 1	0.005-0.145 1-60	2	Landscaping and capping with a dry cover and a vegetative cover

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
41	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Physical classification + Dewatering + Magnetic separation + Washing + Flotation	1	Subaqueous	300			Tailings	92	0.002-0.2	75	
45	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface		1	Heaps	1							
16	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Washing + Flotation	1	Heaps	32							Progressive capping with a dry cover and a vegetative cover
18	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Washing	4	Heaps	32							Landscaping and capping with a dry cover and a vegetative cover
19	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Washing	2	Heaps	33							Landscaping and capping with a dry cover and a vegetative cover
20	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Physical classification	0		8							
44	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Physical classification + Magnetic separation	2	Heaps + Subaqueous			Sea water addition	Tailings	75		45	
86	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Physical classification + Gravity separation + Magnetic separation + Electrostatic separation + Washing + Flotation + Dewatering	3	Heaps + Ponds	80	Combination	Neutralisation + Precipitation	Tailings		0.2-1.5		Sealing and capping with a dry cover and a vegetative cover

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
55	Industrial and construction minerals and rocks	Industrial and construction minerals	Surface	Physical classification + Gravity separation + Magnetic separation + Washing + Attrition scrubbing + Dewatering	1	Ponds	11							Capping with a dry cover and a vegetative cover
63	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Physical classification + Gravity separation + Washing + Flotation + Dewatering + Drying + Compaction	1	Heaps	46		Filtration (filter press and belt)	Tailings	6			Removal of waste including discharge into the sea
64	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Physical classification + Gravity separation + Washing + Flotation + Dewatering + Drying + Compaction	1	Heaps	30		Filtration (filter press and belt)	Tailings	7			Removal of waste including discharge into the sea
65	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Electrostatic separation + Flotation	1	Heaps	125			Tailings	6			
66	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Electrostatic separation + Flotation + Hot Leaching process	1	Heaps	57			Tailings	5			Progressive rehabilitation
67	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Electrostatic separation + Flotation + Hot Leaching process	1	Heaps	114			Waste-rock	5			

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	**Extractive sector**	**Extractive subsector**	**Extraction**	**Mineral treatment**	**Waste facilities**	**Type**	**Land use (ha)**	**Dam raising method**	**Waste treatment type**	**Waste**	**Water mass fraction (%)**	**Particle size range (D_{10} - D_{90} - mm)**	**Fines content (%)**	**Closure plan**
68	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Flotation + Hot Leaching process	1	Heaps	175			Tailings	7	0.11-2.13	4	
78	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Flotation + Dewatering + Tank leaching	1	Subaqueous								
84	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Physical classification + Gravity separation + Magnetic separation + Washing + Flotation + Dewatering	2	Heaps	4		Cycloning + Filter press					Progressive rehabilitation and capping with a dry cover and a vegetative cover
39	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Physical classification + Magnetic separation + Washing	5	Heaps + Ponds	16							
40	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Magnetic separation + Washing + Optical sorting	1	Ponds	5			Waste-rock	5	15-470	1	Capping with a vegetative cover
17	Industrial and construction minerals and rocks	Industrial and construction minerals	Underground	Physical classification + Manual selection	0		1							

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	**Extractive sector**	**Extractive subsector**	**Extraction**	**Mineral treatment**	**Waste facilities**	**Type**	**Land use (ha)**	**Dam raising method**	**Waste treatment type**	**Waste**	**Water mass fraction (%)**	**Particle size range (D_{10} - D_{90} - mm)**	**Fines content (%)**	**Closure plan**
10	Metal ores	Base metals	Surface	Physical classification + Heap leaching + Thickening + desliming	2	Heaps + Ponds	30	Combination	Cycloning					Landscaping and capping with a dry cover and a vegetative cover
47	Metal ores	Base metals	Surface	Washing + Tank leaching + Dewatering	2	Heaps								Sealing and capping with a dry cover and a vegetative cover
71	Metal ores	Base metals	Surface	Flotation + Dewatering	3	Heaps + Ponds	479	Downstream		Tailings	23		100	Landscaping, sealing and capping of ponds with a dry cover. Landscaping and capping with a dry and vegetative cover.
83	Metal ores	Base metals	Surface	Physical classification + Flotation + Dewatering	2	Heaps + Ponds	2 300							Capping with a dry cover
15	Metal ores	Base metals	Underground	Flotation + Dewatering	1	Ponds	92	Combination						Capping with a dry cover
21	Metal ores	Base metals	Underground	Gravity separation + Flotation + Dewatering	1	Ponds	100							
25	Metal ores	Base metals	Underground	Physical classification + Flotation + Tank leaching + Dewatering	2	Heaps + Ponds	100		Thickening + Solidification					Landscaping, sealing and capping with a dry cover
46	Metal ores	Base metals	Underground	Flotation + Dewatering	2	Heaps + Ponds	199	Downstream	Thickening + Flocculants	Tailings Waste-rock	30 6	0.015-0.050 0.8-40	90 1	Capping with a dry cover. Removal of the heaps.
48	Metal ores	Base metals	Underground	Physical classification + Flotation + Tank leaching + Dewatering	1	Ponds	87			Tailings	21	0.004-0.125	69	Capping with a dry cover

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
51	Metal ores	Base metals	Underground	Dewatering + Flotation + Tank leaching	1	Ponds	37	Downstream						Capping with a dry cover, a vegetative cover and a wetlands for the collection and treatment of water
52	Metal ores	Base metals	Underground	Flotation + Dewatering	1	Ponds	181	Combination	Cycloning + Sedimentation	Tailings	20	0.015-0.050	95	Capping with a dry cover and a vegetative cover
62	Metal ores	Base metals	Underground	Physical classification + Flotation + Dewatering	1	Ponds	1 638	Upstream		Tailings		0.036-0.155	71	Capping with a vegetative cover
72	Metal ores	Base metals	Underground	Flotation + Dewatering	1	Ponds	150	Upstream	Neutralisation	Tailings	10	< 0.037	100	Capping with a dry cover and vegetative cover
26	Metal ores	Base metals	Underground		0									
27	Metal ores	Base metals	Underground		0									
14	Metal ores	Iron and steel alloying elements	Surface	Physical classification + Magnetic separation + Flotation + Dewatering	2	Heaps + Ponds	450	Combination	Thickening + Flocculants					Landscaping and capping with a dry cover and a vegetative cover
23	Metal ores	Iron and steel alloying elements	Surface	Physical classification + Gravity separation + Magnetic separation + Flotation + Dewatering	3	Heaps	73		Vibrating screen + Filter press					Backfilling of a part of the waste. Capping with a dry cover and a vegetative cover.
42	Metal ores	Iron and steel alloying elements	Surface	Physical classification + Gravity separation + Magnetic separation + Dewatering	2	Heaps + Subaqueous	1 200		Thickening + Coagulants + Flocculants	Tailings	77	< 0.2	60	

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
60	Metal ores	Iron and steel alloying elements	Surface	Physical classification + Gravity separation + Magnetic separation + Dewatering	7	Heaps + Ponds	400	Combination	Thickening + Flocculants	Tailings Waste-rock	78	0.035-1.05 20-800	30 1	Capping with a dry cover and a vegetative cover
12	Metal ores	Iron and steel alloying elements	Underground	Physical classification + Magnetic separation + Flotation + Dewatering	2	Heaps + Ponds	930	Combination						Landscaping and capping with a dry cover and a vegetative cover
13	Metal ores	Iron and steel alloying elements	Underground	Physical classification + Gravity separation + Magnetic separation + Flotation + Dewatering	2	Heaps + Ponds	356	Combination						Capping with a dry cover and a vegetative cover
61	Metal ores	Iron and steel alloying elements	Underground	Physical classification + Gravity separation + Magnetic separation + Flotation + Dewatering	1	Ponds	39	Upstream	Neutralisation + Flocculants	Tailings	10	< 0.26	63	Capping with a vegetative cover
74	Metal ores	Iron and steel alloying elements	Underground	Physical classification + Gravity separation	2	Heaps + Ponds	460	Combination		Tailings		< 0.3	55	Backfilling of a part of the waste. Landscaping and capping with a dry cover and a vegetative cover.
43	Metal ores	Light metals	Surface	Physical classification + Gravity separation + Magnetic separation + Washing + Flotation + Dewatering	3	Heaps + Ponds + Subaqueous	460			Tailings	40	0.001-0.211	40	Capping with a dry cover, a partial water cover and a vegetative cover

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	**Extractive sector**	**Extractive subsector**	**Extraction**	**Mineral treatment**	**Waste facilities**	**Type**	**Land use (ha)**	**Dam raising method**	**Waste treatment type**	**Waste**	**Water mass fractio n (%)**	**Particle size range (D_{10} - D_{90} - mm)**	**Fines content (%)**	**Closure plan**
49	Metal ores	Light metals	Surface	Physical classification + Gravity separation + Washing + Tank leaching + Dewatering + Bayer process: Grinding + Digestion + Settling + Precipitation + Calcination	1	Ponds	183	Combinatio n	Washing + Filtration (vacuum filter) + Mud farming (Compaction + Neutralisation)	Tailings	32	0.001-0.05	92	Capping with a vegetative cover
76	Metal ores	Light metals	Underground		0	NI/ND	11							
77	Metal ores	Light metals	Underground		0	NI/ND	65							
85	Metal ores	Light metals	Unknown	Bayer process: Grinding + Digestion + Settling + Precipitation + Calcination	2	Ponds + Subaqu eous	25		Filtration (filter press)	Tailings	28		80	Capping with a vegetative cover for the land-based EWF. No closure plan for the STD EWF.
36	Metal ores	Precious metals	Surface	Physical classification + Tank leaching	2	Heaps + Ponds	46							Backfilling of a part of the waste. Sealing and capping with a dry cover and a vegetative.
37	Metal ores	Precious metals	Surface	Physical classification + Tank leaching	3	Heaps + Ponds	38		Cyanide destruction					Backfilling of a part of the waste. Capping with a dry cover and a vegetative cover.
38	Metal ores	Precious metals	Surface	Physical classification + Tank leaching + Dewatering	2	Heaps + Ponds	25		Cyanide destruction					Backfilling of a part of the waste. Landscaping and capping with a dry cover and a vegetative cover.

Site and extraction activities				Mineral treatment	Waste facilities				Waste treatment	Waste physical characteristics				EWF closure
Site ID #	Extractive sector	Extractive subsector	Extraction	Mineral treatment	Waste facilities	Type	Land use (ha)	Dam raising method	Waste treatment type	Waste	Water mass fraction (%)	Particle size range (D_{10} - D_{90} - mm)	Fines content (%)	Closure plan
70	Metal ores	Precious metals	Surface	Physical classification + Gravity separation + Flotation + Dewatering	3	Heaps + Ponds	39	Upstream		Tailings	25		40	Backfilling of a part of the waste. Capping with a dry cover and a vegetative cover.
87	Metal ores	Precious metals	Surface	Heap leaching	1	Heaps	152							Progressive rehabilitation and capping with a dry cover and a vegetative cover
88	Metal ores	Precious metals	Underground	Gravity separation + Flotation + Dewatering	2	Heaps	16		Thickening + Flocculants + Filtration (filter press)	Tailings	15	0.015-0.090	70	Capping with a dry cover and a vegetative cover
69	Metal ores	Precious metals	Underground	Flotation + Tank leaching + Autoclave oxidation + Counter current decantation wash + Neutralisation	6	Heaps + Ponds	204	Downstream	Neutralisation + Cyanide destruction + Wetland	Tailings	80 %	0.002-0.180		Sealing, capping and landscaping of ponds with a dry cover. Landscaping and sealing and capping of reactive heaps with a reactive cover, a dry cover and a vegetative cover.

3 EMISSION AND CONSUMPTION LEVELS

3.1 Introductory remarks

3.1.1 Data collection

In this chapter, emission and consumption levels resulting from the management of extractive waste collected from different operating sites in Europe are presented.

The data and information were collected using a questionnaire drafted for this purpose by a dedicated questionnaire subgroup of the Technical Working Group. Operators reported data and information on waste management and waste facilities, along with emission and consumption levels associated with the management of extractive waste. In total, 87 questionnaires that contained data within the scope of this document were collected and analysed. Sites from 21 different European countries participated in this exercise.

The number of questionnaires collected in the different sectors is presented in Table 3.1.

Among the sectors, the metalliferous ores extractive waste management sector provided the highest number of questionnaires, with 35 questionnaires, while the industrial and construction minerals sector provided 28 site-specific questionnaires and the energy sector 24.

Most of the data provided by operators and presented in this chapter refer to the reference years 2013-2014 (95 % of the questionnaires). When possible, the data and information provided have been checked against data from literature.

Table 3.1: Number of questionnaires received for the management of extractive waste by country and by extracted commodity

Country	Industrial and construction minerals	Bauxite, alumina, magnesite, ilmenite	Base metals (Cu, Ni, Pb, Sn, Zn)	Precious metals (Ag, Au, Pt)[1]	Iron ore and other metalliferous ores (Co, Cr, Mn, Mo, V, W)[2]	Coal, lignite, peat[3]	Hydrocarbons	Oil shale	Uranium ore	TOTAL
AT					2					**2**
BE										**0**
BG										**0**
CY			1							**1**
CZ									1	**1**
DE	5					3				**8**
DK										**0**
EE	1							3		**4**
EL	2	2								**4**
ES	3		4		1		2			**10**
FI	2		2	2	1					**7**
FR	1	1								**2**
HR							1			**1**
HU							2			**2**
IE		1	3			1				**5**
IT	5						3			**8**
LT										**0**
LU										**0**
LV										**0**
MT										**0**
NL										**0**
NO	2	1			1					**4**
PL			1			2	1			**4**
PT			1							**1**
RO	1					1			2	**4**
SE			3		3					**6**
SI										**0**
SK	1									**1**
TR				5						**5**
UK	5						2			**7**
TOTAL	**28**	**5**	**15**	**7**	**8**	**7**	**11**	**3**	**3**	**87**

[1] The collected questionnaires refer to the management of extractive waste from gold and silver extraction.
[2] The collected questionnaires refer to the management of extractive waste from iron, chromium and tungsten ores extraction.
[3] The collected questionnaires refer to the management of extractive waste from coal and peat extraction.

An overview of the specific data included in this chapter and provided in the questionnaires by operators is presented in Table 3.2.

The table shows the number of questionnaires filled in with site-specific data in the dedicated tables on waste composition, waste leaching test results, emissions to air, emissions to water, emissions to soil, consumption of energy, consumption of water and consumption of reagents.

Table 3.2 points out that more data were provided on consumption levels than on the different emission levels, e.g. 68 sites out of 87 provided data on consumption levels of water but only 15 sites provided data on emissions to air. Less than half of the sites (39 out of 87) provided specific data on waste composition and a quarter (22 out of 87) on extractive waste leaching properties.

Table 3.2: Summary of the site-specific data on waste characteristics, emission levels and consumption levels provided in the collected questionnaires

Data collected on:	Industrial and construction minerals	Bauxite, alumina, magnesite, ilmenite	Base metals (Cu, Ni, Pb, Sn, Zn)	Precious metals (Ag, Au, Pt)[1]	Iron ore and other metalliferous ores (Co, Cr, Mn, Mo, V, W)[2]	Coal, lignite and peat[3]	Onshore extracted hydrocarbons	Oil shale	Uranium ore	TOTAL
Waste composition	12	3	10	5	5	1	3	0	0	**39**
Leaching properties	4	3	6	4	4	0	1	0	0	**22**
Emissions to air	1	0	8	3	2	1	0	0	0	**15**
Emissions to water	8	2	10	3	5	3	0	1	2	**34**
Emissions to soil	8	2	10	0	6	1	0	0	2	**29**
Energy consumption	17	2	8	7	4	4	3	2	3	**50**
Water consumption	23	3	12	7	8	6	6	2	1	**68**
Reagents and auxiliary materials consumption	3	1	7	4	6	0	1	0	1	**23**
TOTAL	**28**	**5**	**15**	**7**	**8**	**7**	**11**	**3**	**3**	**87**

[1] The collected questionnaires refer to the management of extractive waste from gold and silver extraction.
[2] The collected questionnaires refer to the management of extractive waste from iron, chromium and tungsten ores extraction.
[3] The collected questionnaires refer to the management of extractive waste from coal and peat extraction.
NB: Data on emissions to soil were counted if data on seepage were provided.

3.1.2 Data presentation

As previously stated, the data presented in this chapter correspond to the site-specific data reported by operators on emission and consumption levels in the questionnaire tables designed for that purpose.

Additionally, data from literature were collected to compare, when possible, with the site-specific data provided by operators.

The data collected are presented in graphs in an anonymised form. Each questionnaire is identified by a number.

Along with the graphs presenting the reported emission and consumption levels, additional contextual information which may help explain the consumption and emission levels is also presented.

The levels presented in this chapter represent examples of emission and consumption levels achieved in the management of extractive waste.

In some cases, such as for emissions to air, the data provided may encompass emissions resulting from the management of extractive waste and emissions from the extraction operation itself, which is not within the scope of this document.

3.1.2.1 Emissions to soil and groundwater

Emissions to soil and groundwater resulting from the management of extractive waste are usually diffuse emissions such as seepage from extractive waste.

Therefore, the average seepage rate (volume of seepage per year and per surface unit) was calculated based on the reported total yearly volume of seepage, and the total surface area used for the deposition of extractive waste.

The average seepage rate is presented in Section 3.2.

No additional information is presented as no information on seepage quality was collected.

3.1.2.2 Emissions to surface water

The site-specific data on emissions to water are presented in Section 3.3.

The data on emission levels provided by operators are summarised in graphs showing for each indicator/pollutant the following:

- the indicator/pollutant levels:
    - in the EWIW entering the EWF prior to any water treatment:
        - maximum, average, median and minimum levels reported;
    - in the added water, i.e. possible water added to the EWIW prior to discharge before or after water treatment:
        - maximum, average, median and minimum levels reported;
    - in discharged EWIW:
        - maximum, average, median and minimum levels reported;
- the total annual volume of discharged EWIW reported by operators: this encompasses both continuous and batch direct discharges;
- the water treatments implemented prior to discharge of EWIW based on information provided by operators;
- the indicator/pollutant levels in the extractive waste managed on site and its leaching rate:

    - minimum and maximum range reported by operators;
- the type of extractive wastes managed on site as reported by operators: excavation, mineral processing, washing, cutting/sawing, or drilling wastes (oil and gas); when part of the extractive waste is classified as containing hazardous substances, this has also been indicated;
- the reported extractive waste properties: inert, hazardous, reactive, potentially acid-generating (PAG), acid-generating, leaching or self-ignition properties;
- the type of extractive waste treatment implemented on site as reported by operators: dewatering, compaction, cyanides detoxification, blending with alkali materials, addition of coagulants/flocculants, or no treatment.

3.1.2.3 Emissions to air

The site-specific data provided on emissions to air are presented in Section 3.4.

No stack emissions resulting from the management of extractive waste were identified; only diffuse emissions are reported.

Two main types of emissions to air can occur:
- dusting: emissions of particles from the extractive waste management site;
- gaseous emissions: emissions of methane or VOCs for example from the extractive waste management site.

Dust generation during the management of extractive waste may originate from different sources:
- mechanical attrition, e.g. due to contact between two hard materials like rock or repeated attrition by trucks driving on a solid surface;
- dispersion of fine materials, e.g. dispersion of powdered or granulated auxiliary materials used for treating extractive waste;
- climatic influences such as evaporation and wind transport, e.g. slurried extractive waste from mineral processing drying out and being carried away by the wind;
- combustion processes, e.g. particles from exhaust gases of machinery being used in extractive waste management.

Nonetheless, it is often difficult to make the distinction between the dust originating from the extractive waste management and the dust originating from the extraction, e.g. blasting, loading and transport of the run-of-mine materials. Huertas and co-authors calculated the contribution of extractive waste facilities to the total dusting for open-pit coal extraction in Colombia (Huertas *et al.* 2012). The study suggests that coal extractive waste heaps contribute on average to 18 % of TSP emissions and 60 % of PM_{10} emissions. Of course, these values are specific to one sector and one country. Nevertheless, the study provides a good overview of the complexity of monitoring emissions of dust resulting solely from the management of extractive waste. It helps to explain why the dust levels presented in this report are generally meant to be indicative of the total diffuse particle emissions measured at sites where extractive waste management and mineral resources extraction are carried out simultaneously, without providing any distinction on the origins of the dust.

As is the case for dust, it is often difficult to make a distinction between emissions of VOCs or gases originating from the management of extractive waste and those originating from the extraction process, unless they can be linked to a specific extractive waste stream (e.g. flaring of gases captured from a single liquid extractive waste stream).

3.1.2.4 Consumption levels

3.1.2.4.1 Consumption of energy

In the management of extractive waste, energy is consumed mainly for the transport of waste using pumps, conveyors or trucks for example. Energy can also be consumed for the treatment of extractive waste or the treatment of EWIW stemming from the extractive waste facilities. Finally, energy can be consumed for preventive measures implemented during the management of extractive waste such as the consumption of energy for the prevention of dust emissions.

The site-specific data provided by operators in the questionnaire on the consumption of energy for the management of extractive waste and for the prevention of negative environmental impacts resulting from extractive waste management were used to calculate the total energy consumption. The specific energy consumption was then calculated using the total energy consumption and the total amount of extractive waste generated, where both parameters were available.

Finally, the calculated specific consumption of energy is presented in Section 3.5.1.

As operators had the possibility to provide their energy consumption in different units, and in order to be able to compare different data, the following conversion factors were used to convert the different energy consumption figures into a single value expressed in kWh:

- 1 litre of fuel was considered as 1 litre of diesel when no additional information was provided;
- 1 litre of diesel consumption was assumed to be equivalent to 10 kWh of energy consumption (ETB 2016a);
- 1 litre of gasoline consumption was assumed to be equivalent to 9 kWh of energy consumption (ETB 2016a);
- 1 Nm^3 of gas was considered as 1 Nm^3 of natural gas when no additional information was provided;
- 1 Nm^3 of natural gas consumption was assumed to be equivalent to 10 kWh of energy consumption (ETB 2016b).

3.1.2.4.2 Consumption of water

<u>Water use versus water consumption</u>

The site-specific data provided by operators on the water balance, the consumption of water for the management of extractive waste and the consumption of water for the prevention of dust formation were used to calculate the specific water consumption and the specific water use in the management of extractive waste.

A distinction has been made between use and consumption of water, as the use of water does not necessarily imply consumption and part of the water used in a process can be re-used or recycled.

Water is often used to transport the extractive waste, such as extractive waste from mineral processing being sent to a pond in a slurry form. However, it should be stressed that not all of the water used in the management of extractive waste is actually consumed. The water cycle at extraction sites can be characterised by large flows of water being used, recycled and re-used again in the different steps of the extraction and treatment process and of the extractive waste management. Thus, a given drop of water may pass through the process and extractive waste management cycle several times before being consumed and replenished by a new drop of intake water or precipitation water.

Water that is reclaimed from the extractive waste management step and re-used in the extraction process should not necessarily be considered as water consumption from extractive waste management, even if it was added in this process step. This is, for instance, the case for water added in the extractive waste management step to facilitate pumping of extractive waste or to prevent dust formation.

Therefore, water should only be considered as consumed in the management of extractive waste when it is lost in that step or is not used for any further process purposes following passage through the extractive waste management step.

Water may also be used in large quantities for the prevention of extractive waste generation. A typical example of such use represents the placing back of extractive residues into excavation voids for rehabilitation and construction purposes, as residues are mixed with water. Thanks to this operation, the generation of extractive waste, e.g. from excavation and mineral processing, can be largely or fully prevented. However, the residues deposited in the excavation voids may contain considerable amounts of water, which were not present in the original rock material in which the excavations took place. The water used in the placement of the residues is usually drained off during the curing process and may be re-used or recycled within the system.

The data provided by operators on water used for the management of extractive waste and the prevention of extractive waste generation are presented in the Section 3.5.2.

Water sources

Different water sources exist in sites managing extractive waste. Some examples of water sources are as follows:

Precipitation

Precipitation may occur in a number of forms, such as rain, snow and hail. Precipitation water may be useful in the process as it can minimise fresh water use or prevent dusting of dry material, such as extractive waste from mineral processing. However, it can also cause leaching and emissions related to water run-off and lead to severe safety issues, e.g. during periods of heavy rain or upon melting of snow accumulated over the winter.

Groundwater

The Water Framework Directive (2000/60/EC) defines groundwater as all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (EC 2000).

Groundwater may be pumped up directly on the extraction site, either for use in the process, to avoid interference with the excavation operations or to prevent it from being contaminated. The latter two purposes often go hand in hand, for instance in the (rare) cases when groundwater close to the mining pit is being pumped and reinjected further away in the aquifers to avoid flooding of the pit and to avoid contamination of the groundwater by the activities in the pit.

Surface water

The Water Framework Directive (2000/60/EC) defines surface water as inland waters, except groundwater; transitional waters and coastal waters, except in respect of chemical status for which it shall also include territorial waters.

Typical sources of surface water are rivers and lakes.

Mine water

Mine water is encountered when operating the excavation site and is generally removed in order to facilitate the excavation operation as part of the dewatering of the mine in operation. It may be a combination of groundwater and precipitation.

Potable water from public supply

Potable water from public supply, or tap water, is mainly intended for human use in offices and buildings (showers, toilets, canteens, etc.), although it may be used for other purposes as well.

Seawater

In some cases, seawater may be employed in the plant because of the proximity to the sea. Seawater is characterised by a high salinity (~ 3.5 % dissolved salts).

The site-specific data provided by operators on the relative make-up of new intakes and the data provided on the rate of reclaimed water in the feed water were used to calculate and present to the readers an overview of the different sources of water used for the management of extractive waste.

3.1.2.4.3 Consumption of reagents

During the excavation and especially for the treatment of mineral resources, a number of reagents and raw materials are consumed. In addition, reagents and/or raw materials are also used for the management of extractive waste, mainly for the treatment of extractive waste and for the prevention of emissions to air. Examples are coagulants and flocculants, neutralisation/precipitation agents, pH adjusters and other possible reagents used during the treatment of extractive waste and excess water from the extractive waste facilities sent for discharge, or reagents used for the prevention of dusting such as bitumen.

Only the reagents used for the management of extractive waste, including prevention of emissions, are considered for the consumption levels and presented in Section 3.5.3.

3.1.2.5 Noise and odour disturbance

The data provided by operators on noise levels at extractive waste management sites and the information provided on odour emissions are presented in Section 3.6.

As for emissions to air, the reported noise and odour emissions may originate from both the extractive waste management activities and the mineral resources extraction activities.

Therefore, the levels presented in the following Section 3.6 are reported levels, measured at sites where extractive waste management and mineral resources extraction are carried out, without any distinction of the origin.

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3.2 Emissions to soil and groundwater

As stated in the introductory remarks, emissions to soil and groundwater are generally diffuse emissions.

Data on volumes of water infiltrating into the soil beneath the EWF or the foundation were collected and are presented in this section.

No data on seepage water quality were collected.

Obviously, prevention and reduction of seepage is relevant when the seepage water quality presents a risk of polluting the soil or deteriorating the groundwater status.

Some average seepage rates are reported in Figure 3.1, based on the water balance provided by operators for different sites.

Seepage rates depend greatly on different parameters such as the basal structure, the water head on the basal structure and the extractive waste's hydraulic conductivity.

The type of waste and the basal structures implemented at each site are indicated below the seepage rates. The reported basal structures vary from site to site, depending on the waste properties and targeted performance levels. The reported hydraulic conductivity of the basal structures varies from permeable, i.e. $\geq 10^{-7}$ m/s, to very low hydraulic conductivity or "impermeable", i.e. $\leq 10^{-9}$ m/s.

Average seepage rates reported by operators ranged from less than 300 litres per hectare of EWF per day to more than 50 m^3/ha/day as reported by the operator of water pond 61.

Operators responsible for the management of heaps containing extractive wastes with a low water content and with an impermeable basal structure reported low seepage rates.

As an example, an impermeable basal structure made of geomembranes such as HDPE (High-Density PolyEthylene) liners can have a leakage rate of a few tens of litres per day and per hectare. McLeod calculated a leakage rate of 50 litres/ha/day assuming five holes per hectare in the geomembrane, a hydraulic conductivity of extractive waste of 10^{-7} m/s and a 100-metre water head above the geomembrane (McLeod 2016).

KEY OBSERVATIONS BASED ON THE DATA:
Not only does the seepage rate depend on the waste characteristics, the water head and the basal structure but construction quality control and quality assurance systems are of primordial importance to ensure an efficient basal structure.

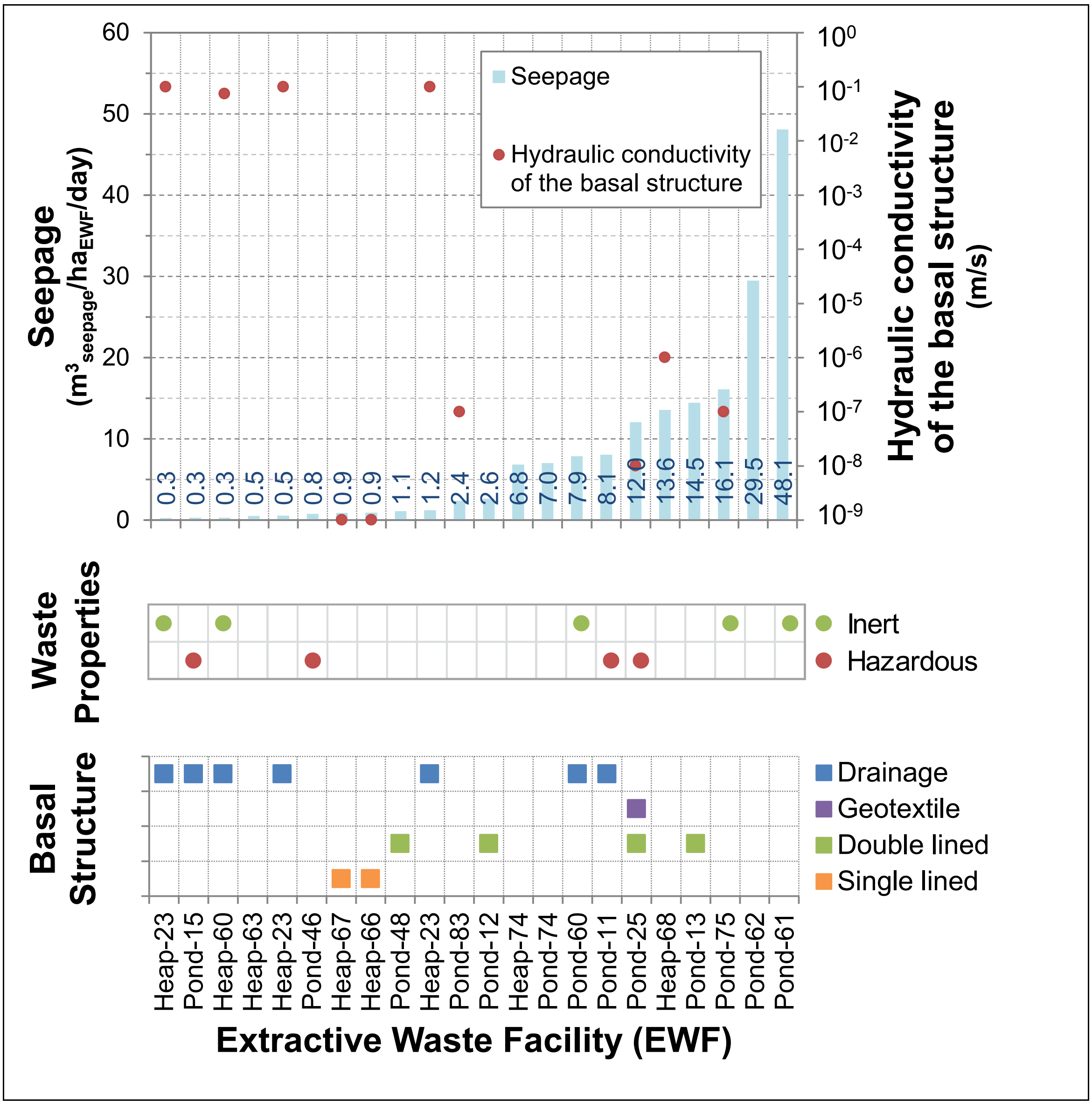

Figure 3.1: Annual seepage rates reported by operators (site numbers indicated)

3.3 Emissions to surface water

3.3.1 Acidity (pH) and dissolved substances

3.3.1.1 pH

The reported pH levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.2 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure pH levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these pH levels along with EWIW treatment techniques implemented prior to discharge and the pH ranges in the extractive waste (minimum and maximum levels) and in the leachate (based on the leaching test). Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Many factors may influence the initial pH levels in the EWIW before treatment (red points on the graph) such as:

- Potentially acid-generating (PAG) wastes and acid-generating extractive wastes that may generate EWIW with low pH levels for both:
    - closed or abandoned sites, as shown by the literature data collected for US sites (Skousen and Ziemkiewicz 2005);
    - operating sites;
- residues of chemicals that may also influence the initial pH levels:
    - higher or lower initial pH levels due to residues of leaching solutions (basic or acid for extraction of alumina or uranium oxides for example).

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water or drainage water (added water levels are indicated in green in Figure 3.2).

Finally, prior to discharge, the pH is usually adjusted by addition of acids or acidic substances (e.g. sulphuric acid, carbon dioxide) or bases or alkaline substances (e.g. caustic soda, lime). The usual treatments that will influence the EWIW pH levels are:

- neutralisation/precipitation or chemical precipitation (see definition in Section 8);
- pH adjustment;
- wetlands and other passive treatments such as OLDs/OLCs, ALDs or SAPS.

The reported median and average pH levels in EWIW after treatment range from 5.5 to 10.5 (indicated in blue) including data collected from literature related to Canadian sites (MEND 2014). At most sites, the average pH levels of discharged EWIW are in the range of 6 to 9. Only one operator reported discharging EWIW at a pH higher than 9 on average: site 21 which has two discharge points, one with a pH level of 7.3 and the other with a pH level of 10.5 which seems to correspond to the pH after the neutralisation/precipitation process.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, the pH levels in the discharged EWIW can be adjusted in the range of 6 to 9 by implementing neutralisation/precipitation and pH adjustment treatments.
At the closure phase or during after-closure, passive treatments to control the pH may not always be effective at keeping the average pH levels in the range of 6 to 9.

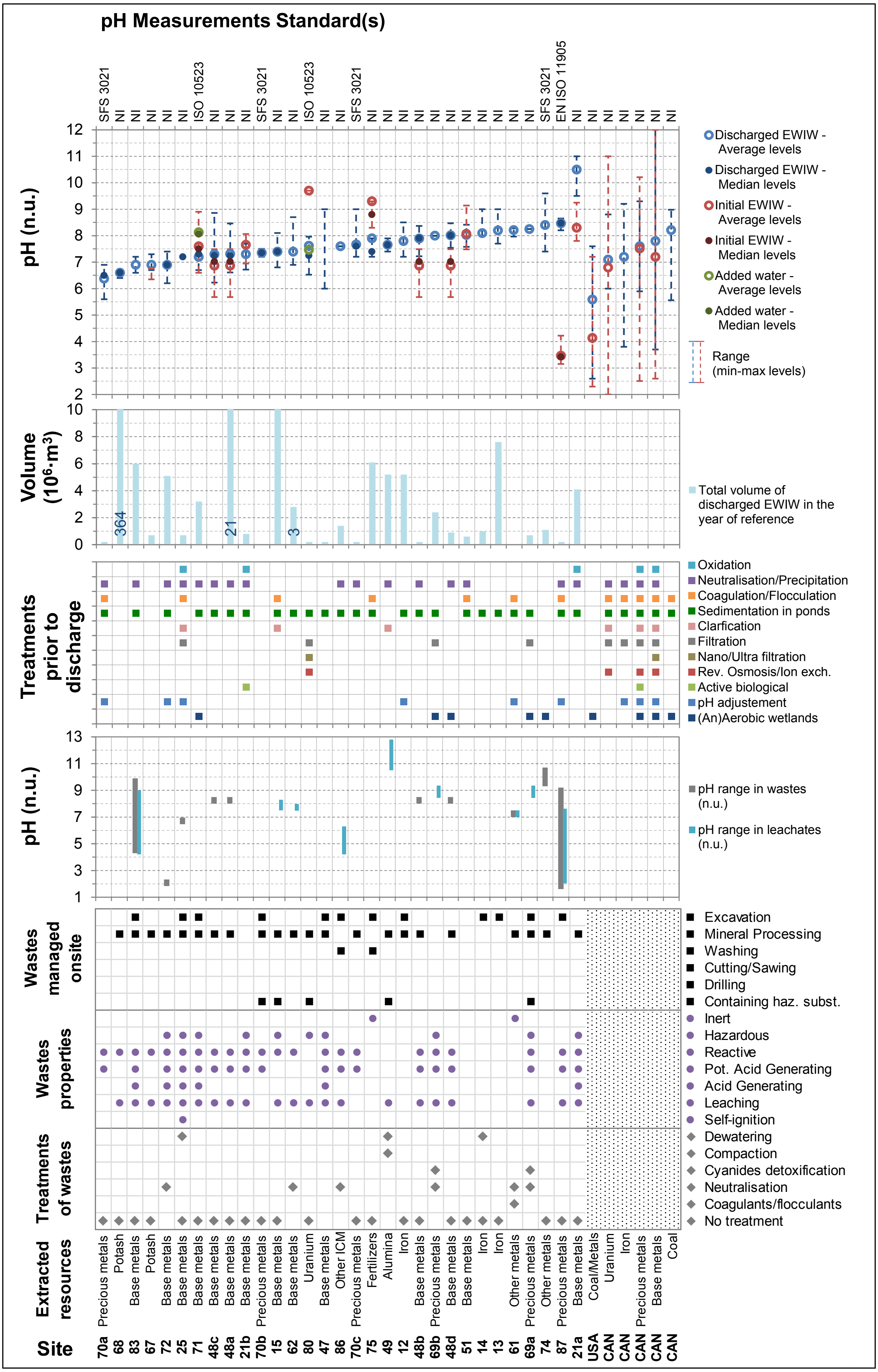

Figure 3.2: Annual EWIW pH levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in the US and Canada

3.3.1.2 Total Dissolved Substances (TDS)

The reported TDS levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.3 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure TDS levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these TDS levels along with EWIW treatment techniques implemented prior to discharge, the TDS ranges in the extractive waste (minimum and maximum levels) and the leaching rate (based on the leaching test). Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Many factors may influence the initial TDS levels in the EWIW before treatment such as:

- non-inert extractive wastes with leaching properties including PAG and AG extractive waste:
    - e.g. for EWIW from the management of extractive wastes resulting from the extraction of metalliferous ores, coal, lignite, peat or hydrocarbons;
- non-inert extractive wastes which dissolves:
    - e.g. higher levels of TDS are observed in EWIW from the management of extractive wastes resulting from the extraction of potash

Prior to discharge and before or after treatment, EWIW may be mixed with other water streams such as drainage water (added water levels are indicated in green in Figure 3.3).

The usual treatments that will influence the EWIW TDS levels are:

- aeration and chemical oxidation;
- neutralisation/precipitation;
- membrane technologies such as ultrafiltration or reverse osmosis;
- ion exchange;
- bioreactors;
- wetlands and other passive treatments such as OLDs/OLCs, ALDs or SAPS.

The reported median and average TDS levels in EWIW after treatment range from < 1 g/l to ~ 30 g/l (indicated in blue in Figure 3.3).

KEY OBSERVATIONS BASED ON THE DATA:
TDS can vary greatly from site to site.
At most sites that participated in the information exchange exercise, the reported TDS was below 1 g/l.

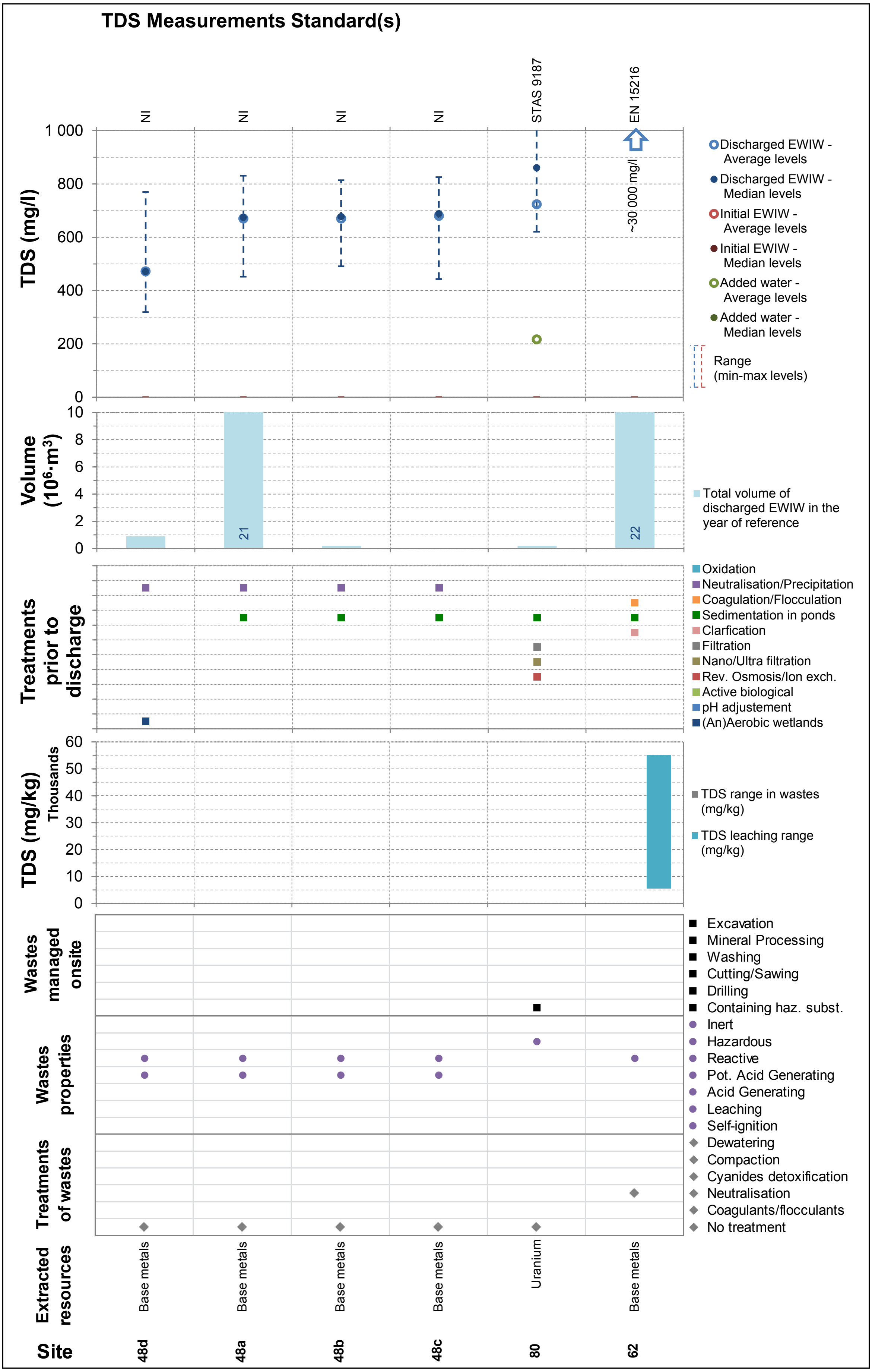

Figure 3.3: Annual TDS levels and contextual information reported by operators (site numbers indicated)

3.3.2 Suspended particles

3.3.2.1 Turbidity

Turbidity is an indicator of the level of suspended solids in the EWIW. One operator provided data on levels of turbidity. The same operator also reported the Total Suspended Solids.

The reported average levels of turbidity at that site ranged from 1 FTU to 5 FTU.

3.3.2.2 Total Suspended Solids (TSS)

The reported TSS levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.4 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure TSS levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these TSS levels along with EWIW treatment techniques implemented prior to discharge. TSS ranges in the leachate (based on the leaching test) were not reported. The range of fines content in the extractive wastes managed on site is reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Many factors may influence the initial TSS levels in the EWIW before treatment (red points on the graph) such as:

- the content of fines (i.e. particle size < 63 μm) and other particles that do not settle easily/rapidly;
- the erosion (in particular water erosion) and the preventive measures implemented at the site to reduce erosion and silting.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water or drainage water (added water levels are indicated in green).

Finally, prior to discharge, the TSS levels are usually reduced by solid/liquid separation systems. The usual treatments that will influence the EWIW TSS levels are:

- sedimentation (in ponds or tanks) with or without addition of coagulants and flocculants;
- clarification, e.g. using lamella clarifiers or air flotation;
- filtration technologies such as microfiltration or media filtration;
- wetlands, which may also act as additional sedimentation ponds.

The reported median and average TSS levels in EWIW after treatment range from ~ 2 mg/l (limit of quantification) to ~ 70 mg/l (indicated in blue) including data collected from literature on Canadian sites (MEND 2014). Canadian data seem to indicate that the management of extractive wastes from coal extraction usually generates EWIW with a higher TSS content. Most of the site-specific average levels are below 35 mg/l. Few operators provided data on initial TSS levels before treatment. Three sites reported initial TSS levels in a range from ~ 40 mg/l to 65 mg/l, whereas the discharged EWIW TSS levels ranged from ~ 3 mg/l to 12 mg/l, indicating a TSS removal of up to 90 %.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, TSS levels in the discharged EWIW can be reduced in the range of 5 mg/l to 35 mg/l when implementing solid/liquid control techniques.
EWIW from coal extractive waste or some industrial and construction minerals can present higher average levels of TSS, up to 70 mg/l.
The reported TSS removal efficiency was up to 90 %.

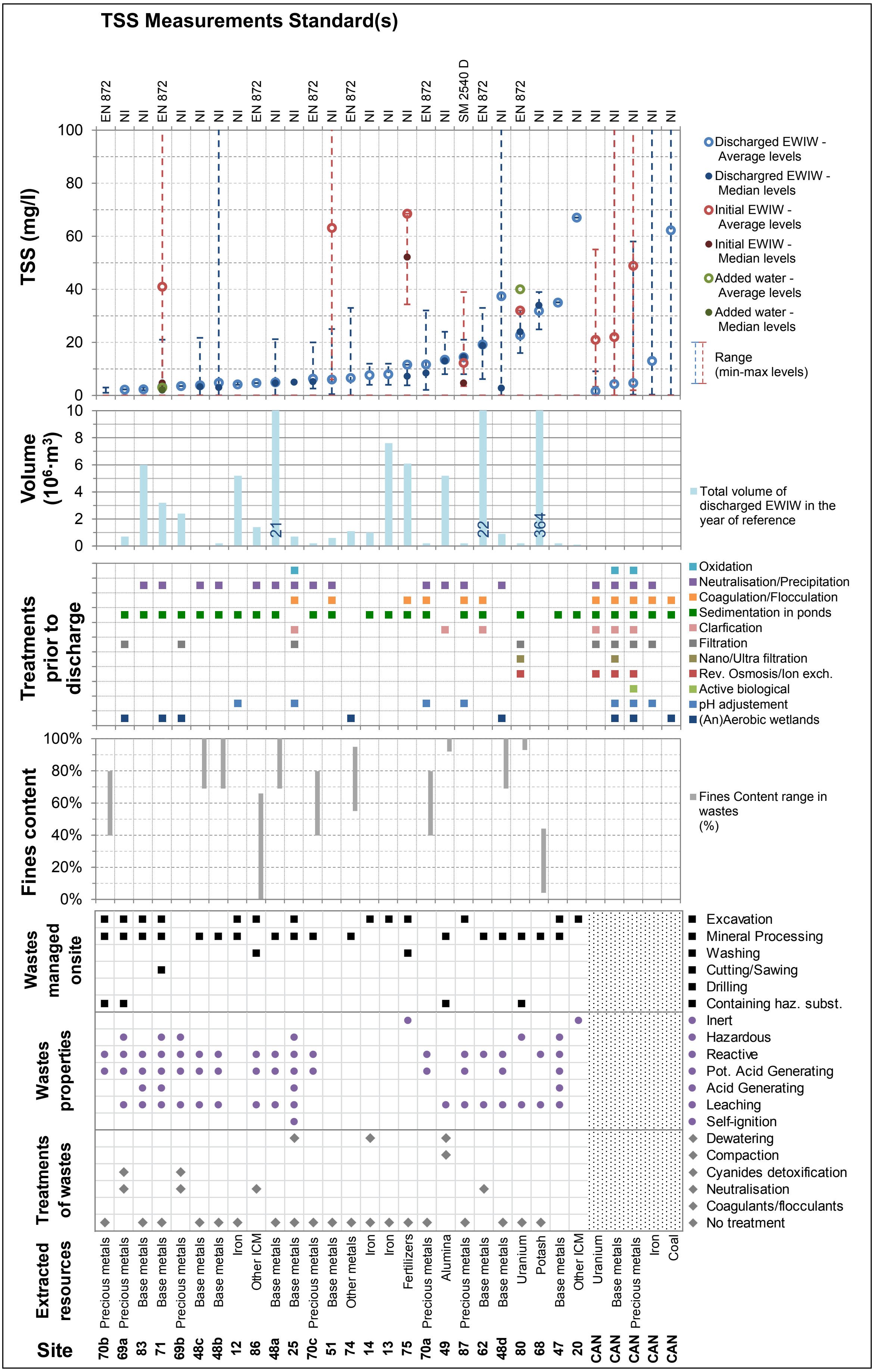

Figure 3.4: Annual TSS levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.3 Sulphur-bearing compounds

3.3.3.1 Sulphides (S^{2-}), sulphites (SO_3^{2-}), thiosulphates ($S_2O_3^{2-}$), sulphur (Total S)

Levels of sulphides, sulphites, tiosulphates or total sulphur in the discharged EWIW were not reported by more than two operators; therefore the data are not presented.

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3.3.3.2 Sulphates (SO_4^{2-})

The reported SO_4^{2-} levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.5 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure SO_4^{2-} levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these SO_4^{2-} levels along with EWIW treatment techniques implemented prior to discharge and the SO_4^{2-} ranges in the extractive waste (minimum and maximum levels) and the leaching rate (based on the leaching test). Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Many factors can influence the initial SO_4^{2-} levels in the EWIW before treatment (red points on the graph) such as:

- potentially acid-generating (PAG) wastes and acid-generating extractive wastes that can generate EWIW with high SO_4^{2-} levels;
- extractive wastes containing gypsum or potash extractive wastes containing high levels of SO_4^{2-}.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water or drainage water (added water levels are indicated in green).

Finally, prior to discharge, the SO_4^{2-} levels are usually reduced by treatment of EWIW. The usual treatments that will influence the EWIW SO_4^{2-} levels are:

- precipitation (e.g. gypsum);
- bioreactors;
- membrane technologies such as ultrafiltration or reverse osmosis;
- ion exchange;
- wetlands and other passive treatments such as OLDs/OLCs, ALDs or SAPS.

The reported treatments implemented by operators prior to discharge are indicated at the bottom of the figure.

The reported median and average SO_4^{2-} levels in EWIW after treatment range from ~ 50 mg/l to ~ 70 g/l (indicated in blue) including data collected from literature (INAP 2003). Operators responsible for the management of potash extractive wastes reported sulphate levels in the range of ~ 35-70 g/l. At the rest of the sites, mainly metalliferous ores extractive waste management sites, operators reported average levels ranging from ~ 50 mg/l to 3 000 mg/l, which is consistent with the levels collected from literature. As shown, sites with higher contents of sulphates in the waste and high leaching rates also exhibit higher levels of sulphate in the discharged EWIW.

A few operators provided data on initial EWIW quality before treatment. One site (48) in particular reported sulphate levels in the EWIW of ~ 1 800 mg/l whereas in the discharged EWIW they ranged from ~ 85 mg/l to 330 mg/l, indicating a ~ 80-95 % abatement efficiency. Data from literature confirm high abatement efficiencies (~ 99 %) when implementing chemical treatment with mineral precipitation or membrane technologies, with the possibility to reach average sulphate levels < 2 000 mg/l. Passive treatments such as wetlands or alkalinity-producing systems have lower removal efficiencies.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, sulphate levels in the discharged EWIW can be reduced to a range of 50 mg/l to 2 000 mg/l using sulphate removal techniques such as chemical treatment with mineral precipitation, membrane technologies, ion exchange or biological sulphate removal.
EWIW from potash extractive waste may present higher levels of SO_4^{2-}, up to 70 g/l on average, based on data reported by operators.
The reported sulphate removal efficiency was in the range of 80 % to 99 % with active treatment techniques.

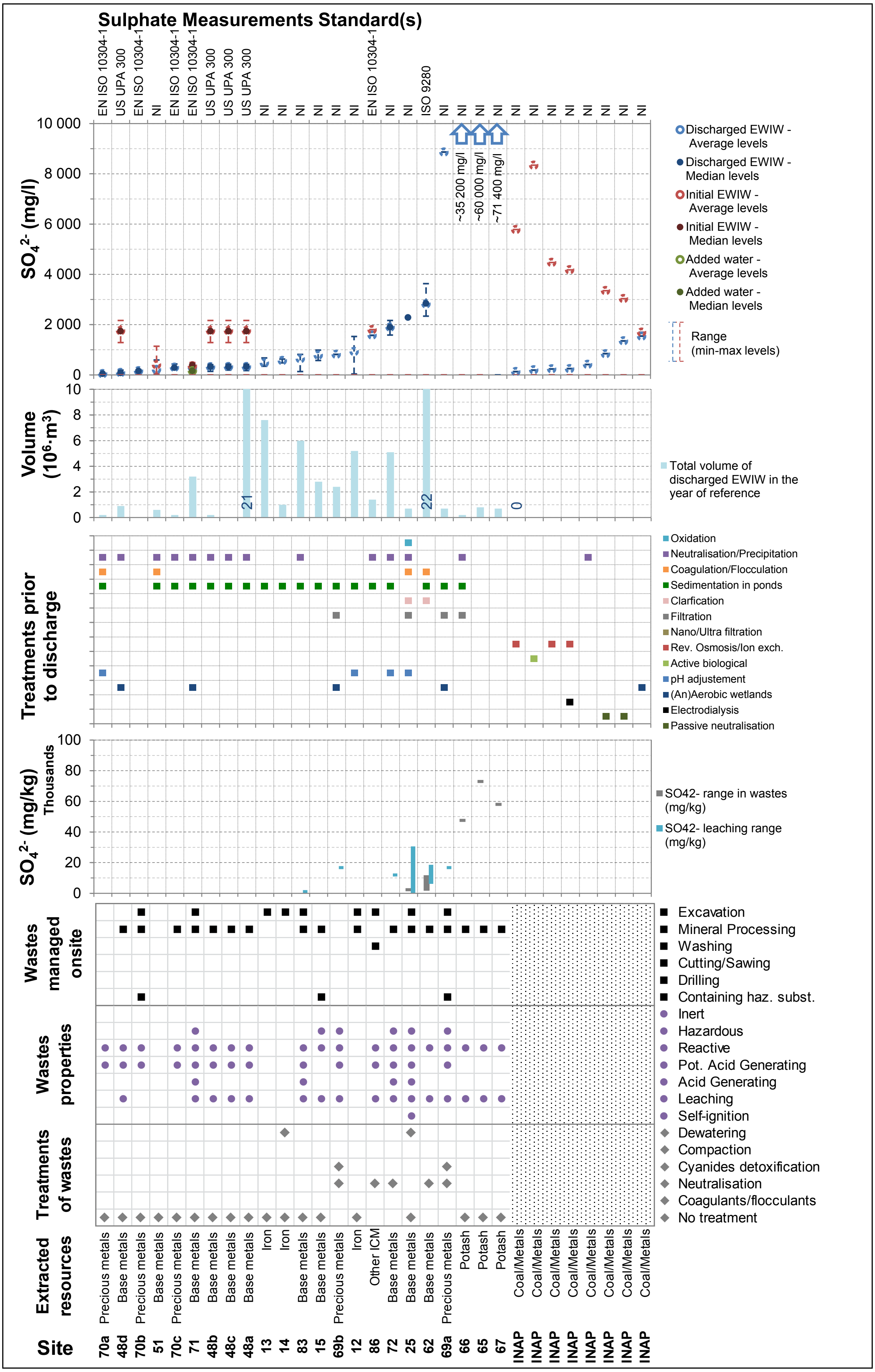


Figure 3.5: Annual sulphate levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to worldwide sites

3.3.4 Nitrogen-bearing compounds

Various nitrogen-bearing compounds originating from the explosives used at the extraction site can be present in EWIW. Mainly nitrites, nitrates and ammonium or ammonia can be present. Total nitrogen (TN), which corresponds to nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen and organic nitrogen, and Total Kjeldahl Nitrogen (TKN), which corresponds to the sum of ammonia-nitrogen plus organic nitrogen but does not include nitrate-nitrogen or nitrite-nitrogen, are two parameters frequently used to monitor nitrogen in the EWIW.

Nitrogen emissions may be of concern at sites where operators manage extractive wastes from mineral resources extraction with explosives, as explosives residues may be a source of EWIW contamination. Process chemicals such as $NaNO_3$ may also be a source of nitrogen contamination in EWIW. Finally, nitrogen may be of concern at sites for the management of extractive wastes from potash extraction.

In extractive waste management, nitrogen is generally removed from EWIW by passive treatment in ponds or wetlands, biological active treatment or ion exchange technologies.

3.3.4.1 Nitrites (NO_2^-)

Five operators reported average and median nitrite levels in the discharged EWIW ranging from ~ 0.1 mg/l to ~ 0.5 mg/l. Two operators provided data on initial EWIW quality before treatment (sites 71 and 51). They reported nitrite levels in the initial EWIW of 0.16 mg/l and 0.18 mg/l, respectively, and nitrite levels in the discharged EWIW of ~ 0.1 mg/l. These reported levels indicate a ~ 40 % abatement efficiency.

3.3.4.2 Nitrates (NO_3^-)

The reported NO_3^- levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.6 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure NO_3^- levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these NO_3^- levels along with EWIW treatment techniques implemented prior to discharge. No data on NO_3^- ranges in the extractive waste (minimum and maximum levels) or on leaching rates (based on the leaching test) were reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water (added water levels are indicated in green).

Finally, prior to discharge, the NO_3^- levels are usually reduced by treatment of EWIW. The usual treatments are:
- bioreactors;
- membrane technologies such as ultrafiltration (only if used in combination with bioreactors) or reverse osmosis;
- ion exchange;
- wetlands.

The reported median and average NO_3^- levels range from ~ 5 mg/l to ~ 35 mg/l.

A few operators provided data on initial EWIW quality before treatment. One site (71), using wetlands, reported nitrate levels in EWIW of 31 mg/l prior to treatment and 3 mg/l after treatment, indicating a ~ 90 % abatement efficiency. Another site (21) reported nitrate levels in EWIW of 18 mg/l prior to treatment and 7 mg/l after treatment, indicating a ~ 60 % abatement efficiency using biological treatment. The same site provided additional information on the total nitrogen levels before and after the biological treatment implemented on site (i.e. Moving Bed Biological Reactor (MBBR)) indicating a ~ 95 % removal efficiency on average.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, nitrate levels in the discharged EWIW can be reduced to a range of 2 mg/l to 9 mg/l using a form of biological treatment.
The reported nitrate removal efficiency was in the range of 60 % to 90 %.

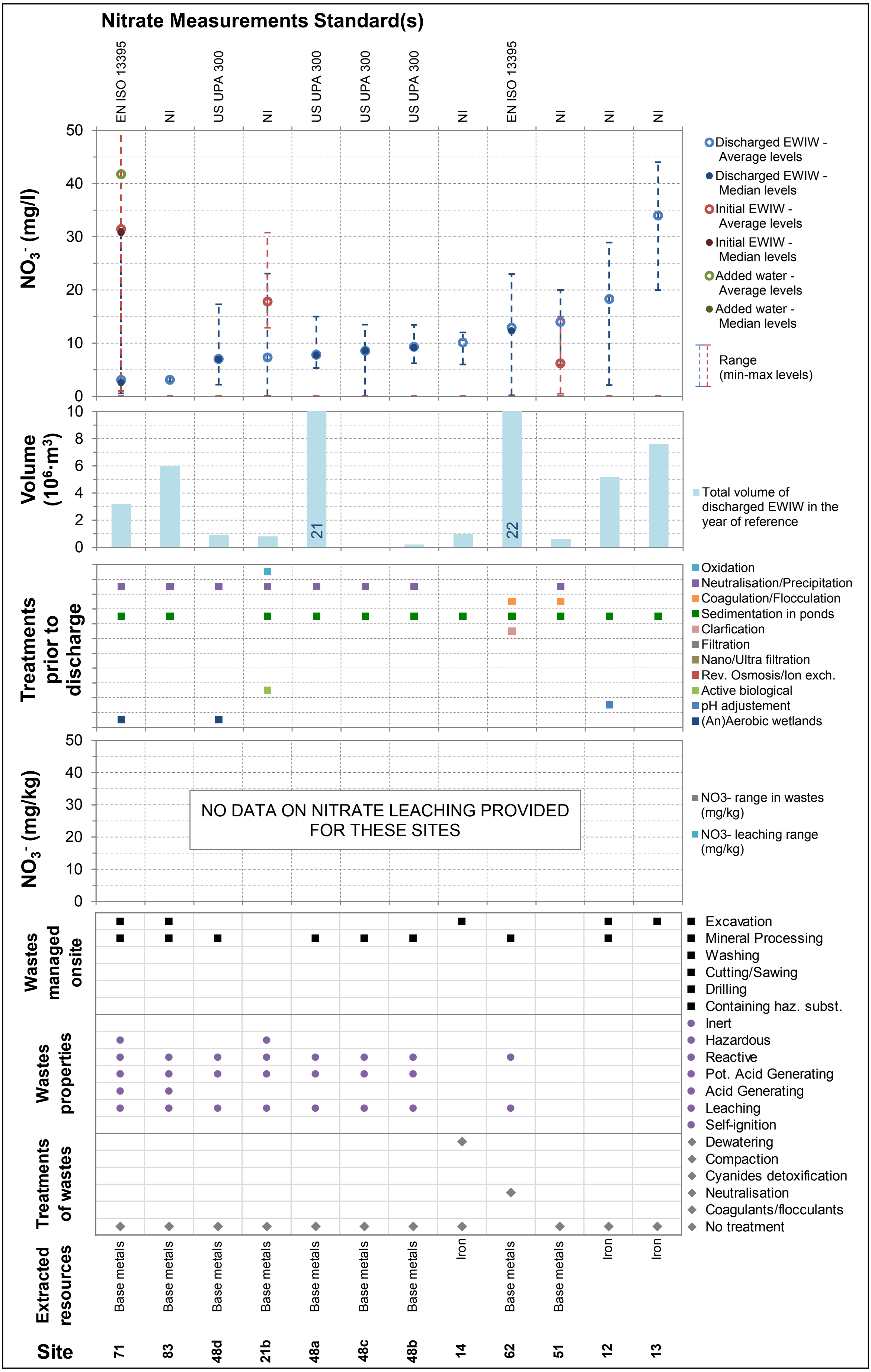


Figure 3.6: Annual nitrate levels and contextual information reported by operators (site numbers indicated)

3.3.4.3 Ammonia/ammonium (NH_3/NH_4^+)

The reported NH_4^+ levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.7 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure NH_4^+ levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these NH_4^+ levels along with EWIW treatment techniques implemented prior to discharge. No data on NH_4^+ ranges in the extractive waste (minimum and maximum levels) or on leaching rates (based on the leaching test) were reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water (added water levels are indicated in green).

Finally, prior to discharge, the NH_4^+ levels are usually reduced by treatment of EWIW. The usual treatments are:

- air stripping (to remove NH_3);
- bioreactors;
- membrane technologies such as reverse osmosis;
- ion exchange;
- wetlands.

The reported median and average NH_4^+ levels range from ~ 0.2 mg/l to 35 mg/l.

The level of 35 mg/l was reported by an operator responsible for the management of extractive waste from potash extraction. No biological treatment is possible in potash EWIW due to high concentrations of salt (NaCl) in the EWIW. Other nitrogen removal techniques were not reported to be implemented.

Site 69 reported two EWIW discharges, one for the mine drainage water, with an ammonium level of 24 mg/l, and one for the EWIW, with an ammonium level of 6 mg/l.

When biological treatment (wetlands or biological reactors) can be used to remove ammonium, the reported levels were in general < 6 mg/l.

A few operators provided data on initial EWIW quality before and after treatment.

Sites 21 and 48 reported a ~ 70-90 % abatement efficiency using biological treatment.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, ammonium levels in the discharged EWIW can be reduced to a range of 0.2 mg/l to 6 mg/l using a biological treatment.
The reported ammonium removal efficiency was in the range of 70 % to 90 %.

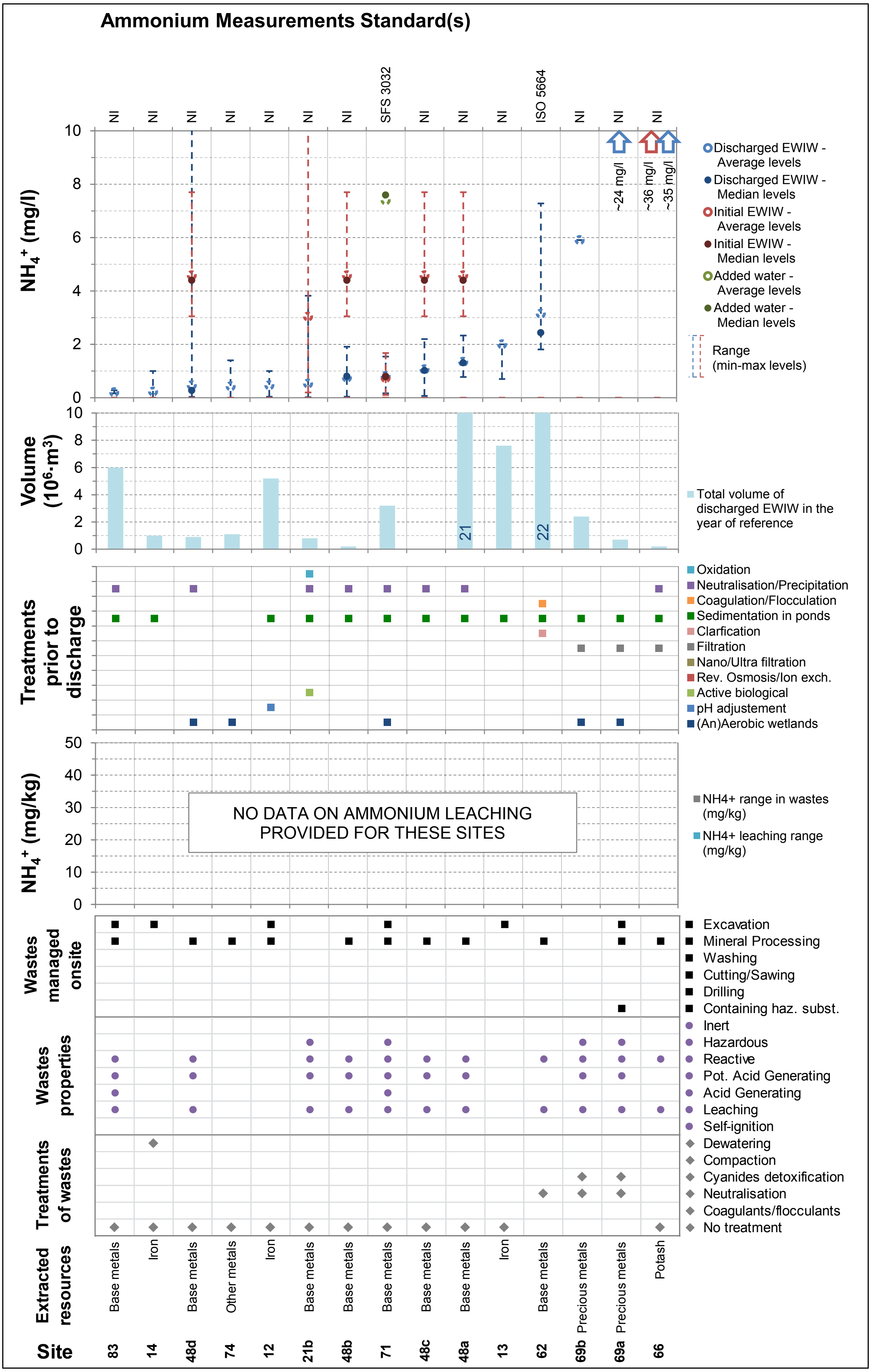


Figure 3.7: Annual ammonium levels and contextual information reported by operators (site numbers indicated)

3.3.4.4 Total Nitrogen (TN)

The reported TN levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.8 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure TN levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these TN levels along with EWIW treatment techniques implemented prior to discharge. No data on TN ranges in the extractive waste (minimum and maximum levels) or on leaching rates (based on the leaching test) were reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water (added water levels are indicated in green).

Finally, prior to discharge, the TN levels are usually reduced by treatment of EWIW. Treatments usually used are the same as for nitrates and ammonia.

The reported median and average TN levels range from < 5 mg/l to slightly more than 40 mg/l.

The level of 42 mg/l was reported by an operator responsible for the management of extractive waste from potash extraction. No biological treatment is possible in potash EWIW due to high concentrations of salt (NaCl) in the EWIW. Other nitrogen removal techniques were not reported to be implemented.

In addition to biological treatment, reverse osmosis and/or ion exchange technologies can be used to remove nitrogen. An example of the performance for a treatment including membrane technologies is provided by site 80, where the operator responsible for the management of extractive wastes from uranium ore extraction reported an abatement efficiency of ~ 75 % and a TN level of 11 mg/l.

Site 71 reported mixing EWIW with TN levels of 2-3 mg/l on average (~ 450 m^3/h average flow) with drainage water with TN levels of 16-17 mg/l on average (~ 30 m^3/h average flow) collected on the extractive waste management site before treatment. After treatment, ~ 50 % of the nitrogen is removed from the EWIW.

A few operators provided data on initial EWIW quality before treatment.

Site 21 provided additional information (but not via the questionnaire) on a MBBR with a ~ 95 % abatement efficiency.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, ammonium levels in the discharged EWIW can be reduced to a range of 5 mg/l to 25 mg/l using an appropriate combination of nitrogen removal techniques such as biological treatment or membrane technologies.
The reported removal efficiency was in the range of 50 % to 95 % on average.

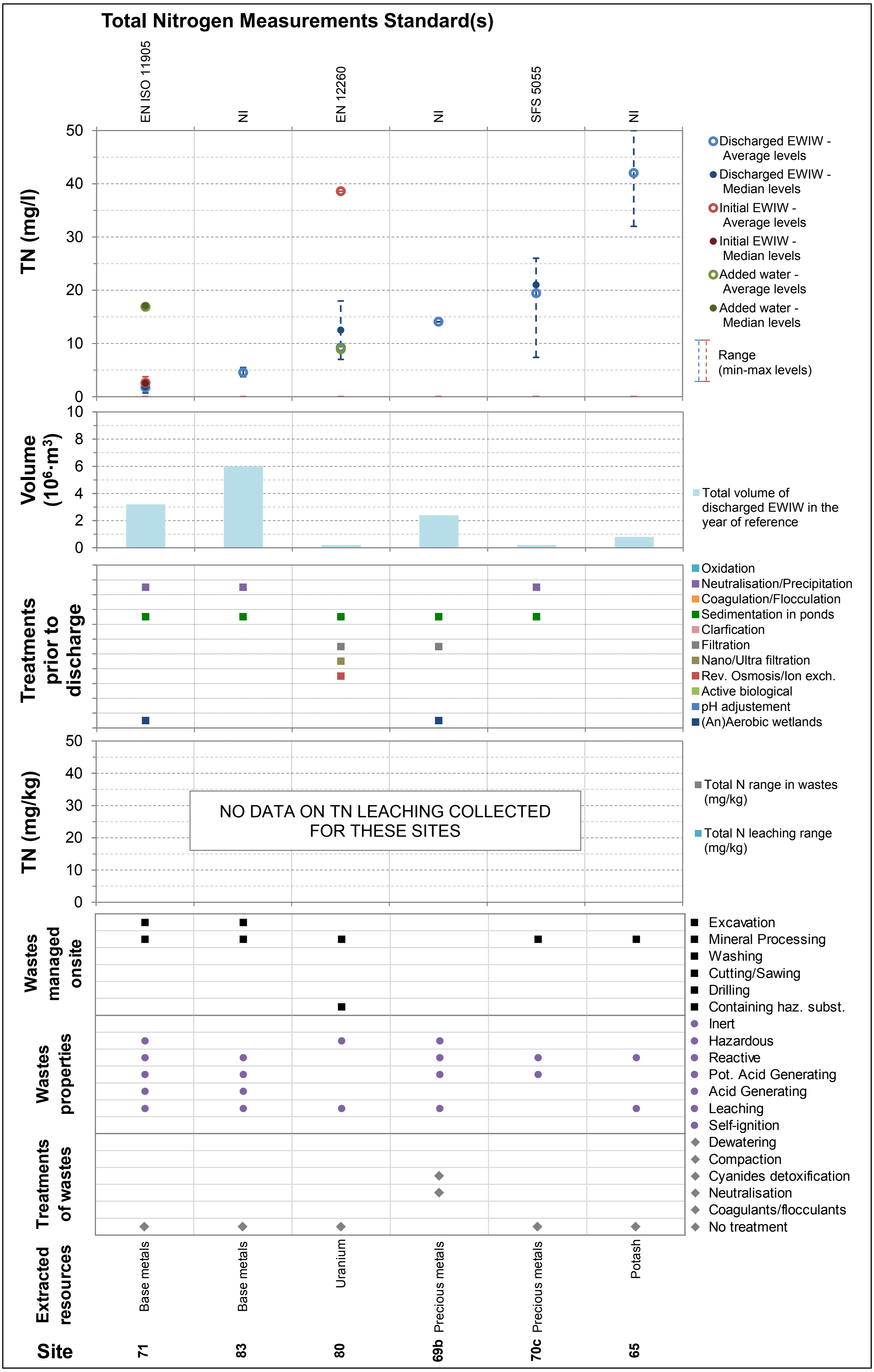


Figure 3.8: Annual TN levels and contextual information reported by operators (site numbers indicated)

3.3.5 Phosphorus

3.3.5.1 Phosphates (PO_4^{3-})

Phosphates are the main source of phosphorus in EWIW. Nevertheless, more operators provided data on Total Phosphorous (TP) content than on phosphates (PO_4^{3-}), for which four operators reported average levels below 0.02 mg/l.

3.3.5.2 Total Phosphorus (TP)

The reported TP levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.9 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure TP levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these TP levels along with EWIW treatment techniques implemented prior to discharge. No data on TP ranges in the extractive waste (minimum and maximum levels) or on leaching rates (based on the leaching test) were reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The main sources of phosphorus may be:

- phosphates originating from soil erosion;
- phosphorus originating from the capping cover, e.g. fertilisers or sewage used as soil improvers for the capping of the EWF;
- phosphates originating from the extractive waste, e.g. extractive waste resulting from the extraction and from the processing of minerals used for the production of fertilisers such as apatite or other phosphate rocks.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water or drainage water (added water levels are indicated in green).

Usually phosphates and hence TP are removed from the EWIW using:

- passive or active biological treatments (wetlands or reactors);
- chemical precipitation with Ca, Al or Fe salts.

Most of the discharged EWIWs present average levels of TP in the range of < 0.01 mg/l (limit of quantification) to ~ 0.2 mg/l.
The operator responsible for the management of extractive waste from phosphate rock extraction reported levels of TP of 0.07 mg/l on average and 0.04 mg/l as the median value. The initial level of TP in the EWIW was reported to be 0.5 mg/l, which indicates an abatement of ~ 90 %. Two operators reported higher average levels of TP: site 66 and site 21.
At site 66, where the management of extractive wastes from potash extraction is carried out, the operator reported average TP levels of 0.7 mg/l. Nonetheless, initial levels of TP in the EWIW were reported on average 2.3 mg/l which indicates an abatement of ~ 70 % at site 66.
At site 21, the initial levels of TP were reported to be lower than the discharged ones which might be due to the use of soil improvers, including sewage, used for the vegetative capping cover.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, TP levels in the discharged EWIW can be reduced to a range of < 0.01 mg/l to 2 mg/l by passive or active biological treatment of EWIW, passive treatment in ponds or precipitation with salts.
The reported removal efficiency was up to 70 % in the case of passive treatment in ponds.

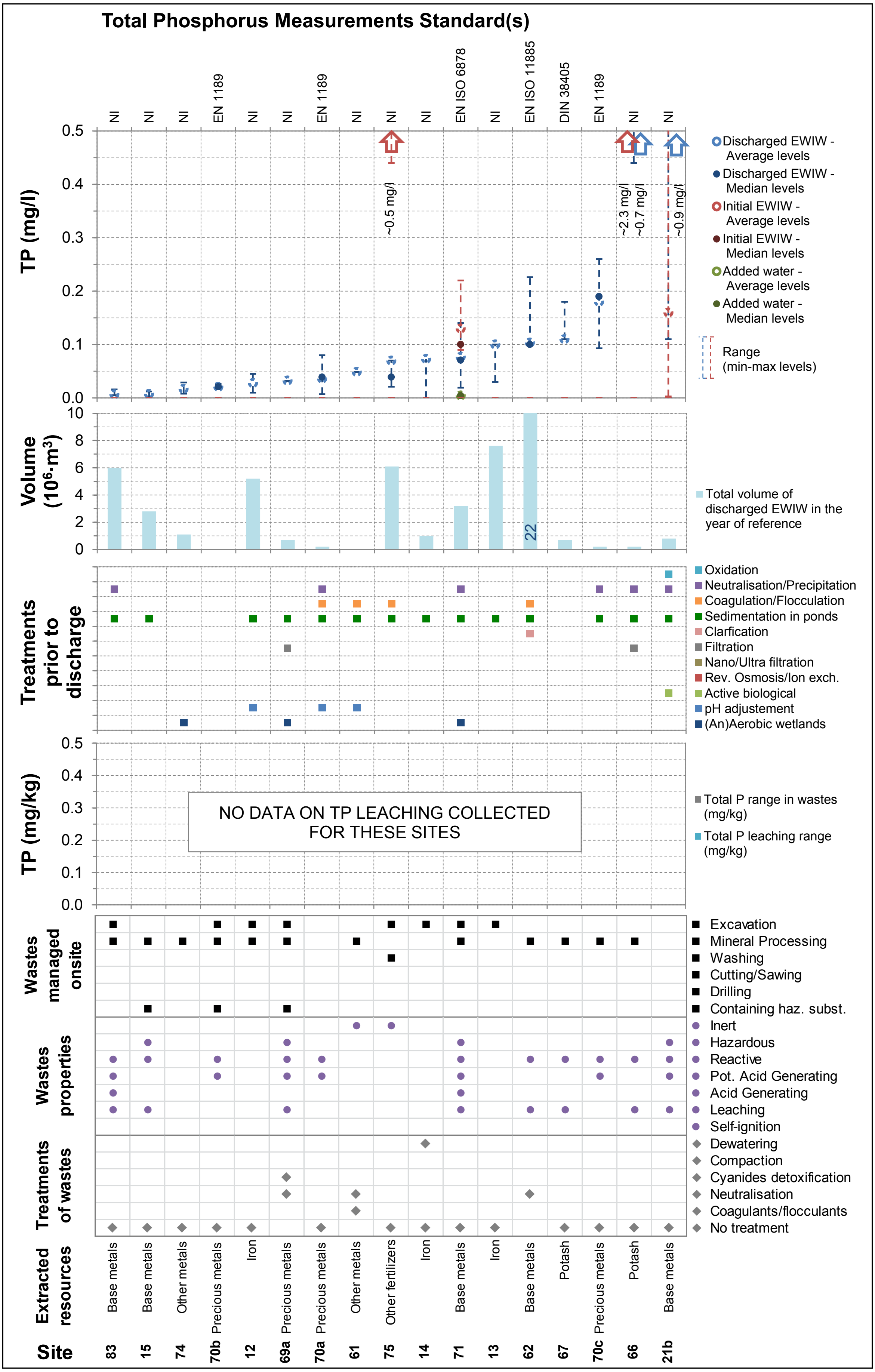


Figure 3.9: Annual TP levels and contextual information reported by operators (site numbers indicated)

3.3.6 Chloride (Cl^-)

The reported Cl^- levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.10 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure Cl^- levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Cl^- levels along with EWIW treatment techniques implemented prior to discharge. Data on Cl^- ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

Chloride levels in EWIW vary greatly from site to site depending on the type of extractive waste.

EWIW with high levels of Cl^- originates mainly from the management of extractive wastes resulting from the extraction of potash, hydrocarbons and PAG extractive wastes.

Chlorides are usually removed from EWIW by using one or a combination of the following techniques:

- membrane technologies such as reverse osmosis, or electrodialysis;
- ion exchange;
- thermal treatment such as freezing and thawing, or distillation, which can also be applied for the treatment of smaller volumes of EWIW;
- passive evaporation in ponds is another method that can be used to concentrate the brine in arid climates if EWIW can be stored and does not release other pollutants in the air (e.g. VOCs);
- crystallisation processes can also be used for desalinisation of EWIW;

For larger volumes of EWIW, for example in the potash sector, no treatment was reported to be implemented. Some operators reported discharging EWIW into surface water by monitoring upstream and downstream levels of chloride in the body of water and controlling the volume discharged in order to keep the chloride levels below the permit values.

The reported median and average levels range from < 20 mg/l to ~ 200 g/l

Operators responsible for the management of extractive wastes from potash extraction reported average levels of Cl^- in the range of 100 g/l to 200 g/l.

Some acid-generating wastes resulting from the extraction of metalliferous ores can produce EWIW with levels of Cl^- reaching on average 40 g/l.

However, most of the operators responsible for the management of extractive wastes from metalliferous ores extraction reported average levels of chloride in EWIW in the range of 20 mg/l to ~ 200 mg/l.

KEY OBSERVATIONS BASED ON THE DATA:
Membrane technologies or thermal treatments can be used to reduce chloride levels.
Operators responsible for the management of EWIW (brine) from potash extractive waste management reported chloride levels > 120 g/l.
Most of the operators responsible for the management of EWIW from metalliferous ores extractive waste reported chloride levels < 0.4 g/l.
No membrane filtration or thermal treatment was reported at the sites that participated in the data collection.

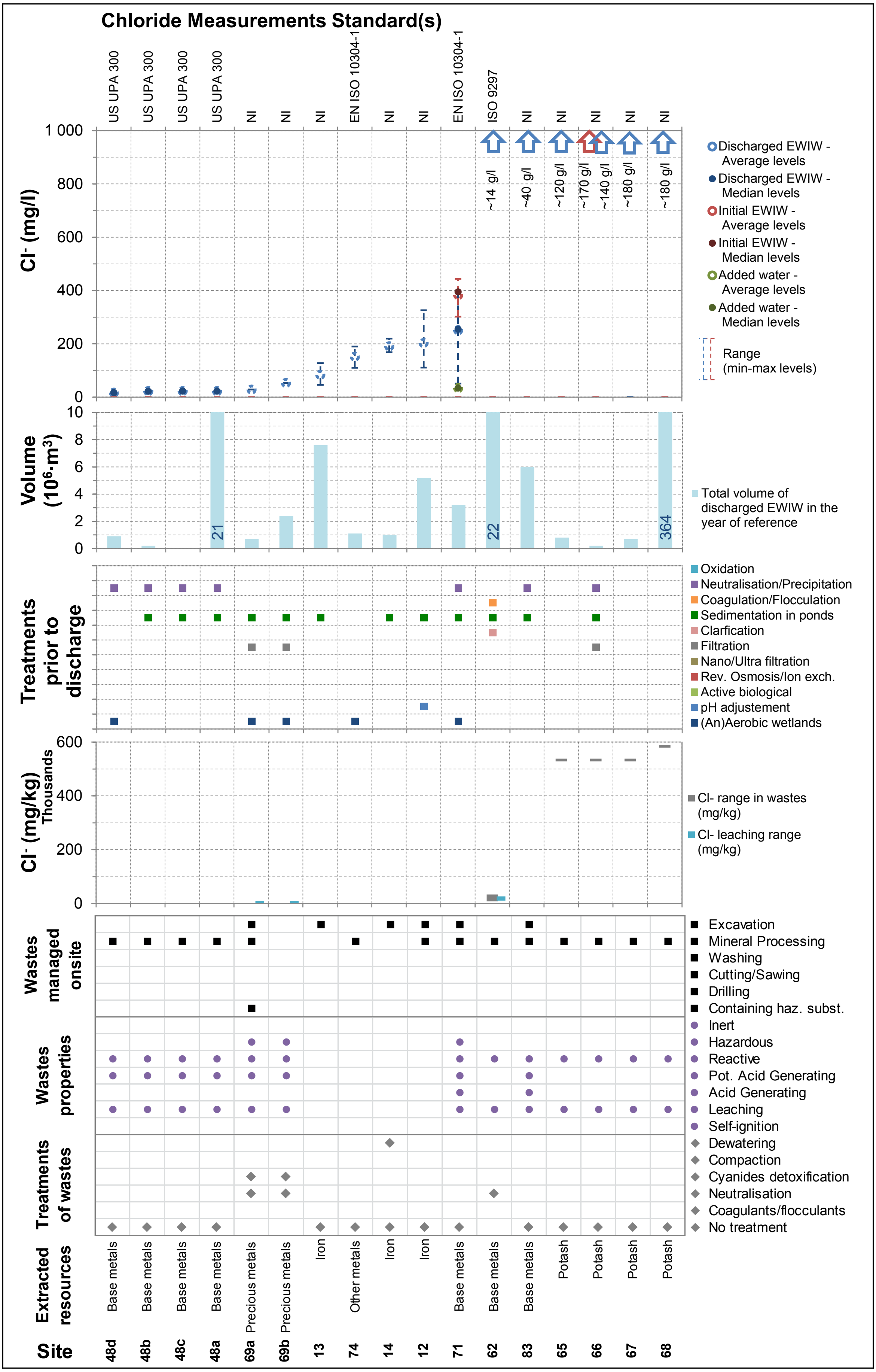


Figure 3.10: Annual chloride levels and contextual information reported by operators (site numbers indicated)

3.3.7 Organic contaminants

3.3.7.1 Biological Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Hydrocarbons Content (THC), Oil and Grease

In the completed questionnaires, one parameter was mainly reported for the evaluation of the level of organic contaminants in EWIW: the Chemical Oxygen Demand (COD).

Other parameters such as Biological Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Hydrocarbons Content (THC) or Oil and Grease content may be relevant but were not widely reported by operators.

3.3.7.2 Chemical Oxygen Demand (COD)

The reported COD levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented in Figure 3.11 for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure COD levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these COD levels along with EWIW treatment techniques implemented prior to discharge. Data on COD ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The main cause of high COD levels in EWIW is contamination by organic matter, which may originate from:

- the management of extractive waste resulting from the extraction of coal, lignite, peat or hydrocarbons, although no operator responsible for such an extractive waste reported data on COD in EWIW;
- the organic matter used for the capping cover of the EWF;
- the on-site spills of organic substances such as oil.

Prior to discharge and before treatment, EWIW may be mixed with other water streams such as mine water or drainage water (added water levels are indicated in green).

Usually COD is reduced in the EWIW using:

- decantation (ponds or clarifiers) or centrifuge systems to remove the organic particles;
- biological treatments (decomposition of organic matter by microorganisms).

At most sites, COD levels are below 100 mg/l.

Higher levels of COD (~ 90-190 mg/l on average) have been reported at sites for the management of extractive wastes resulting from the extraction of potash.

One operator (72) responsible for the management of extractive waste resulting from base metals extraction also reported higher levels of COD (~ 130 mg/l on average). At site 72, the operator mixes EWIW from operational EWFs with EWIW from a closed EWF with a vegetative cover. The vegetative cover may be a source of organic matter and higher COD levels.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, COD is generally kept in the range of < 15 mg/l to 100 mg/l.

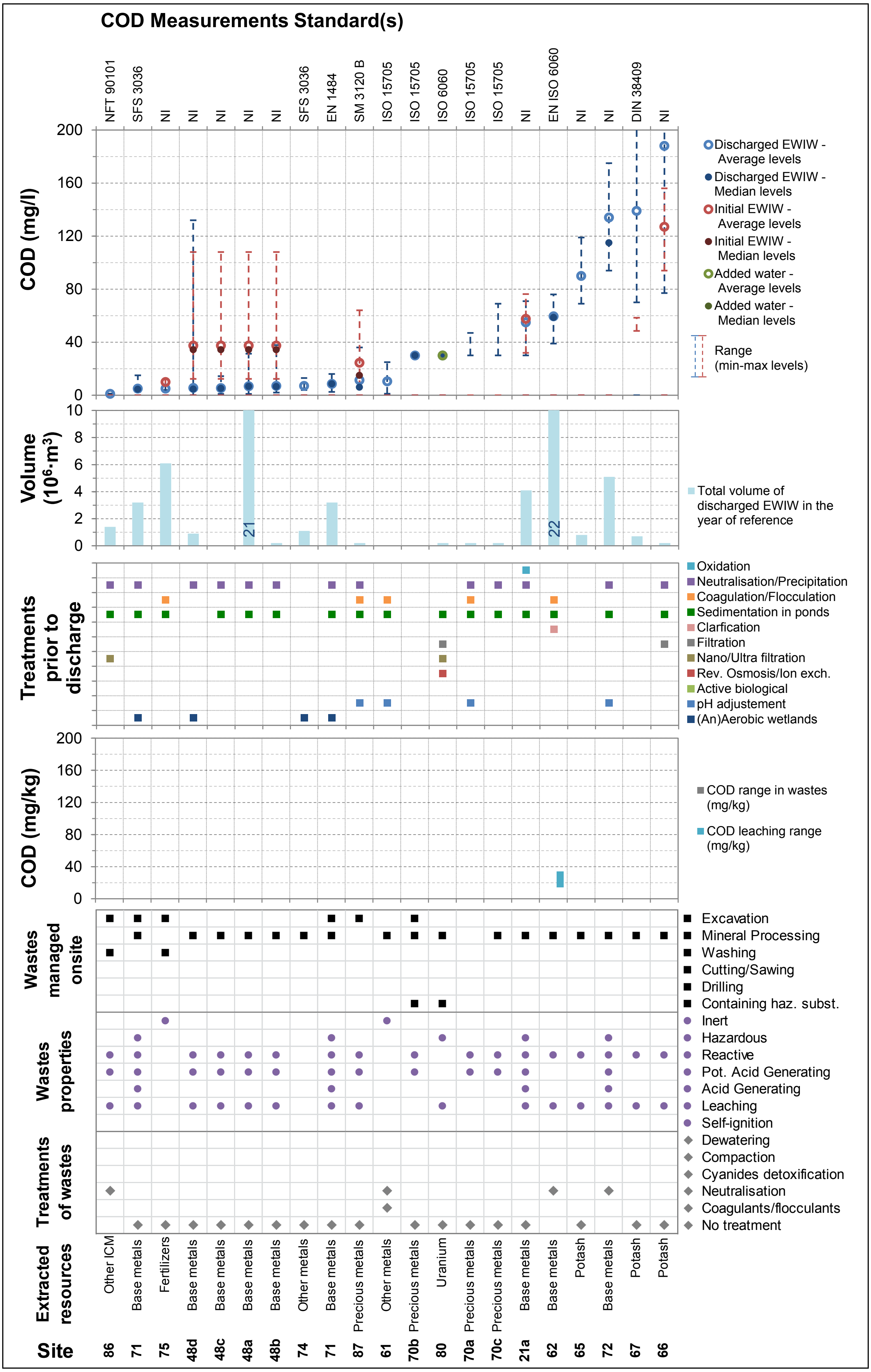


Figure 3.11: Annual COD levels and contextual information reported by operators (site numbers indicated)

3.3.8 Metals and metalloids

Metals and metalloids usually originate from the extractive waste itself, although a part may come from the auxiliary materials and reagents used in the mineral processing.

The most common EWIW treatment method used to remove dissolved metals from the EWIW are:

- chemical precipitation techniques such as:
    - hydroxide precipitation (neutralisation/precipitation);
    - sulphide precipitation;
    - co-precipitation (with metal chloride or sulphate salts);

  including, possibly:
    - prior to precipitation of dissolved metals, chemical oxidation (e.g. Fenton process) or aeration;
    - after precipitation, solid/liquid control techniques to separate the solid precipitates from the EWIW;
- membrane technologies such as nanofiltration or reverse osmosis;
- ion exchange;
- biological treatments such as active bioreactors or passive treatments such as aerobic and anaerobic wetlands or limestone drains for polishing.

3.3.8.1 Arsenic (As)

The reported levels of arsenic in the discharged EWIW are presented in Figure 3.12.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these As levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.01 mg/l to 0.13 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, arsenic levels are on average below 0.050 mg/l while the average levels reported by Canadian operators (MEND 2014) were on average below 0.025 mg/l.
Some operators reported relatively high contents of arsenic in the extractive wastes managed on site, up to 50-70 mg/kg, but low levels of arsenic in the discharged EWIW, < 0.01-0.02 mg/l on average.
Few operators reported the levels of arsenic in the initial EWIW.
Based on data from literature, 90-98 % of arsenic can be removed from EWIW prior to discharge by implementing an appropriate combination of water treatment techniques, which may include membrane technologies. Meanwhile, based on the levels reported by operators (66) and (71), ~ 50 % of arsenic is removed prior to discharge.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of arsenic in discharged EWIW can be in the range of < 0.01 mg/l to 0.050 mg/l when implementing metal removal techniques. The reported arsenic removal efficiency was in the range of 50 % to 98 %.

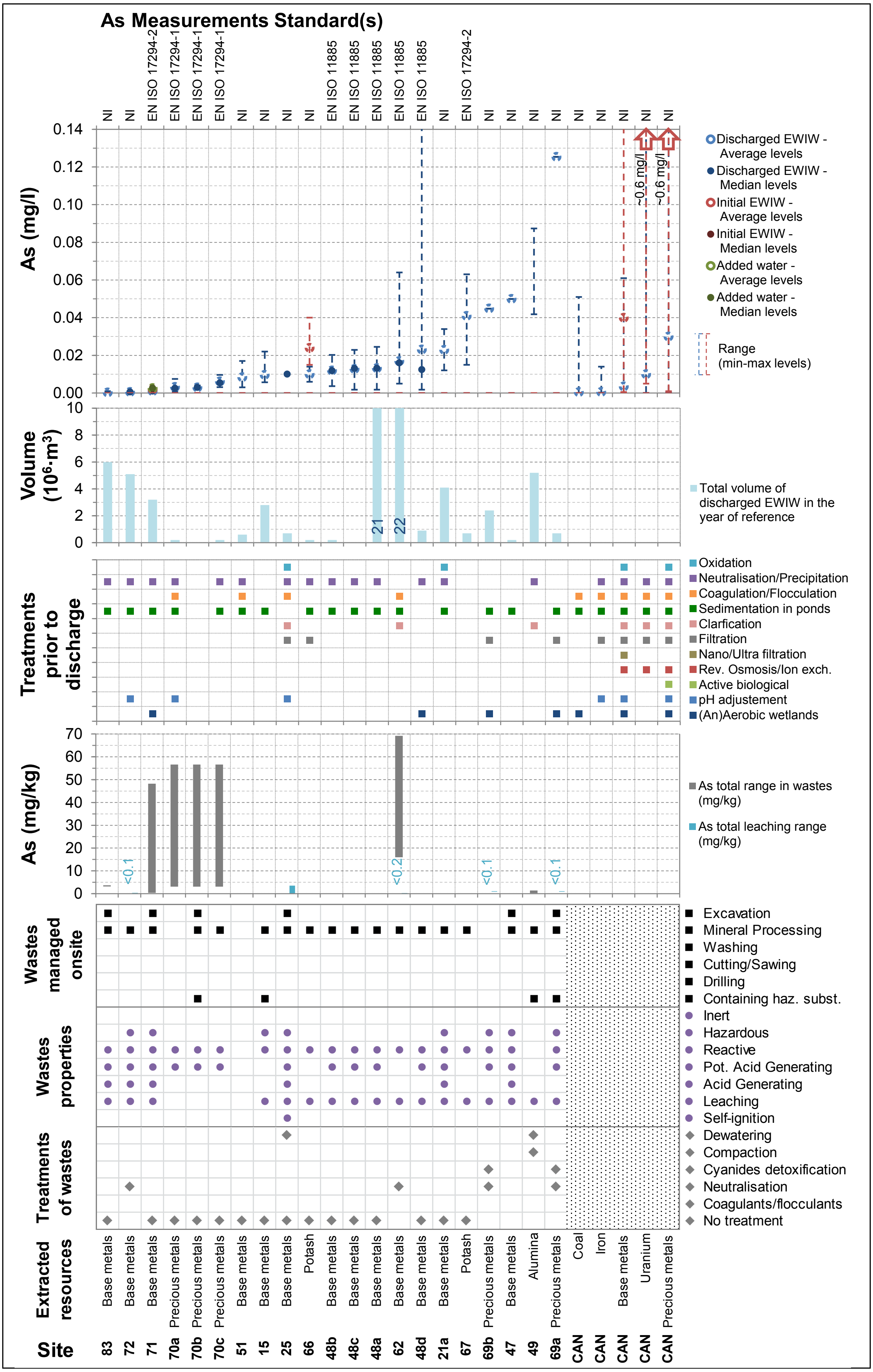


Figure 3.12: Annual arsenic levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.2 Cadmium (Cd)

The reported levels of cadmium in the discharged EWIW are presented in Figure 3.13.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Cd levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.001 mg/l to 0.02 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, cadmium levels are on average below 0.002 mg/l apart from two sites, 87 and 25, which reported higher levels of cadmium in the discharged EWIW, 0.02 mg/l, despite implementing neutralisation/precipitation techniques. At site 87, the reported levels of cadmium in the extractive waste ranged from < 1 mg/kg up to 450 mg/kg.

Site 87 also reported a level of cadmium in the initial EWIW of 0.36 mg/l on average, indicating nevertheless an average cadmium removal efficiency of ~ 95 %.

Site 66 reported a cadmium removal efficiency of ~ 50 %.

Data reported on cadmium levels in the extractive waste and the leaching rates seem to confirm that higher levels of cadmium can be observed in the EWIW at sites with higher levels of cadmium in the extractive waste.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of cadmium in discharged EWIW can be in the range of 0.002 mg/l to 0.02 mg/l when implementing metal removal techniques.
The reported cadmium removal efficiency was in the range of 50 % to 95 %.

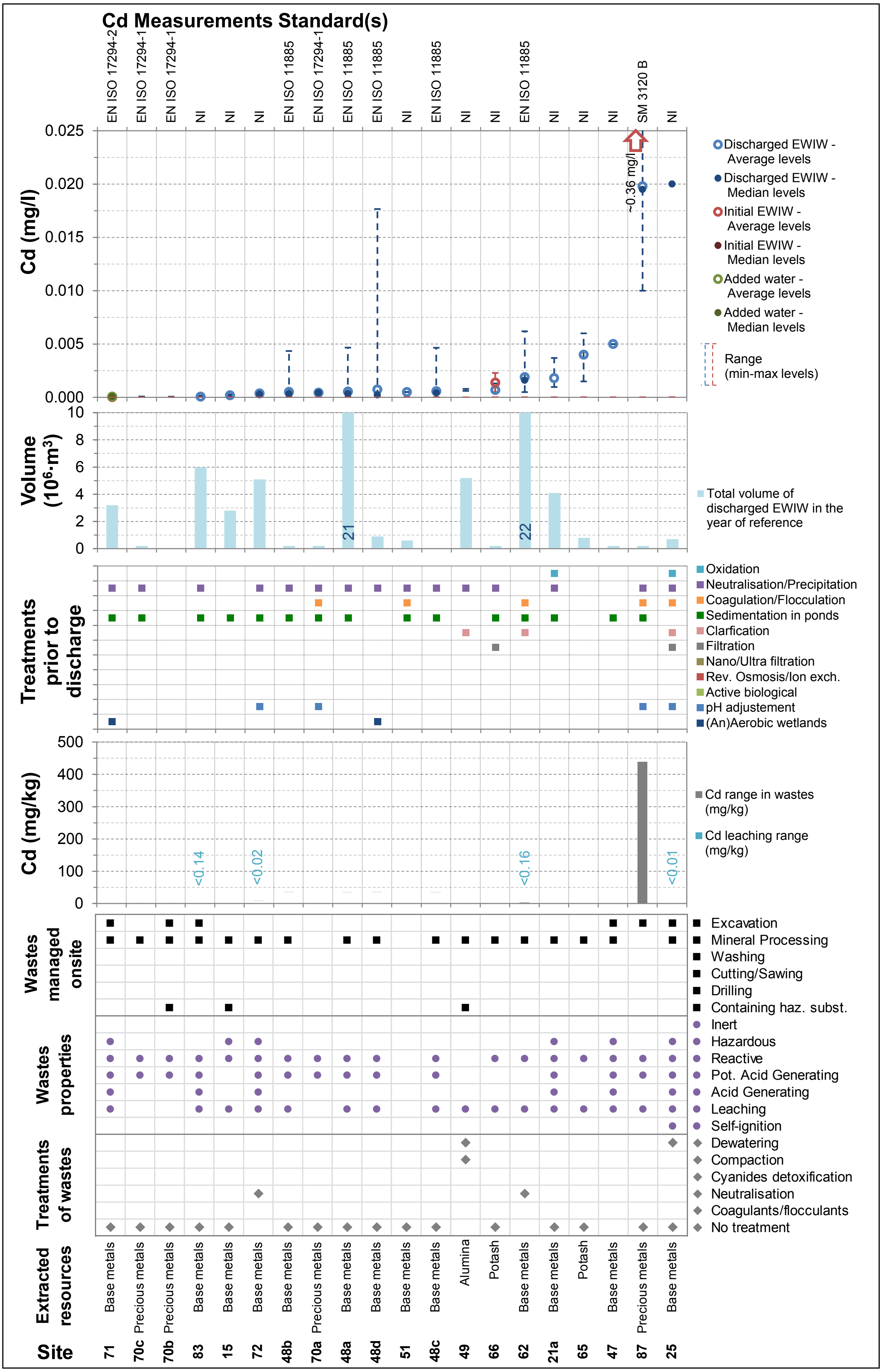


Figure 3.13: Annual cadmium levels and contextual information reported by operators (site numbers indicated)

3.3.8.3 Chromium (Cr)

The reported levels of chromium in the discharged EWIW are presented in Figure 3.14.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Cr levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from the limit of detection (LoD) to 0.07 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, chromium levels are on average below 0.015 mg/l.

Two sites, 47 and 67, reported higher levels of chromium in the discharged EWIW, 0.05 mg/l and 0.07 mg/l on average, but did not report implementing neutralisation/precipitation techniques.

Meanwhile, one site (66) reported higher levels of chromium in the discharged EWIW (0.04 mg/l) after neutralisation/precipitation treatment.

At site 67, where extractive waste resulting from potash extraction is managed, the initial levels of chromium in the EWIW (< 0.02 mg/l) were reported to be below the discharged ones.

However, at site 66, where potash extractive waste is managed, the initial levels of chromium were reported to be 0.13 mg/l, indicating an average chromium removal of ~ 70 %.

Site 87 also provided data on levels of chromium in the initial and discharged EWIW. The removal efficiency at site 87 was calculated to be on average ~ 60 %.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of chromium in discharged EWIW can be in the range of < 0.002 mg/l to 0.015 mg/l when implementing metal removal techniques.
The reported chromium removal efficiency was in the range of 60 % to 70 %.

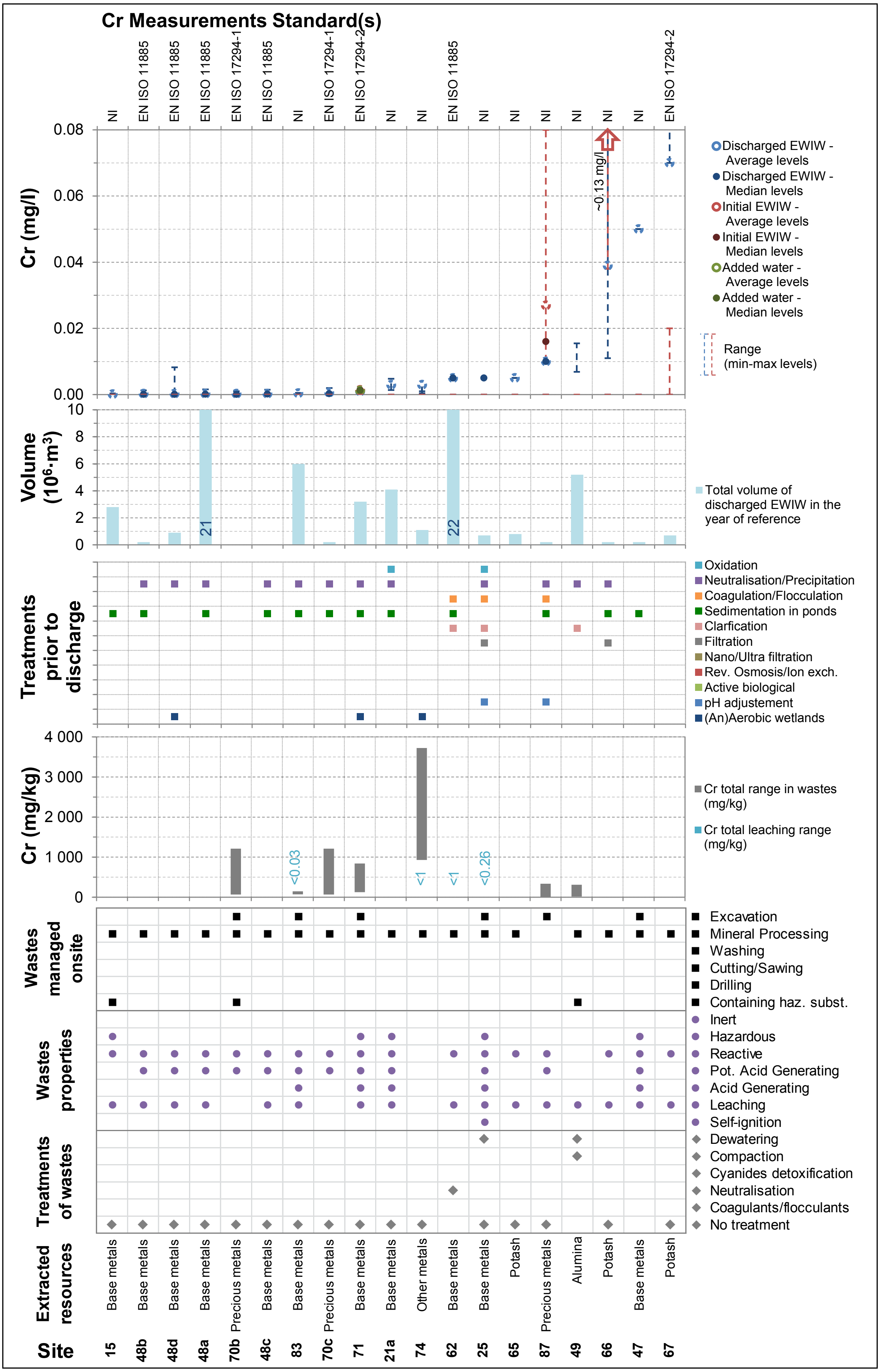


Figure 3.14: Annual chromium levels and contextual information reported by operators (site numbers indicated)

3.3.8.4 Copper (Cu)

The reported levels of copper in the discharged EWIW are presented in Figure 3.15.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Cu levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.002 mg/l to 3.6 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, copper levels are on average below 0.1 mg/l.

In Canada, based on the data collected from literature (MEND 2014), average levels reported by operators are below 0.025 mg/l.

Two sites, 67 and 14, reported higher levels of copper in the discharged EWIW, 0.3 mg/l and 3.6 mg/l on average, but did not report implementing neutralisation/precipitation techniques or any other metal removal technique.

Three operators reported on the levels of copper in the initial EWIW.

Based on the data provided by operators and the information collected from literature, an average copper removal efficiency of 84 % to > 99 % was calculated for sites where extractive waste from metalliferous ore extraction is managed.

At site 66, where extractive waste from potash extraction is managed, the removal efficiency was calculated to be ~ 50 % based on the reported average levels.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of copper in discharged EWIW can be in the range of < 0.002 mg/l to 0.1 mg/l when implementing metal removal techniques.
The reported copper removal efficiency was in the range of 50 % to > 99 %.

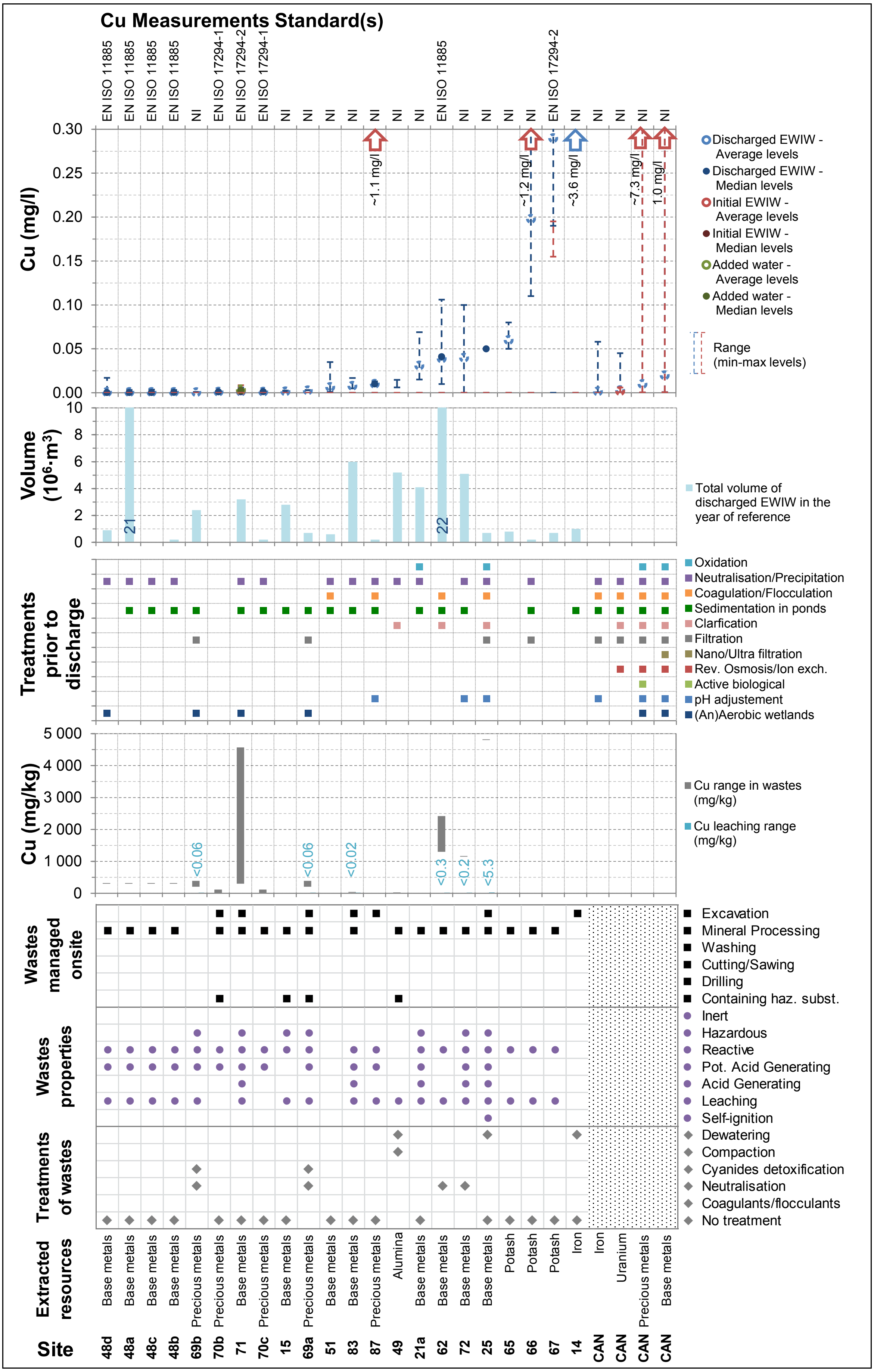


Figure 3.15: Annual copper levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.5 Iron (Fe)

The reported levels of iron in the discharged EWIW are presented in Figure 3.16.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Fe levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.01 mg/l to 13 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, iron levels are on average below 2.5 mg/l.

In Canada, the highest average levels were reported by operators responsible for the management of extractive waste from iron ore extraction (1.3 mg/l) whereas, for the others, the levels were on average below 0.7 mg/l (MEND 2014).

One site (67), where extractive waste from potash extraction is managed, reported higher levels of iron in the discharged EWIW, 13 mg/l on average, but did not report implementing neutralisation/precipitation techniques or any other metal removal technique.

Some operators reported on the initial levels of iron in the EWIW prior to treatment.

Based on the data provided by operators and the information collected from literature, an iron removal efficiency of 94 % to 99 % was calculated for sites with high levels of iron in the EWIW.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of iron in discharged EWIW can be in the range of < 0.01 mg/l to 2.5 mg/l when implementing metal removal techniques.
The reported iron removal efficiency was in general in the range of 94 % to 99 %.

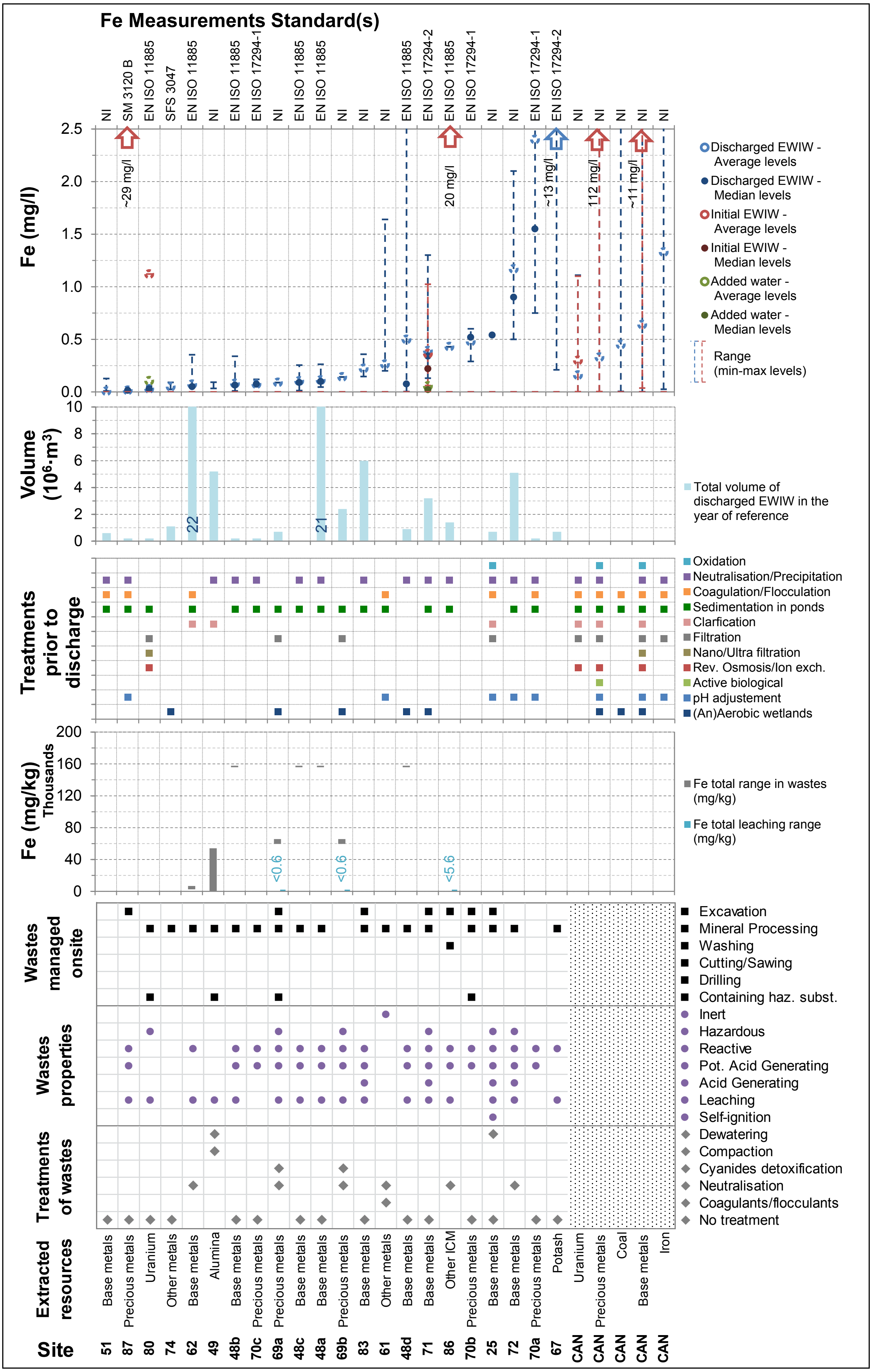


Figure 3.16: Annual iron levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.6 Lead (Pb)

The reported levels of lead in the discharged EWIW are presented in Figure 3.17.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Pb levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from the limit of detection (LoD) to ~ 0.5 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, lead levels are on average below 0.05 mg/l.

In Canada, the highest average levels were reported by operators responsible for the management of extractive waste from base metals ore extraction (~ 0.005 mg/l) (MEND 2014).

Two sites, 21 and 25, reported higher levels of lead in the discharged EWIW, 0.16 mg/l and ~ 0.5 mg/l on average, respectively, despite implementing neutralisation/precipitation techniques and oxidation techniques. At both sites, the management of extractive waste includes extractive waste resulting from lead concentrates production.

Among operators which reported data on lead levels in EWIW, three additional sites (15, 48 and 51) reported managing extractive waste resulting from lead concentrates production.

No data were reported on initial water quality, but, at site 25, the operator reported a higher leaching rate of lead from the extractive waste (up to 3.5 mg/kg).

Based on the data provided by operators on the initial levels of lead in the EWIW prior to treatment and the information collected from literature, a lead removal efficiency varying from ~ 60 % to 99 % was calculated.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of lead in discharged EWIW can be in the range of < 0.01 mg/l to 0.05 mg/l when implementing metal removal techniques.
The reported lead removal efficiency was in the range of 60 % to 99 %.

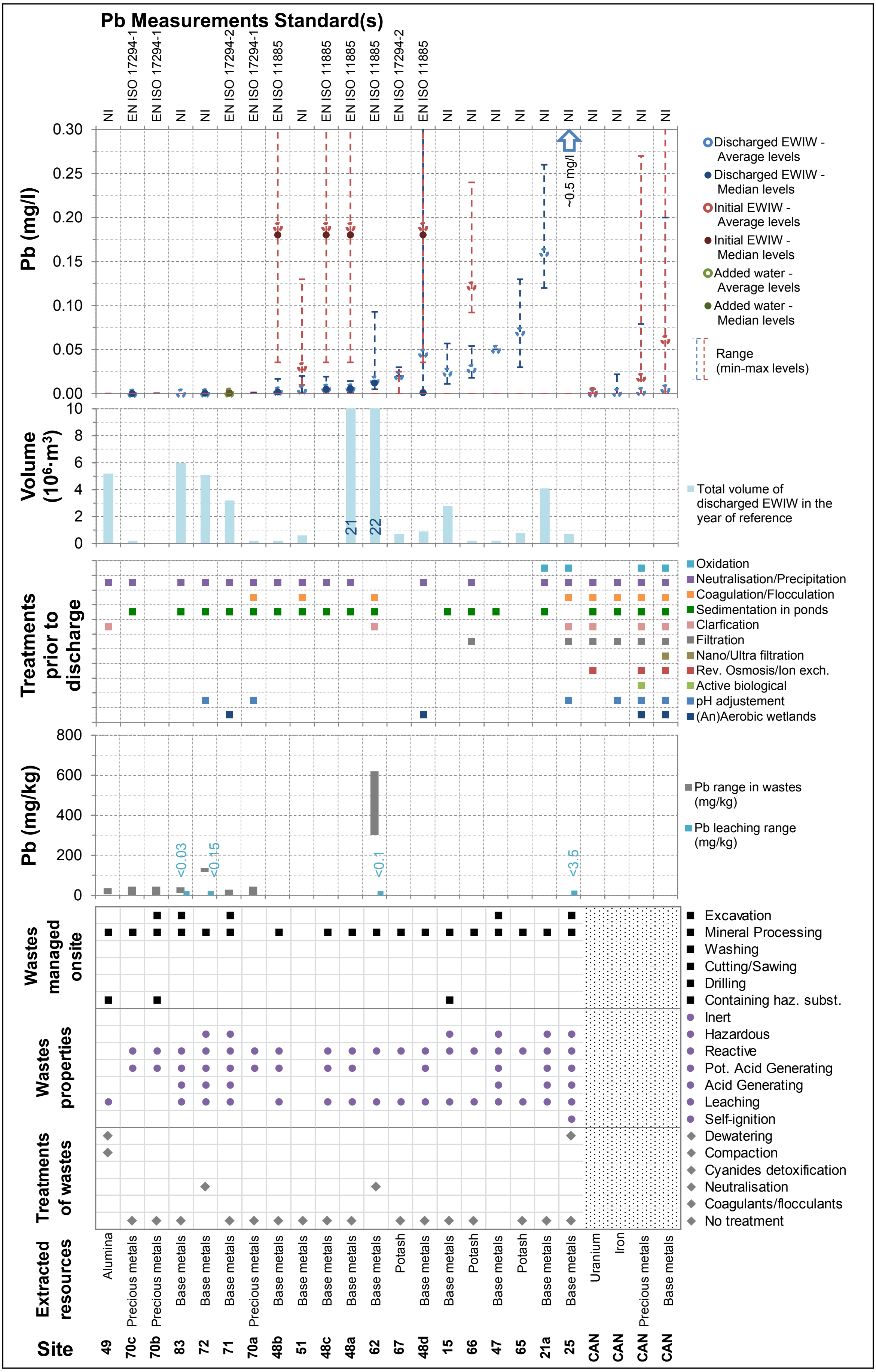


Figure 3.17: Annual lead levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.7 Manganese (Mn)

The reported levels of manganese in the discharged EWIW are presented in Figure 3.18.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Mn levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from 0.013 mg/l to 7.6 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, manganese levels are on average below 0.5 mg/l.

The site 86 reported higher levels of manganese in the discharged EWIW, 7.6 mg/l on average, despite implementing neutralisation/precipitation techniques. At that site, the initial levels of manganese prior to treatment were reported to be on average 12 mg/l. Based on these average levels, the calculated removal efficiency of manganese is ~ 40 %.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of manganese in discharged EWIW can be in the range of 0.1 mg/l to 2 mg/l when implementing metal removal techniques.
The only reported manganese removal efficiency was ~ 40 %.

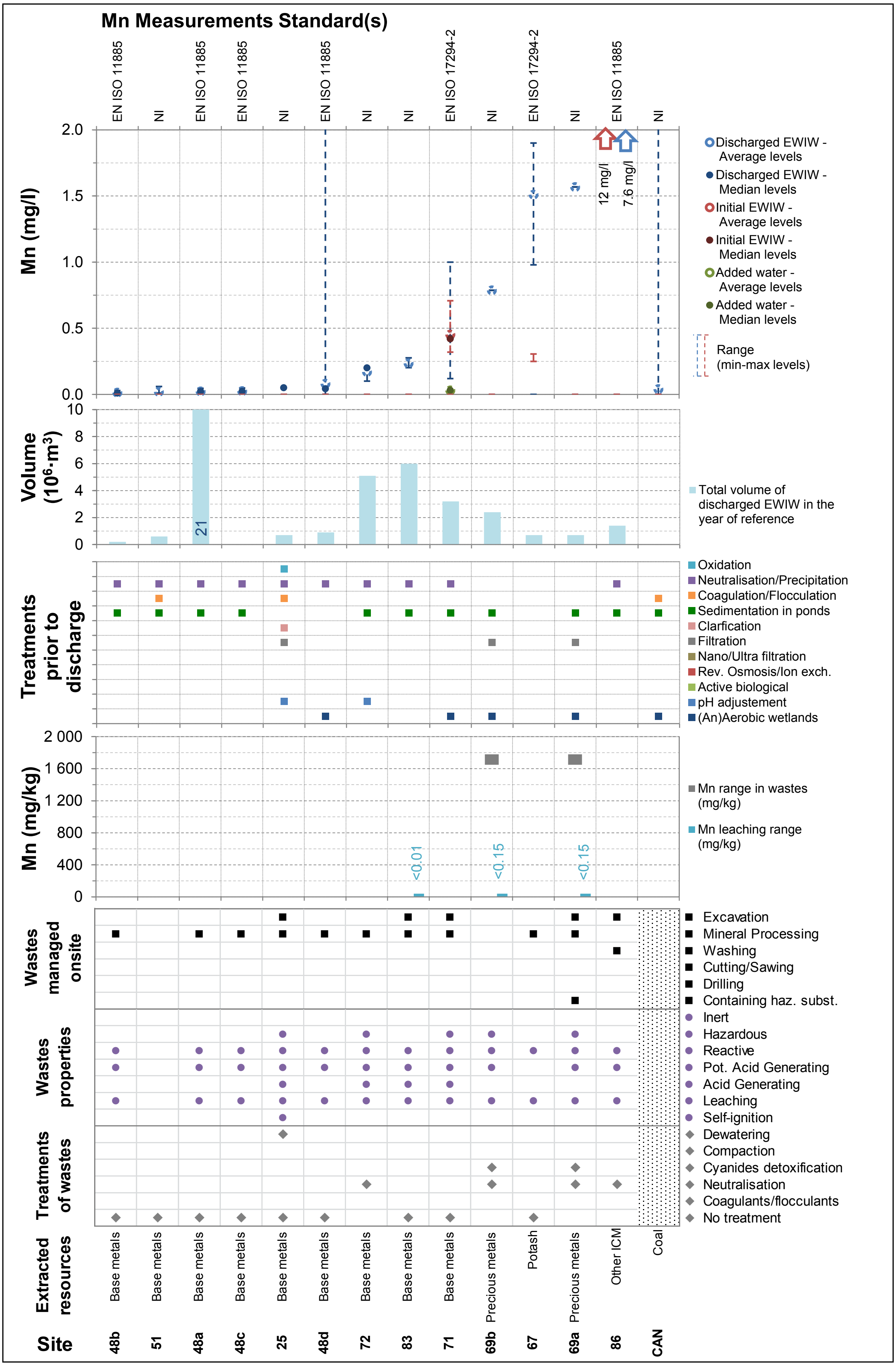


Figure 3.18: Annual manganese levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.8 Mercury (Hg)

The levels of mercury in the discharged EWIW are presented in Figure 3.19.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Hg levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.3 µg/l to 0.005 mg/l.

Two operators reported levels below the limit of detection (LoD), which was reported to be 0.01 mg/l for one and 0.005 mg/l for the other. Other operators reported a LoD below 0.0005 mg/l.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, mercury levels are on average below 0.002 mg/l.

The initial levels of mercury prior to treatment were not reported.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of mercury in discharged EWIW can range from 0.3 µg/l to 2 µg/l when implementing metal removal techniques.
No data were available to estimate the mercury removal efficiency.

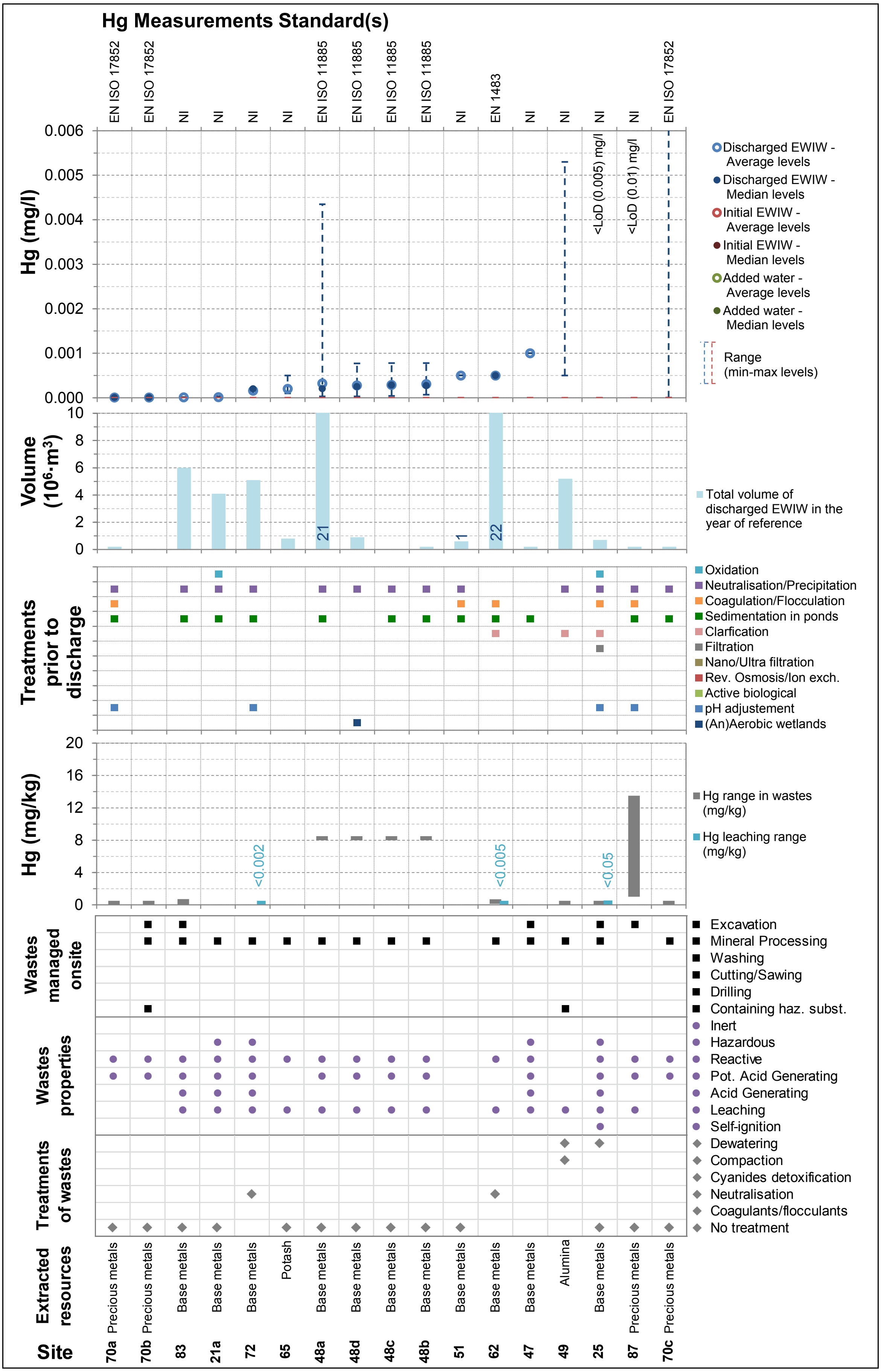


Figure 3.19: Annual mercury levels and contextual information reported by operators (site numbers indicated)

3.3.8.9 Nickel (Ni)

The reported levels of nickel in the discharged EWIW are presented in Figure 3.20.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Ni levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.001 mg/l (limit of detection) to ~ 0.25 mg/l.

In Canada, the highest average levels were reported by operators responsible for the management of extractive waste from base metals ore extraction (0.09 mg/l) whereas, for the others, the levels were on average below 0.04 mg/l (MEND 2014).

Based on the data collected from literature, an average nickel removal efficiency of 90 % to 98 % was calculated.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, nickel levels are on average below 0.1 mg/l.

Sites 62, 86 and 70 reported higher levels of nickel in EWIW (0.15-0.24 mg/l).

Sites 62 and 86 reported higher nickel leaching rates compared to other operators (0.15-0.24 mg/l for site 62 and 2-18 mg/kg for site 86), while site 70 did not provide data on leaching rates.

Based on the data provided on initial levels of nickel, removal efficiencies of ~ 50 % to ~ 80 % were calculated.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of nickel in discharged EWIW can be in the range of 0.01 mg/l to 0.1 mg/l when implementing metal removal techniques.
The reported nickel removal efficiency was in the range of 90 % to 98 % based on data from literature and 50 % to 80 % based on data from the questionnaires.

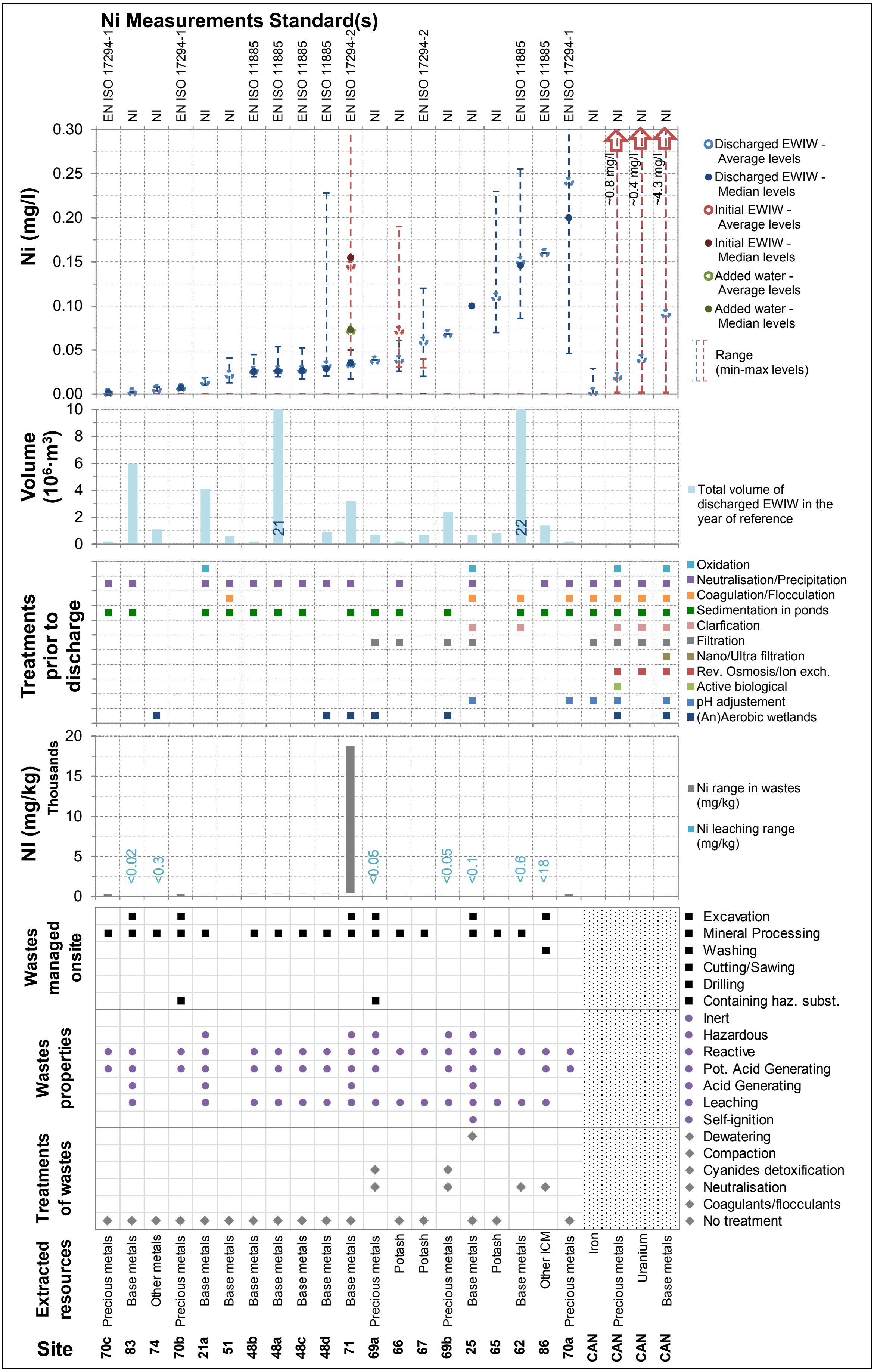


Figure 3.20: Annual nickel levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.10 Zinc (Zn)

The reported levels of zinc in the discharged EWIW are presented in Figure 3.21.

The reported levels in the discharged EWIW (average, median, minimum and maximum levels of the annual measurements) are presented for each site (identified by a number) and each continuous discharge point at a specific site (identified by a, b, c and d). The standard used to measure the levels is indicated at the top. Batch discharges are reported as one total discharge. Total discharged volumes of EWIW are presented below these Zn levels along with EWIW treatment techniques implemented prior to discharge. Data on the content ranges in the extractive waste (minimum and maximum levels) and the leaching rates (based on the leaching test) are also presented when reported. Finally, additional contextual information (as reported by operators) is also presented: information on the type of extractive wastes managed at each specific site along with the properties of these wastes, the reported treatment of wastes prior to deposition and the extractive industry these wastes originate from.

The reported median and average levels range from < 0.005 mg/l to 1.2 mg/l.

In Canada, the highest average levels were reported by operators responsible for the management of extractive waste from base metals ore extraction (0.06 mg/l) whereas, for the others, the levels were on average below 0.02 mg/l (MEND 2014).

Based on the data collected from literature, an average zinc removal efficiency of > 99 % was calculated for the base and precious metals sectors.

At most of the sites where neutralisation/precipitation techniques are implemented to reduce the content of metals, nickel levels are on average below 0.5 mg/l.

Two sites reported higher levels: site 21 despite implementing an oxidation (Fenton) process and neutralisation/precipitation to remove metals, and site 65 which did not report implementing oxidation or neutralisation/precipitation.

Neither of these two sites provided data on the initial quality of EWIW prior to treatment.

One site, 87, reported extremely high levels of zinc in the EWIW prior to chemical precipitation treatment. After treatment, the reported average level was 0.43 mg/l, indicating a removal efficiency of > 99 %.

Other sites, such as 51, 48 and 66, reported Zn levels in initial and discharged EWIW. The calculated removal efficiencies were ~ 50 %, 80-90 % and ~ 80 %, respectively.

KEY OBSERVATIONS BASED ON THE DATA:
During the operational phase, average levels of zinc in discharged EWIW can range from < 0.005 mg/l to 0.5 mg/l when implementing metal removal techniques.
The reported zinc removal efficiency was in general in the range of 80 % to > 99 %.

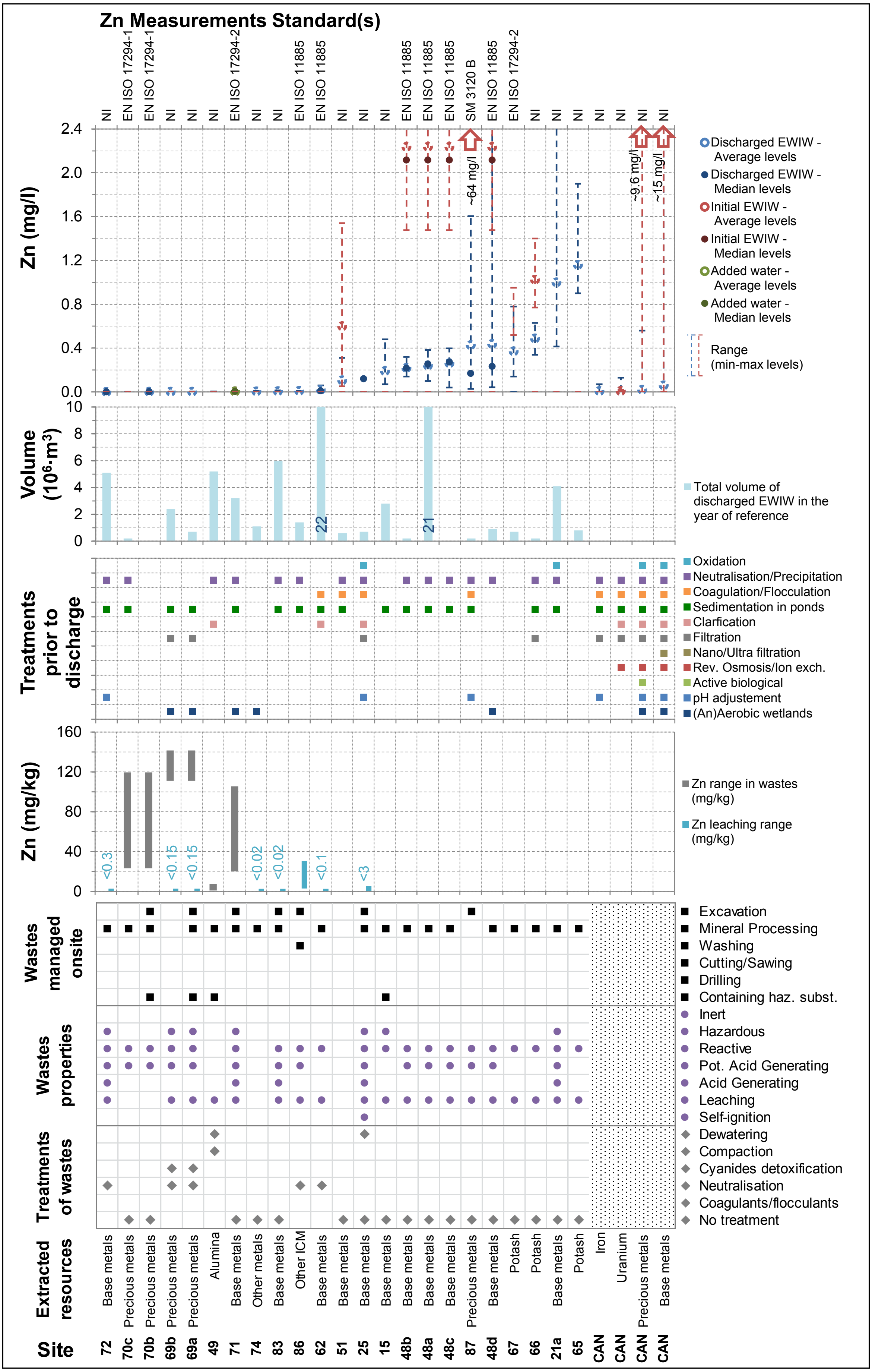


Figure 3.21: Annual zinc levels and contextual information reported by operators (site numbers indicated) and supplemented with literature data related to sites in Canada

3.3.8.11 Other metals and metalloids

The levels of some metals and metalloids in EWIW, such as antimony (Sb), barium (Ba), molybdenum (Mo), selenium (Se), thorium (Th), uranium (U) or vanadium (V), were reported by less than five operators. Therefore, these levels are not presented in graphs.

Antimony was reported by operators responsible for the management of extractive waste resulting from base metals and precious metals extraction. Reported yearly average levels were below 0.4 mg/l. At sites where neutralisation/precipitation is used, which also correspond to sites where extractive waste resulting from base metals extraction is managed, levels were below 0.2 mg/l.

Barium was reported by operators responsible for the management of extractive waste resulting from base metals extraction. Reported yearly average levels were below 0.3 mg/l. At all the sites, neutralisation/precipitation was used to treat EWIW.

Molybdenum was reported by operators responsible for the management of extractive waste resulting from base metals, uranium and potash extraction. Reported yearly average levels were below 0.5 mg/l.

Selenium was reported by operators responsible for the management of extractive waste resulting from base metals extraction. The reported levels were below 0.01 mg/l, including maximum levels. Based on literature data related to sites in Canada (MEND 2014), yearly average levels of selenium at sites responsible for the management of extractive waste resulting from extraction of iron, base metals, precious metals and uranium were below 0.006 mg/l.

Selenium levels in EWIW above 0.07 mg/l as a yearly average were reported by operators responsible for the management of extractive waste resulting from coal extraction. However, based on the information available, only 1 site reported an EWIW treatment aimed at removing selenium out of the 11 sites reporting EWIW treatment processes. Based on literature data, the calculated removal efficiencies varied from ~ 60 % to 99 % based on average inflow and outflow levels (MEND 2014). Selenium can usually be removed using one or a combination of techniques which may include biological active or passive treatment, adsorption, iron co-precipitation, oxidation/reduction or reverse osmosis (NAMC 2010).

No operator reported the monitoring of thorium in EWIW, whereas uranium levels in EWIW were reported by one operator. The reported levels were below 0.1 mg/l as a yearly average. The reported treatment of EWIW included microfiltration and ultrafiltration and reverse osmosis.

3.3.9 Other

3.3.9.1 Cyanides

Three operators reported data on cyanides (total cyanides) in discharged EWIW.

Based on the reported cyanide levels in the questionnaires and the information collected from literature (MEND 2014), cyanide levels in EWIW did not exceed 0.03 mg/l.

In Europe, cyanides are removed from the extractive waste prior to deposition using, in most cases, a detoxification process based on the oxidation of cyanides by a mixture of air and SO_2.

Other cyanide detoxification processes may be relevant, such as hydrogen peroxide oxidation, ozonation or oxidation by Caro's acid (peroxymonosulphuric acid).

KEY OBSERVATIONS BASED ON THE DATA:
Cyanides are partially removed from extractive waste prior to deposition (down to maximum levels of a few ppm).
Reported levels of cyanides in the EWIW are below 0.1 mg/l.

3.3.9.2 NORMs

Only one site provided data on NORM levels in EWIW. The operator reported levels of ^{226}Ra in EWIW. The reported levels were on average 0.06 mg/l with an initial average level prior to treatment of 0.19 mg/l. At that site, the water treatment includes the use of membrane technologies.

Collected data from literature (MEND 2014) show that, in Canada, operators discharge EWIW with an average level < 0.025 mg/l even when initial levels prior to treatment are as high as 2.6 mg/l.

Radium is usually removed by co-precipitation with metal sulphate or metal chloride salts such as barium chlorides, barium sulphates or strontium sulphates.

No data were reported on the level of NORMs in EWIW resulting from the management of extractive wastes from oil and gas extraction.

KEY OBSERVATIONS BASED ON THE DATA:
Co-precipitation is usually implemented to remove ^{226}Ra from the EWIW.
Literature data indicate that average levels of ^{226}Ra below 0.025 mg/l can be achieved.

3.4 Emissions to air

Emissions to air resulting from the management of extractive waste are mainly diffuse emissions of particles or fugitive emissions of gas or VOCs present in the extractive waste or EWIW and depending on the type of wastes managed on site.

A total of 16 operators reported results of ambient air quality monitoring in the vicinity of the site.

In some cases, the monitoring is carried out at the closest villages.

Mainly particulate matter (PM), particulate matter smaller than 10 microns (PM_{10}), particulate matter smaller than 2.5 microns ($PM_{2.5}$) and dust deposition are monitored.

In some cases, the chemical composition of the dust is monitored.

Most of the operators pointed out that the reported ambient air quality is affected by both the extractive activities (excavation and mineral processing) carried out on site and the extractive waste management.

The exact relative share of extractive activities and extractive waste management in the reported levels cannot be precisely evaluated.

In general, in order to prevent or reduce dusting, the following techniques have been reported to be implemented:

- spraying of extractive waste and roads used to transport the extractive waste with water or other emulsions;
- capping of extractive waste with temporary or permanent covers;
- covering of trucks or other machinery such as conveyors used for the transport of extractive waste;
- use of pipelines to transport extractive waste resulting from the mineral processing;
- use of wind barriers or fences;
- implementation of speed limits for trucks;
- implementation of wind speed restrictions for the handling of waste (no extractive waste handling in the case of strong winds);
- landscaping.

The reported average levels of PM ranged from ~ 20 $\mu g/m^3$ to ~ 1 000 $\mu g/m^3$.
The reported average levels of PM_{10} ranged from ~ 7 $\mu g/m^3$ to ~ 30 $\mu g/m^3$.
The reported average levels of dust deposition ranged from 0.3 $mg/m^2/day$ to 300 $mg/m^2/day$.

Operators responsible for the management of drilling muds and other oil and gas drilling and extractive wastes did not report any levels of gas, VOCs, Polycyclic Aromatic Hydrocarbons (PAHs) or other substances.

Nevertheless, reduced gas completion was reported as a possible technique to reduce emissions to air resulting from the completion of wells.

KEY OBSERVATIONS BASED ON THE DATA:
Emissions to air are mainly diffuse emissions from the extractive waste management area, i.e. dusting or particle emissions.
At most sites, particles are emitted from both the activities related to the extractive process, including mineral processing, and from the management of extractive waste.
Precise quantification of emission levels originating from the management of extractive waste was not possible.

3.5 Consumption levels

3.5.1 Energy

Figure 3.22 summarises the data collected on energy consumption levels for the management of extractive waste as reported by operators. These data are presented to provide the reader with examples of energy consumption levels. Comparing different consumption levels can be very difficult, as energy consumption varies greatly from site to site, depending on the type of extractive waste management method, the level of dewatering (e.g. slurry or dry), the transport method (e.g. trucks or pipelines with pumps), the working distances (e.g. up to several tens of kilometres) and other site-specific parameters such as the topography.

Most of the operators reported a total energy consumption per tonne of managed extractive waste below 10 kWh and at most sites the reported energy consumption levels were in the range of 1 $kWh/t_{extractive\ waste}$ to 4 $kWh/t_{extractive\ waste}$.
Two operators reported higher energy consumption levels. One operator reported the management of smaller amounts of extractive waste but nonetheless substantial overall energy consumption, while the other operator reported energy-intensive EWIW treatment.

No specific techniques were reported to reduce the energy consumption for the management of extractive waste apart from optimising the movements of trucks and transport distances, which is usually implemented by operators to reduce costs.

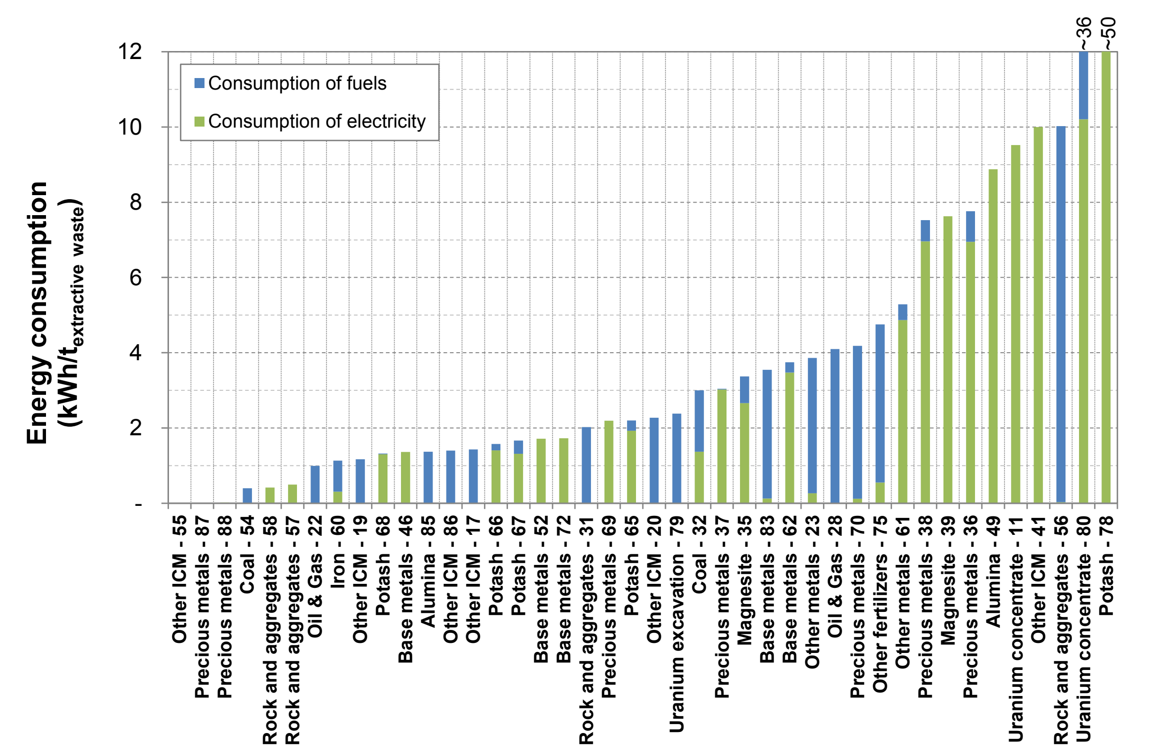


Figure 3.22: Reported site-specific energy consumption levels for the management of extractive waste

KEY OBSERVATIONS BASED ON THE DATA:
Energy consumption levels vary greatly from site to site.
At most sites, energy consumption is less than 10 $kWh/t_{extractive\ waste}$.

3.5.2 Water

Figure 3.23 summarises the data collected on water usage levels for the management of extractive waste as reported by operators. As for energy consumption levels, these data are presented to provide the reader with some examples of water usage levels. Comparing different levels can be very difficult, as water usage varies greatly from site to site, depending on the type of extractive waste management method, the transport method, the water content in the extractive waste resulting from the mineral processing and obviously on the climate, e.g. arid or wet.

Most of the operators did not report using water for the management of extractive waste although they reported the transport of extractive waste resulting from mineral processing mixed with water to the extractive waste deposition area.

Two operators reported significantly higher water usage than the other operators using water. They reported using 16 $m^3_{water}/t_{extractive\ waste}$ and 33 $m^3_{water}/t_{extractive\ waste}$, respectively. These sites are close to the sea and, therefore, significant volumes of seawater are used to wash the extractive waste in order to remove some impurities (e.g. caustic soda) from the extractive waste or to dissolve it (e.g. salt residues from potash extraction).

Some operators reported the usage of water to prevent the generation of extractive waste. No further details were provided.

In the management of extractive waste, water is mainly used to transport the fine extractive waste in pipelines and to prevent dusting.

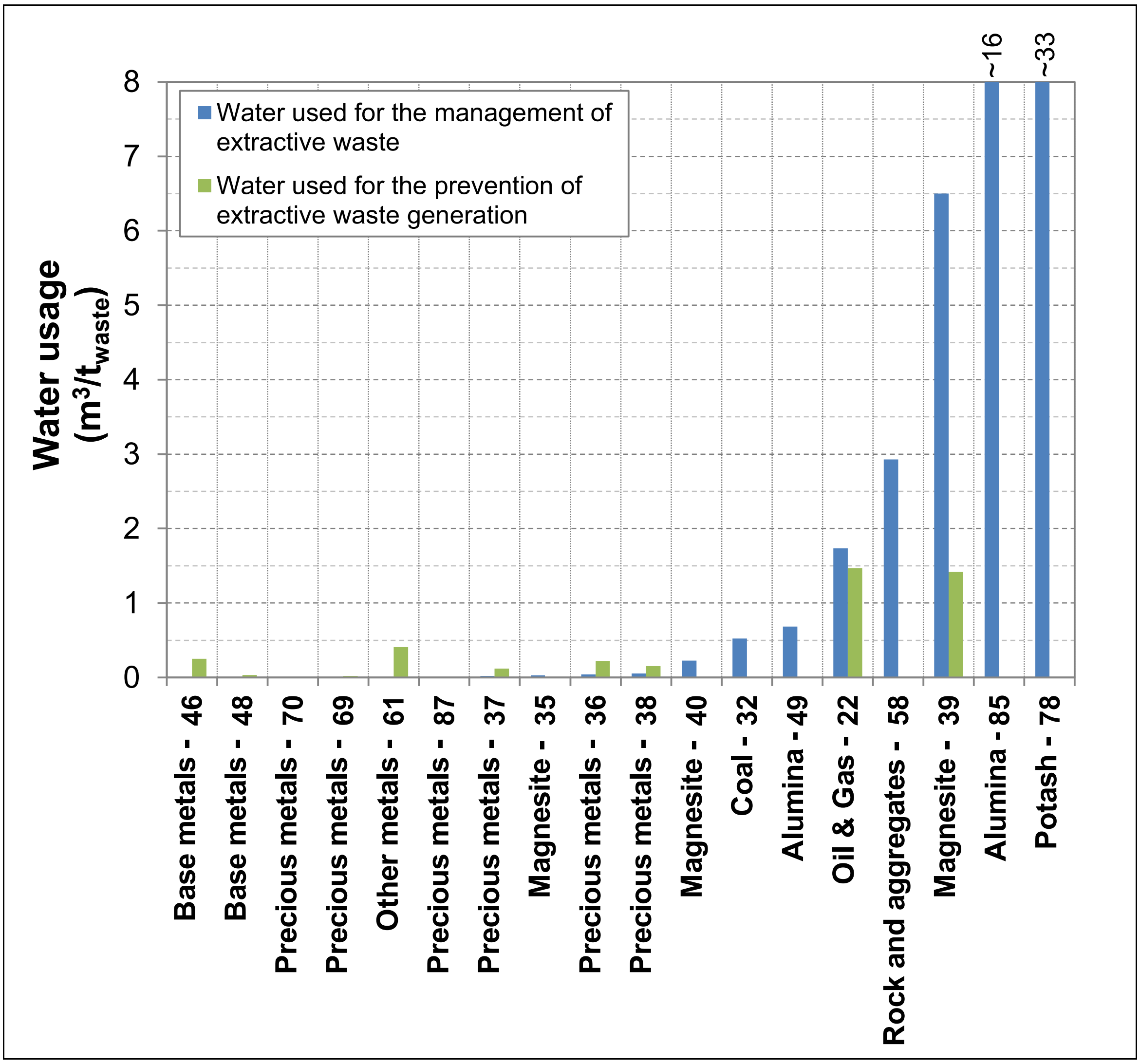


Figure 3.23: Examples of site-specific water usage levels for the management of extractive waste

In order to reduce the overall consumption of water and new water intakes, water is usually recycled or re-used internally.

Some operators reported reclaiming from 30 % up to 100 % of the water collected from the extractive waste facilities, with the excess being discharged.
A total of 80 % of the operators reported recycling more than 60 % of the reclaimed water.

Recycling of reclaimed water is of course dependent on climatic conditions and technical possibilities to recycle or re-use the water. Furthermore, water might be discharged without recycling for safety reasons. When recycled, the water is generally returned to the points in the process that require water, such as the flotation circuit. It might also be used for the spraying of extractive waste management areas and roads.

The reclaimed water can constitute 20 % to 100 % of the water used to transport the extractive waste to the extractive waste facilities. Actually, at 90 % of the sites, the share of reclaimed water in the transport water was > 60 %.

KEY OBSERVATIONS BASED ON THE DATA:
Water usage and water re-use or recycling rates vary greatly from site to site.

3.5.3 Reagents and auxiliary materials

Consumption levels of reagents and auxiliary materials cover a broad range of reagents and materials used in the management of extractive waste.

Consumption levels of different reagents and materials depend not only on site-specific conditions (e.g. acidity loads to be treated, temperature) but also on the grade and type of reagents and materials used (e.g. the effective neutralisation value of alkali materials for ARD treatment depends on the type of material and the granulometry).

The most common reagents and auxiliary materials used for the management of extractive waste are:

- materials used for the containment of extractive waste, generally extractive residues but also including other auxiliary materials such as geotextiles and liners;
- reagents and auxiliary materials used for the stabilisation of extractive waste, which include materials used for preparing extractive waste to be placed back into excavation voids such as bentonite or Portland cement but also buffering materials used for the management of ARD or reagents used for cyanide detoxification.

The most common reagents and auxiliary materials used for the management of extractive wastes, including the treatment of EWIW, are:

- oxidation reagents;
- hydroxide precipitation reagents;
- sulphide precipitation reagents;
- co-precipitation reagents;
- coagulants;
- flocculants;
- pH adjusters.

3.6 Noise and odour disturbance

3.6.1 Noise levels

A comparison of noise levels across different sites is difficult as the measurement of noise levels is not always carried out at the fence of the site. In some cases, the reported levels have been measured at the closest village.

Furthermore, the levels reported in most cases do not reflect the noise levels brought about as a result of the management of extractive waste solely. On the contrary, at most sites, the reported levels encompass the noise caused by the extraction activities.

Nevertheless, the noise levels reported by operators are presented in Figure 3.24 as examples, along with noise prevention and reduction measures, and extractive waste transport means.

As shown, reported day levels vary from ~ 35dB to ~ 65dB whereas night levels vary from ~ 25dB to ~ 55dB. At most sites, the levels are below 55 dB.

The most reported noise abatement measure is the use of acoustic barriers. Some operators also reported suspending extractive waste management activities during the night. Equipment maintenance was reported as a further measure to limit noise disturbance. Finally, one operator reported the implementation of speed limits for trucks transporting extractive waste.

Pipeline transport of extractive wastes resulting from the mineral processing was also reported as a preventive measure by one operator. Other operators, although using pipeline transport of extractive waste, did not report this technique as a preventive measure for noise reduction. In most cases, the extractive waste is transported by truck.

The transport of extractive waste by truck, and truck loading and unloading, as well as the construction of the extractive waste facilities (e.g. dam raising), are usually the noisiest activities related to the management of extractive wastes.

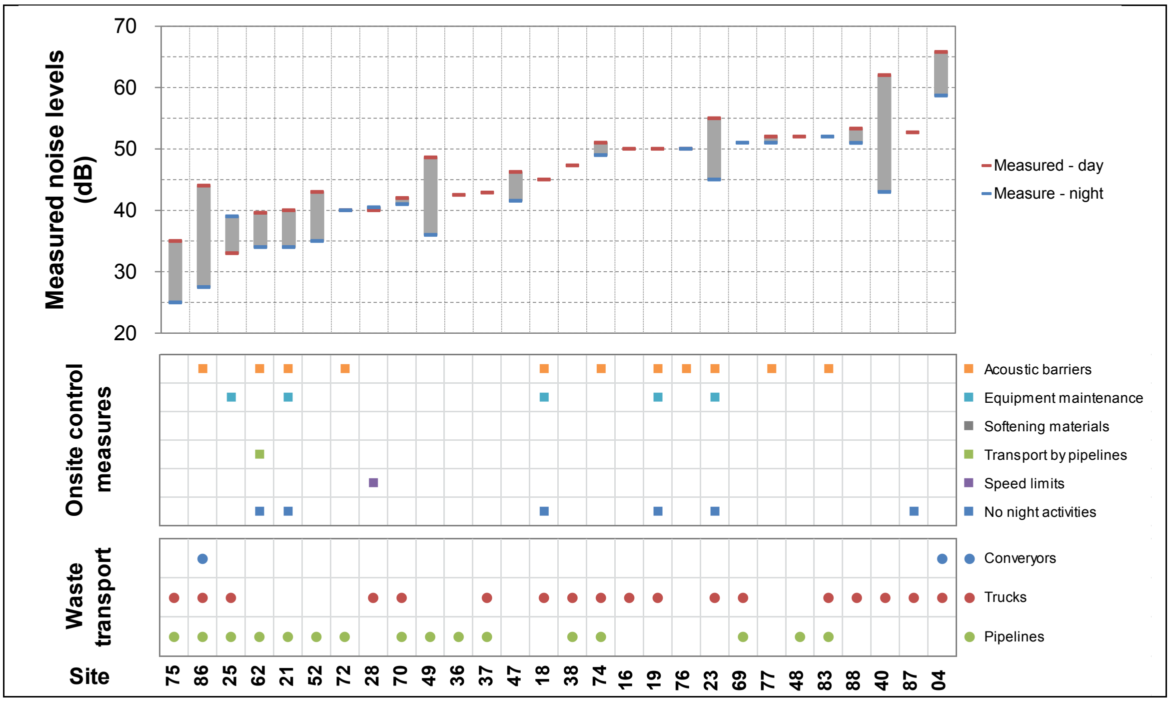


Figure 3.24: Indicative noise levels and contextual information reported by operators

3.6.2 Odours

No odour levels were provided by operators. However, the use of guidelines to handle sewage sludge (potential source of odours) and the use of odour suppression bacteria and odour-masking agents were reported by two operators as examples of measures to prevent or reduce odour disturbance.

4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

This chapter describes techniques (or combinations thereof), and associated monitoring, considered to have the potential for achieving a high level of environmental protection in the activities within the scope of this document. This chapter presents the BAT candidates for the management of waste from extractive industries, associated monitoring and developments in them, based on information collected from operators and literature in the framework of the exchange of information organised under Article 21(3) of Directive 2006/21/EC. The techniques described include both the technology used and the way in which the extractive waste management installations (including extractive waste deposition areas) are designed, built, maintained, operated and decommissioned.

It covers management systems and process-integrated techniques. Waste prevention and management, including waste minimisation and recycling processes, are also considered, as well as techniques that reduce the consumption of energy, water, reagents and auxiliary materials by optimising use and re-use. The techniques described cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site rehabilitation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions.

Since Directive 2006/21/EC defines BAT according to Article 2(11) of Directive 96/61/EC (repealed by Directive 2010/75/EU), the BAT have been described as far as possible in the standard structure presented in Table 4.1 in order to outline the information on each technique, to enable a comparison of techniques and to allow the assessment against the definition of BAT in the Directive.

This chapter does not provide an exhaustive list of techniques that could be applied in the extractive waste management sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual site.

Table 4.1: Standard 10-heading description structure

Heading within the sections	Type of information included
1. Description	A brief technical description of the technique with a view to being used in the BAT Conclusions.
2. Technical description	A more detailed and concise technical description (using chemical or other equations, pictures, diagrams and flow charts if necessary).
3. Achieved environmental benefits	The main potential environmental benefits to be gained through implementing the technique (including reduced emissions to water, air and land; reduced consumption of energy, water, reagents and auxiliary materials; as well as production yield increases, reduced waste, etc.).
4. Environmental performance and operational data	Actual and site-specific performance data (including emission levels, consumption levels - of energy, water, reagents and auxiliary materials - and amounts of residues/wastes generated) from well performing sites (with respect to the environment as a whole) applying the technique accompanied by the relevant contextual information. Any other useful information on the following items: how to design, operate, maintain, control and decommission the technique; emission monitoring issues related to the use of the technique; sensitivity and durability of the technique; issues regarding accident prevention. Links between inputs (e.g. nature and quantity of fuel, energy, water, reagents and auxiliary materials) and outputs (emissions, residues/wastes, products) are highlighted, in particular where relevant to enhancing an understanding of different environmental impacts and their interaction, for example where trade-offs have been made between different outputs such that certain environmental performance levels cannot be achieved at the same time. Emission and consumption data are qualified as far as possible with details of relevant operating conditions (e.g. percentage of full capacity, fuel composition, bypassing of the (abatement) technique, inclusion or exclusion of other than normal operating conditions, reference conditions), sampling and analytical methods, and statistical presentation (e.g. short

Heading within the sections	Type of information included
	and long-term averages, maxima, ranges and distributions). Information on conditions/circumstances hampering the use of the (abatement) technique at full capacity and/or necessitating full or partial bypassing of the (abatement) technique and measures taken to restore full (abatement) capacity.
5. Cross-media effects	Relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques, in order to assess the impact on the environment as a whole. Any side effects and disadvantages caused by the implementation of the technique. The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.
6. Technical considerations relevant to applicability	It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be: • an indication of the type of sites or processes within the sector to which the technique cannot be applied; • constraints to implementation in certain generic cases, considering, e.g.: o whether it concerns a new or an existing site, taking into account factors involved in retrofitting (e.g. space availability) and interactions with techniques already installed; o site size, capacity or load factor; o quantity, type or quality of product manufactured; o type of fuel or reagents and auxiliary materials used; o animal welfare; o climatic conditions. These restrictions are indicated together with the reasons for them. These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual site.
7. Economics	Information on the costs of techniques (capital/investment, operating and maintenance) and any possible savings (e.g. reduced consumption of energy, water, reagents and auxiliary materials, waste charges, reduced payback time compared to other techniques), revenues or other benefits including details on how these costs/savings or revenues have been calculated/estimated. Cost data are preferably given in euro (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected is indicated. The price/cost of the equipment or service is accompanied by the year it was purchased. Information on the market for the sector in order to put costs of techniques into context. Information relevant to both new and existing sites. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned and possible economic limitations to its applicability. Information on the cost-effectiveness of the technique (e.g. in EUR per mass of pollutant abated) and related assumptions for their calculation may be reported. The Reference Document on Economics and Cross-media Effects (ECM) and the Reference Document on the General Principles of Monitoring (MON) are taken into account with regard to economic aspects and monitoring costs, respectively.
8. Driving force for implementation	Where applicable, specific local conditions, requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives such as subsidies, tax breaks) which have driven or stimulated the implementation of the technique to date).
9. Example sites	Reference to (a) site(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in the EU or worldwide.
10. Reference literature	Literature or other reference material (e.g. books, reports, studies) that was used in writing the section and that contains more detailed information on the technique. When the reference material consists of a large number of pages, reference will be made to the relevant page(s) or section(s).

4.1 Generic BAT candidates

4.1.1 Corporate management

4.1.1.1 Organisational and Corporate Management System

Operators responsible for the management of extractive waste can improve the overall management efficiency by implementing systematic procedures at the management level.

Management systems implemented by operators may be standardised or not.

By adhering to management systems which are standardised and certified by a third party, operators provide additional credibility. Nonetheless, non-standardised systems may be equally effective when properly designed and implemented.

An Organisational and Corporate Management System (O&CMS) and tools relevant to the planning and design of the extractive waste management encompass the following elements:

- Risk Management;
- Extractive Waste Inventory Management Tools such as stream inventory or mass balances;
- Operational Management Tools such as QA/QC systems (see Section 4.2.1.2.1) or Management of Changes (see Section 4.2.1.2.2);
- Strategic Management Tools such as Benchmarking.

Further descriptions and information on the different techniques can be found in the CWW BREF (Brinkmann *et al.* 2016).

The technique is implemented in all the life cycle phases of the extractive waste management, where this may improve the overall O&CMS:

- *Planning and design phase*
  Operators responsible for the management of extractive waste adhere to the principles of an O&CMS before the planning and design phase of the extractive waste management.
- *Operational (construction, management and maintenance) phase*
  The O&CMS is reviewed and adapted based on the observed environmental performance findings over time.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

4.1.1.2 Environmental Management System

A complete description of the Environmental Management System (EMS) can be found in the CWW BREF (Brinkmann *et al.* 2016) and in the MTWR BREF (EC-JRC 2009).

An EMS, such as EMAS or ISO 14001 or other standardised or non-standardised equivalent systems, incorporates all the following features:

- commitment of the managers, including senior managers;
- development of an environmental policy that includes the continuous improvement for the extractive waste management by the operators;
- planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
- implementation of the procedures paying particular attention to:
  - structure and responsibility;

  - training, awareness and competence;
  - communication;
  - employee involvement;
  - documentation;
  - efficient process control;
  - maintenance programmes;
  - emergency preparedness and response;
  - safeguarding compliance with environmental legislation;
- checking performance and taking corrective action, paying particular attention to:
  - monitoring and measurement (see also the Reference Report on Monitoring ROM);
  - corrective and preventive action;
  - maintenance of records;
  - independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
- review of the EMS and its continuing suitability, adequacy and effectiveness by senior management;
- developing a clear protocol for major management activities taking into account BAT and practices: the operator can be informed about new BAT and practices by other operators in the sector, consultants, sectoral associations, as well as by consulting reference documents such as this and other BREF documents;
- consideration for the environmental impacts possibly occurring at the closure phase (the final decommissioning) as well as the after-closure phase, from the stage of designing a new extractive waste deposition area (including the EWF), and throughout its entire operating life;
- application of sectorial benchmarking of the environmental performance against the best performance achievable from the extractive waste management on a regular basis, if possible, in order to identify areas of excellence and areas where further improvement is needed. This can be achieved through systematic monitoring and reporting of the overall environmental performances. In this way, the EMS can more effectively focus on the areas with the lowest performances or the highest improvement potential;
- integration of the Risk Management Systems (RMS) and the EMS. This implies that a continuous exchange of information is ensured among the EMS, the Environmental Risk and Impact Evaluation (see Section 4.1.2.3) and all Organisational and Corporate Management tools (see Sections 4.1.1 and 4.2.1.2).

As an example, among the 87 sites that participated in the questionnaire exercise, an EMS is applied in 70 sites (51 sites are certified), a Health and Safety Management System is applied in 64 sites (42 sites are certified) and 7 sites do not have either an EMS or a Health and Safety Management System.

The level of detail and nature of the EMS (e.g. standardised or non-standardised) is adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions, to the size of the organisation and to the type of operation.

The technique is implemented in all the life cycle phases of the extractive waste management, where this may improve the overall EMS:

- *Planning and design phase*
  Operators responsible for the management of extractive waste adhere to the principles of an EMS relevant to the planning and design of the extractive waste management.
- *Operational (construction, management and maintenance) phase*
  The EMS is reviewed and adapted based on the observed environmental performance findings over time.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

4.1.2 Information and data management

4.1.2.1 Techniques to characterise extractive waste

4.1.2.1.1 Initial extractive waste characterisation

1. Description
This technique consists of investigating the behaviour and characteristics of representative samples of the extractive waste as a prerequisite to ensure that it is managed under environmentally safe conditions in the short and long term.

2. Technical description
According to Recital (2) of Commission Decision 2009/360/EC, *the purpose of the characterisation of extractive waste is to obtain the relevant information on the extractive waste to be managed in order to be able to assess and to monitor its properties, behaviour and characteristics and thereby ensure that it is managed under environmentally safe conditions in the long term. Furthermore, the characterisation of extractive waste should facilitate the determination of the options for managing such waste and the related mitigation measures*.

According to Article 5(3) of Directive 2006/21/EC, extractive waste characterisation shall be included in the EWMP. The technical requirements for extractive waste characterisation are elaborated in Annex II to Directive 2006/21/EC and completed in Commission Decision 2009/360/EC, according to which:

- (Article 1 of Commission Decision 2009/360/EC) extractive waste characterisation shall cover the following categories of information:
    - background information;
    - geological background of deposit to be exploited;
    - nature of the waste and its intended handling;
    - geotechnical behaviour of the waste;
    - geochemical characteristics and behaviour of the waste.
- (Article 2 and Recital 3 of Commission Decision 2009/360/EC) the necessary information and data for the characterisation of extractive waste should be collected on the basis of existing relevant and appropriate information or, if needed, by sampling and testing; this information is duly justified in the EWMP (Article 5 of Directive 2006/21/EC).

The criteria for defining inert extractive waste are laid down in Article 1(1) of Commission Decision 2009/359/EC. According to Article 1(2) of said Decision, *waste may be considered as inert waste without specific testing if it can be demonstrated, to the satisfaction of the competent authority, that the criteria set out in paragraph 1 have been adequately considered and are met on the strength of existing information or valid procedures or schemes. The Member States may draw up lists of waste materials to be regarded as inert.*

According to Recital 5 of Commission Decision 2009/360/EC, *from a technical point of view, it is appropriate to exempt* extractive *waste defined as inert in accordance with the criteria laid down in Commission Decision 2009/359/EC from part of the geochemical testing* (see also Article 1(3) of Commission Decision 2009/360/EC).

Non-inert waste includes both hazardous waste (as defined in Article 3(2) of Directive 2006/21/EC) and non-inert non-hazardous waste.

Following the implementation of Directive 2006/21/EC and the associated Commission Decisions, guidance documents and standard on aspects related to the characterisation of extractive waste have been developed by CEN/TC 292:

- CEN/TR 16376:2012. "Characterization of waste. Overall guidance document for characterisation of waste from the extractive industries".
- CEN/TR 16365:2012. "Characterization of waste. Sampling of waste from extractive industries".
- CEN/TR 16363:2012. "Characterization of waste. Kinetic testing for assessing acid generation potential of sulphidic waste from extractive industries".
- CEN/TS 16229:2011. "Characterization of waste. Sampling and analysis of weak acid dissociable cyanide discharged into tailings ponds".
- EN 15875:2011: "Characterization of waste. Static test for determination of acid potential and neutralisation potential of sulphidic waste".

The guidelines published in the Global Acid Rock Drainage (GARD) Guide (INAP 2014h), in particular in its Section 8.2, also provide a good reference.

Clause 2 of CEN/TR 16376 includes a description of the extractive waste characterisation process and of the choice of test method. A flow chart illustrating the characterisation process and an example of a testing sequence are shown, respectively, in Figure 4.1 and Figure 4.2.

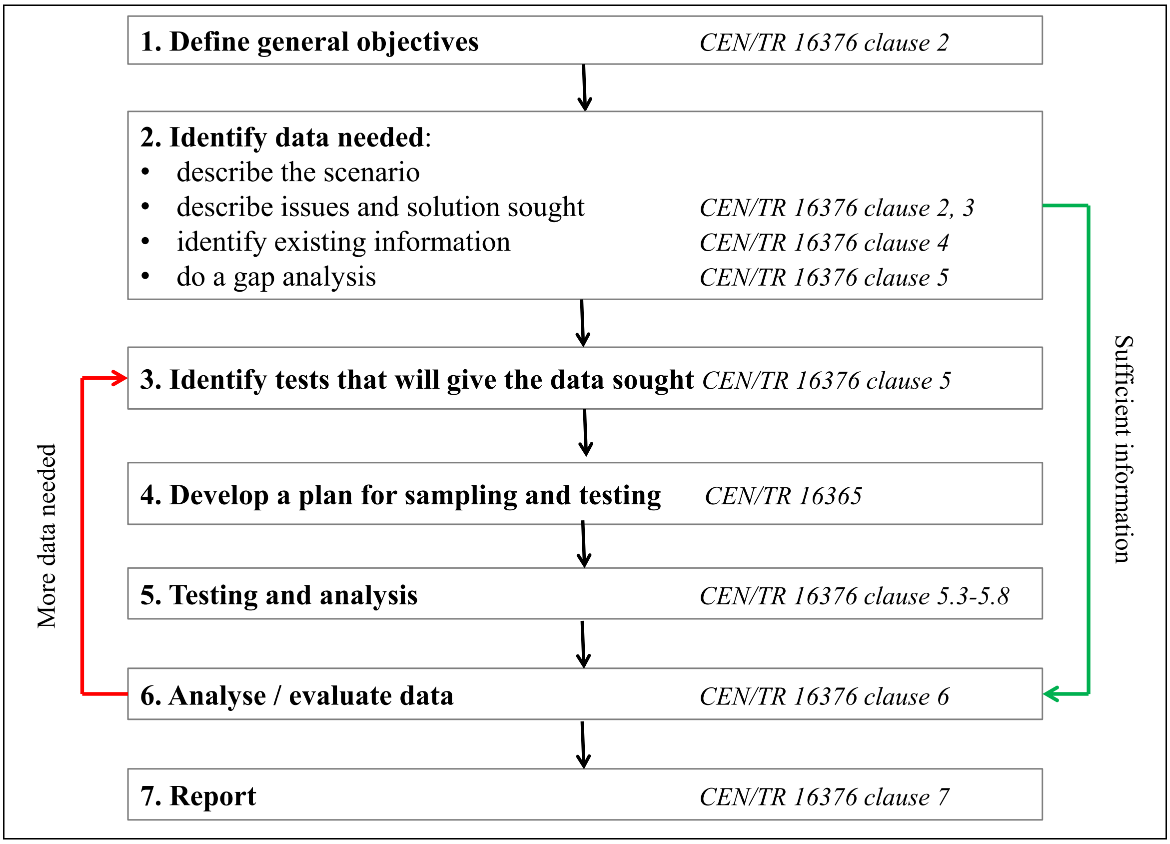


Figure 4.1: Flow chart of the characterisation process, with references to the clauses in CEN/TR 16376 (adapted from CEN/TR 16376)

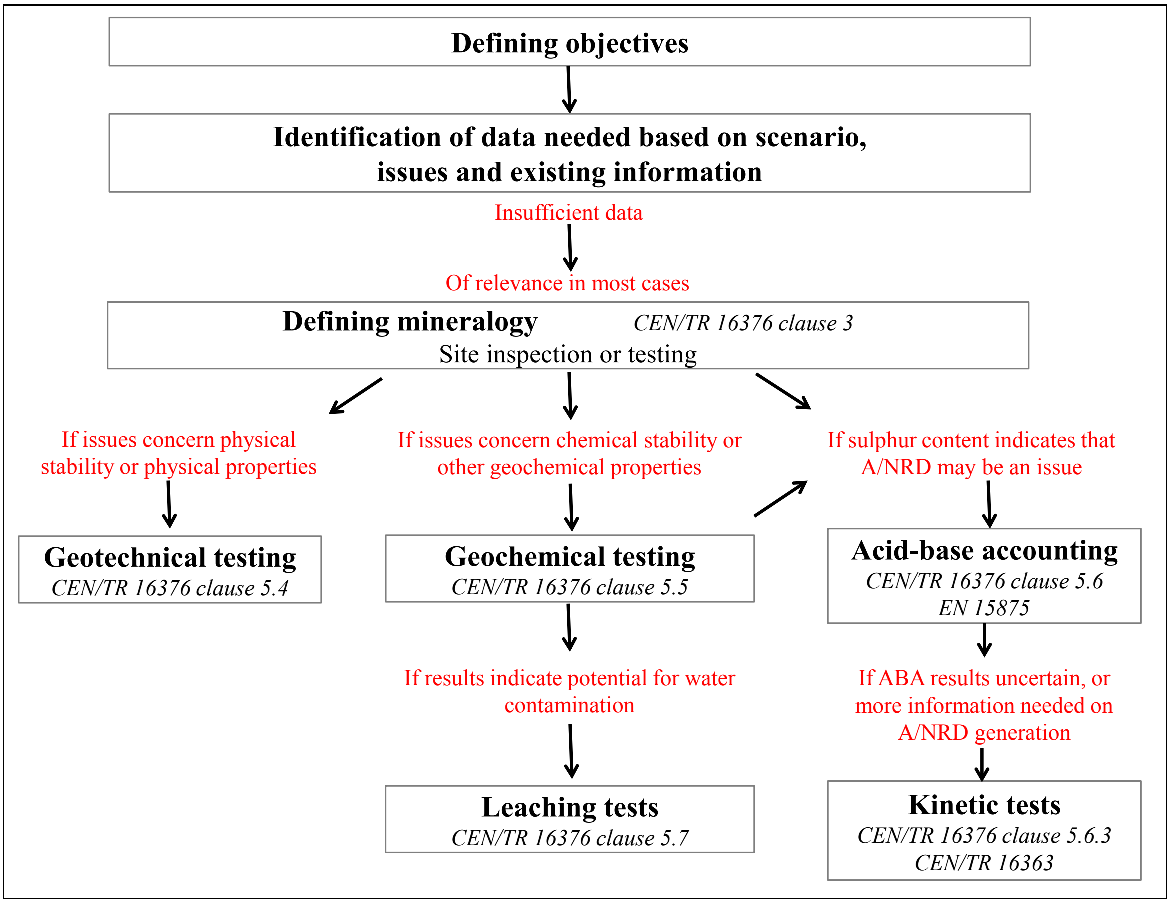


Figure 4.2: Example of a testing sequence in extractive waste characterisation, with references to the clauses within CEN/TR 16376 (adapted from CEN/TR 16376)

The interpretation of the characterisation results takes into account the various scaling effects between the laboratory and the field. It is common to use predictive modelling tools to model the behaviour of different management options.

The technique is implemented in the life cycle phase of the extractive waste management listed below:

- *Planning and design phase*
  Extractive waste characterisation is primarily performed in order to gather the initial information and data on extractive waste characteristics, in preparation for the permit application.

3. Achieved environmental benefits
- Supporting the identification of potential environmental risks and impacts associated with the extractive waste characteristics.
- Helping to address the potential environmental risks and impacts associated with the extractive waste characteristics by supporting their identification.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- None identified.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention.
- Safety requirements.
- Legal and environmental requirements according to Directive 2006/21/EC and related Commission Decisions, particularly Decision 2009/360/EC.
- Standards application (CEN/TR 16376 or equivalent).

9. Example sites

- Generally implemented in Europe.

10. Reference literature

(CEN 2011a, b, 2012a, b, c)
(Downing and Giroux 1998)
(EC-JRC 2009)
(INAP 2014h, i)
(Karlsson 2015; Karlsson and Kauppila 2015a; Karlsson and Punkkinen 2015)
(Kauppila *et al.* 2015; Kauppila and Punkkinen 2015)
(Niemeläinen *et al.* 2015c)
(Wahlström 2015)

4.1.2.1.2 Review and verification of extractive waste characteristics

1. Description

This technique consists of developing, implementing and adapting a plan for the review and verification of the extractive waste characteristics based on the initial extractive waste characterisation and the Environmental Risk and Impact Evaluation.

2. Technical description

This technique consists of developing, implementing and adapting a plan for the review and verification of the extractive waste characteristics based on the initial extractive waste characterisation (see Section 4.1.2.1.1) and the Environmental Risk and Impact Evaluation (see Section 4.1.2.3).

Parameters and frequencies for the review and verification of extractive waste characteristics are properly selected according to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions, as identified in the baseline studies and in the Environmental Risk and Impact Evaluation and reflected in the Extractive Waste Management Plan (EWMP), with reference to the Annexes to CEN/TR 16376.

The review and verification are planned in accordance with the guidance documents developed by CEN/TC 292 (see heading 2 of Section 4.1.2.1.1). The EN standards indicated in these guidance documents are generally used. If EN standards for certain parameters/methods are not available, ISO, national or other international standards, which are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards, are used.

For inert extractive waste, the provisions of Commission Decision 2009/359/EC apply.

The plan, including selected parameters and frequencies, is adapted based on the necessary design objectives (see Section 4.2.1.3.6 for example) and the Environmental Risk and Impact Evaluation (see Section 4.1.2.3). This may imply adding/removing parameters and/or increasing/decreasing frequencies.

The review and verification of the extractive waste characteristics help improve the calibration of the geotechnical models and the slope stability analyses.

The technique is implemented in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  A plan for the review and verification of the extractive waste characteristics, based on the initial extractive waste characterisation and the evaluation of environmental risks and impacts, is developed.
- *Operational (construction, management and maintenance) phase*
  The plan for the review and verification of the extractive waste characteristics is implemented and adapted based on the necessary design objectives and the Environmental Risk and Impact Evaluation.
- *Closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

3. Achieved environmental benefits

- Helping to address the potential environmental risks and impacts associated with the extractive waste characteristics by supporting their identification.

4. Environmental performance and operational data

Parameters and frequencies for the review and verification of the extractive waste composition (dry basis) and leaching characteristics, based on the information received from operators via the questionnaires, are reported in Table 4.2 and Table 4.3 respectively.

In addition, mineralogical, physical and mechanical characteristics (such as bulk density, water content, granulometry, compaction rate, and shear strength) are also monitored (see Section 4.2.1.3.6.3).

Table 4.2: Reported parameters and frequencies for the review and verification of extractive waste characteristics (based on information received from operators via the questionnaires)

Reported parameter*	Reported unit*	Number of sites*	Reported annual frequency range (min.-max., unless only one value reported)*	Reported EN/ISO standard*
pH	-	22	1-615	EN 15875 EN 16192 EN 1995 ISO 10523
TDS	mg/kg	2	1	EN 16192 EN 1995
Electrical conductivity	mS/cm	3	1-184	EN 16192 EN 1995
Density	-	1	24	NI**
TSS	mg/kg	2	1-24	NI**
Insoluble particles	mg/kg	2	12	NI**
COD	mg/kg	1	1	NI**
BOD_5	mg/kg	1	1	NI**
TOC	mg/kg	1	NI**	EN 13137
BTEX	mg/kg	1	NI**	NS only***
PAHs	mg/kg	1	NI**	EN 15527
Phenols	mg/kg	2	1	NS only***
THC	mg/kg	4	1	EN 13137
Anionic detergents	mg/kg	1	1	NI**
AP	$CaCO_3^-$g/kg	13	1-615	EN 15875
NP	$CaCO_3^-$g/kg	1	7-15	EN 15875
Net NP	$CaCO_3^-$g/kg	9	1-615	EN 15875
Net AG	$H_2SO_4^-$g/kg	4	1-43	NI**
NPR	-	2	4-15	EN 15875
Pyrite content	mg/kg	1	NI**	NI**
S^{2-}	mg/kg mg/l	7	1-615	NI**
SO_3^{2-}	mg/kg	2	1-12	NI**
SO_4^{2-}	mg/kg	16	1-615	EN 15875
Total S	mg/kg	16	1-615	EN 15875
C from carbonates	mg/kg	2	4-15	NI**
Al	mg/kg	2	2-13	NI**
As	mg/kg	23	1-615	EN 13657 EN ISO 11885
B	mg/kg	1	50	
Ba	mg/kg	3	1	EN 13657 EN ISO 11885
Cd	mg/kg	20	1-615	EN 13657 EN ISO 11885
Co	mg/kg	8	1-15	NI**
Cr (VI)	mg/kg	1	NI**	NI**
Cr total	mg/kg	17	1-615	EN 13657 EN ISO 11885
Cu	mg/kg	14	1-50	NI**
Fe total	mg/kg	11	1-600	EN 13657 EN ISO 11885
Hg	mg/kg	19	1-615	EN 13657 EN 1483 EN ISO 11885 ISO 1483-E12-4
Mg	mg/kg	8	1-43	NI**
Mn	mg/kg	4	1-4	NI**
Mo	mg/kg	5	1-13	NI**

Reported parameter*	Reported unit*	Number of sites*	Reported annual frequency range (min.-max., unless only one value reported)*	Reported EN/ISO standard*
Na	mg/kg	5	43	EN 13657 EN ISO 11885
Ni	mg/kg	13	1-50	NI**
Pb	mg/kg	24	1-615	EN 13657 EN ISO 11885
Sb	mg/kg	14	2-615	EN 13657 EN ISO 11885
Se	mg/kg	1	NI**	NI**
Sn	mg/kg	2	1-1	NI**
Ti	mg/kg	1	1-3	NI**
U	mg/kg	1	2-13	NI**
V	mg/kg	5	1-50	NI**
Zn	mg/kg	13	1-50	NI**
NO_3^-	mg/kg	2	1	NS only***
Total Kjeldahl N	mg/kg	1	1	NI**
P	mg/kg	2	365	NI**
Total P	mg/kg	2	1	EN 13657 EN ISO 11885
Free CN^-	mg/kg	2	1	NI**
WAD CN^-	mg/kg	1	NI**	NI**
Total CN^-	mg/kg	2	52	NI**
Br^-	mg/kg	1	NI**	NS only***
Cl^-	mg/kg	7	1-43	NS only***
F^-	mg/kg	3	1	NS only***
^{210}Pb	Bq/kg	1	NI**	NI**
^{226}Ra	Bq/kg	2	1	NI**
^{228}Ra	Bq/kg	1	NI**	NI**
^{232}Th	Bq/kg	1	NI**	NI**
^{238}U	Bq/kg	1	NI**	NI**
Equitox (five week)	Eq/m^3	1	NI**	NI**

* Parameters, information and data reported by operators via the questionnaires (in total 87 questionnaires).
** NI stands for No Information, meaning that operators did not provide information.
*** NS stands for National Standard, meaning that operator provided a reference to national standard(s).

Table 4.3: Reported parameters and frequencies for the review and verification of extractive waste leaching properties (based on information received from operators via the questionnaires)

Reported parameter*	Reported unit*	Number of sites	Reported annual frequency range (min.-max., unless only one value reported)*	Liquid/ Solid ratio (L/S)*	Reported EN/ISO standard*
pH	-	22	1-1274	1, 2, 10	EN 12457 EN 12457-3 EN 12457-4 EN ISO 10523
Electrical conductivity	mS/cm	3	12	NI**	NI**
TDS	mg/kg	5	1-5	10	EN 12457-4 EN 15216 EN ISO 11885
Density	-	3	12	NI**	NI**
COD	mg/kg	4	1-10	10	EN 1484
TOC	mg/kg	3	1	10	EN 13137
BTEX	mg/kg	2	1	10	NI**
Phenol index	mg/kg	2	NI**	10	ISO 6439 EN 12457-4
Phenols	mg/kg	2	1-5	NI**	NI**
SO_4^{2-}	mg/kg mg/l	18	1-1274	1, 2, 10	EN 12457-2 EN 12457-3 ISO 9280
Alkalinity	$CaCO_3^-$g/kg	2	1-3	NI**	NI**
Ag	mg/kg	2	1	10	EN 12457-3
Al	mg/kg	3	1	10	EN 12457-3
As	mg/kg mg/l	21	1-1274	1, 2, 10	EN 12457-3
Ba	mg/kg	5	1-10	10	EN 12457-3
Cd	mg/kg mg/l	21	1-1274	1, 2, 10	EN 12457-3
Co	mg/kg mg/l	3	1	1	
Cr (VI)	mg/kg mg/l	5	676	NI**	
Cr total	mg/kg mg/l	22	1-806	1, 2, 10	EN 12457-2 EN 12457-3
Cu	mg/kg mg/l	22	1-1274	1, 2, 10	EN 12457-2 EN 12457-3
Fe total	mg/kg mg/l	4	1	1, 10	EN 12457-3
Hg	mg/kg mg/l	20	1-806	1, 10	EN 1483 EN 12457-3
Li	mg/kg	2	1	10	EN 12457-3
Mg	mg/kg mg/l	3	1	1, 10	EN 12457-3
Mn	mg/kg mg/l	7	1-1274	2, 10	EN 12457-3
Mo	mg/kg	4	1-10	10	EN 12457-4 EN ISO 11885
Na	mg/kg mg/l	3	1	1, 10	EN 12457-3
Ni	mg/kg mg/l	21	1-1274	1, 2, 10	EN 12457-2 EN 12457-3 EN 12457-4 EN ISO 11885 EN ISO 17294-2

Reported parameter*	Reported unit*	Number of sites	Reported annual frequency range (min.-max., unless only one value reported)*	Liquid/ Solid ratio (L/S)*	Reported EN/ISO standard*
Pb	mg/kg mg/l	21	1-1274	1, 2, 10	EN 12457-2 EN 12457-3 EN 12457-4 EN ISO 11885
Sb	mg/kg mg/l	17	1-676	2, 10	EN 12457-3 EN 12457-4 EN ISO 11885 EN ISO 15586 EN ISO 17294-2
Se	mg/kg	5	1-10	10	EN 12457-3 EN 12457-4 EN ISO 11885
Ti	mg/kg	2	1	NI**	NI**
Tl	mg/kg mg/l	5	12	NI**	NI**
V	mg/kg mg/l	10	1-12	1, 10	EN 12457-3
Zn	mg/kg mg/l	22	1-1274	1, 2, 10	EN 12457-2 EN 12457-3 EN 12457-4 EN ISO 11885 EN ISO 17294-2
NO_3^-	mg/kg	2	NI**	NI**	NI**
NH_4^+	mg/kg	2	NI**	NI**	NI**
Cl^-	mg/kg mg/l	14	1-12	1, 2, 10	EN 12457-2 EN 12457-3 EN 12457-4 EN ISO 11885 ISO 9297
F^-	mg/kg mg/l	11	1-12	10	EN 12457-3 EN 12457-4 EN ISO 11885 ISO 10359-1

* Parameters, information and data reported by operators via the questionnaires (in total 87 questionnaires).
** NI stands for No Information, meaning that operators did not provide information.

The sample rate reflects the quantity, type and variability of extractive waste generated at any given time. If the sample medium is homogeneous or relatively homogeneous, sampling at regular time intervals is adequate. If there are large variations in the lithology, alteration, or mineralisation of the extractive waste, it is advisable to sample based on production schedules (tonnage/time).

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- The technique is generally applicable.

7. Economics

- No information provided.

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements.

- Surveillance and early warning.

9. Example sites

- About half of the sites participating in the questionnaire exercise reported carrying out review and verification of extractive waste characteristics.

10. Reference literature

(EC-JRC 2009)
(INAP 2014h)

4.1.2.2 Extractive waste site and management options

4.1.2.2.1 Identification of extractive waste site options

1. Description

This technique consists of identifying distinct site options based on a preliminary characterisation of the sites and the extractive waste, considering the whole life cycle of the extractive waste management and using the information from all relevant expert studies covering safety aspects, geotechnical aspects, environmental aspects, local conditions and preliminarily identified potential impacts.

2. Technical description

This technique consists of identifying distinct site options and preparing a documented rationale for their selection, taking into consideration not only the operational phase but also the closure and the after-closure phases. According to the MTWR BREF (EC-JRC 2009), this method of identifying extractive waste site options implies the application of a life cycle management approach (see Section 4.2.1.1).

Alternative site options are evaluated, particularly for the EIA, with the aim of protecting public safety and minimising environmental impacts. For example, the main alternatives for the deposition of extractive waste from mineral processing, such as a sedimentation pond, dry deposition and deposition under free water cover, are usually compared (ELAW 2010).

After a preliminary evaluation of distinct site options for the location of the extractive waste management area (including the EWF), operators usually perform a detailed investigation and evaluation of the site options considered. Environmental surroundings and conditions are considered for a proper identification.

The prescreening of distinct site options may include an analysis of the following baseline criteria/parameters:

- potential impact on the human and social environment (human proximity, historical sites or recreation areas);
- stability criteria (topography, faults, drainage area, foundation conditions, seismicity);
- permeability of the sites (bedrock fracture zones and the hydraulic conductivity of both soil and bedrock are studied by geophysical and hydraulic conductivity studies);
- weather exposure (wind and water erosion, possible floods);
- seepage issues (groundwater and proximity to potable aquifers);
- ecosystems (biodiversity) and natural habitats;
- operational criteria (capacity, access);
- economic criteria (costs).

Therefore, several expert baseline studies are developed, depending on the environmental and regional conditions within the planning (EIA) and permit procedures of a new (and/or planned expansion) or existing extractive waste site (including the EWF). These studies may address the following aspects (but are not limited to them):

- topography and digital terrain model;
- geology;
- climate and the effects of climate change;
- hydrogeology;
- preliminary information on the selected methods of construction of ponds, dams and heaps, including the basal structure concept design, and on the extractive waste deposition techniques;
- structural safety/integrity of heaps, ponds and dams/embankments;
- preliminary geotechnical analysis;
- water protection (groundwater and surface water, water quality and supply);
- soil protection;
- flora/fauna.

The technique is implemented in the planning and design phase of the extractive waste management:

- *Planning and design phase*
  The identification of extractive waste site options is carried out.

3. Achieved environmental benefits

- Supporting the identification of potential environmental risks and impacts associated with the extractive waste site and management options, including the risk of failure.

4. Environmental performance and operational data

No data on environmental performance related to the process of identifying extractive waste site options were provided by operators via the questionnaires.

As shown by historical data analysis, large dam failure frequency dropped significantly in the last 30-40 years and is now 10^{-4}/dam/year (Ferrante *et al.* 2012). It should be noted that for dams retaining extractive waste this frequency might be higher (see Section 4.2.1.3.3.1.1.1).

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- The level of detail and nature of the identification of extractive waste site options are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.

7. Economics

The costs of an EIA and expert baseline studies vary depending on project and site size.

- The cost of an EIA study can range from less than EUR 10 000 to more than EUR 200 000 (administrative costs and direct/indirect costs for developers), representing a relative cost of less than 0.1 % to 2.5 % of the total investments. However, in most cases, this cost is less than 1 % (GHK 2010).
- The total costs of the design (including all studies) can vary from a few thousand euro to several million euro according to the data collected from operators.
- The investment for a pond to contain extractive waste is usually large, generally accounting for ~ 5-10 % of the total investment of the mine operation (Xin *et al.* 2011).

8. Driving force for implementation

- Risk prevention.
- Legal and environmental requirements according to Directive 2006/21/EC, national or local mining legislation and other environmental legislation, such as an EIA (Directive 2014/52/EU), assessment according to Nature 2000 and the conservation of Natural Habitats and Wild Flora and Fauna (FFH) (Directive, 92/43/EEC and amendments).
- Reduction of costs during the whole life cycle.

9. Example sites

- El Cogulló (ES)
- El Fusteret (ES)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)

10. Reference literature

(ELAW 2010)
(Ferrante *et al.* 2012)
(GHK 2010)
(Orman *et al.* 2011)
(Rico *et al.* 2008b)
(UNECE 2014)
(Xin *et al.* 2011)

4.1.2.2.2 Identification of extractive waste handling/transport, treatment and deposition options

1. Description

This technique consists of identifying distinct extractive waste handling/transport, treatment and deposition options based on a preliminary characterisation of the extractive waste site options and the extractive waste, considering the whole life cycle of the extractive waste management and using the information from all relevant expert studies covering safety aspects, geotechnical aspects, environmental aspects, local conditions and preliminarily identified potential impacts.

2. Technical description

Distinct extractive waste handling/transport, treatment and deposition options, based on a preliminary characterisation of the extractive waste site options (see Section 4.1.2.2.1) and the extractive waste (see Section 4.1.2.1.1), are identified considering the whole life cycle of the extractive waste management and using the information from all relevant expert studies covering safety aspects, geotechnical aspects, environmental aspects, local conditions and preliminarily identified potential impacts. This includes the identification of the following elements:

- intended handling/transport and deposition techniques:
    - handling/transport of extractive waste:
        - handling of extractive waste from excavation, e.g.:
            - conveyor belts;
            - trucks;
        - handling/transport of extractive waste from mineral processing, e.g.:
            - conveyor belts;
            - pipelines;
            - trucks;
        - handling/transport of drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production, e.g.:
            - pipelines;
    - temporary storage of extractive waste:
        - temporary storage of extractive waste from excavation, e.g.:
            - heaps;
        - temporary storage of extractive waste from mineral processing, e.g.:
            - heaps;
            - ponds;

        - temporary storage of drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production, e.g.:
            - closed containers/tanks;
    - permanent deposition of extractive waste:
        - permanent deposition of extractive waste from excavation, e.g.:
            - heaps;
            - co-disposal in ponds;
            - excavation voids (where deposited as extractive waste);
        - permanent deposition of extractive waste from mineral processing, e.g.:
            - heaps (wet and dry filter cake deposition or dry stacking);
            - ponds confining paste or thickened extractive waste from mineral processing;
            - ponds and dams confining slurried extractive waste from mineral processing;
            - excavation voids (where deposited as extractive waste);
        - permanent deposition of drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production, e.g.:
            - off-site treatment and/or disposal;
- intended construction method of ponds, dams and heaps, including the basal structure concept design and possible future covers.

According to the MTWR BREF (EC-JRC 2009), proper deposition of the extractive waste from mineral processing, particularly in a slurry state, will always be critical to the stability of the structure.

The correct selection of deposition techniques is one of the most critical aspects of the dam design and will enhance the dam safety during the whole life cycle of the extractive waste site (including the EWF). This selection will influence the pre-deposition earthworks, the drainage system, the outer slope of the extractive waste surface, the material properties to be included in the stability analysis, the choice and location of the decant systems and the physical characteristics of deposited extractive waste (e.g. the *in-situ* dry density).

An <u>extractive waste mass balance</u> may address all relevant types of extractive waste:
- extractive waste from excavation;
- extractive waste from mineral processing;
- drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production.

For each type of extractive waste, the mass balance may include the following information:
- planned annual amounts of extractive waste temporarily stored in extractive waste deposition areas (including EWFs) or containers/tanks;
- planned annual amounts of extractive waste permanently stored in extractive waste deposition areas (including EWFs);
- planned annual amounts of extractive waste permanently sent off site for treatment and disposal.

Off-site management of extractive waste is mainly carried out in the oil and gas extraction sector. In that sector, operators responsible for the management of extractive waste generally collect and send to waste treatment installations or landfill part or all of the waste drilling muds and other drilling and extractive wastes (solid and liquid) from oil and gas exploration and production. The waste treatment installations do not usually treat solely extractive waste. Such installations are, in general, industrial installations covered by Directive 2010/75/EU.

The technique is implemented in all the life cycle phases of the extractive waste management:
- <u>*Planning and design phase*</u>
  Planning phase

Distinct extractive waste management site options are identified. The concept design assumptions are updated and reviewed in the detailed design.
Design phase
An extractive waste mass balance for the whole life cycle of the extractive waste management is developed. It can allow for the staging of lifts and raises of the extractive waste deposition area (including the EWF) to accommodate the long-term storage of extractive waste and to maintain suitable solids storage capacity.

- *Operational (construction, management and maintenance) phase*
  The extractive waste mass balance is reviewed based on data recorded over time.
- *Closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

3. Achieved environmental benefits

- Supporting the identification of potential environmental risks and impacts associated with the extractive waste site and management options, including the risk of failure.
- Helping to ensure the prevention or minimisation of resource consumption from the management of extractive waste through optimisation and planning of the use of resources and space.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- The level of detail and nature of the identification of extractive waste handling/transport, treatment and deposition options are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.
  The selection and applicability of the deposition method is influenced by several factors, such as the site topography, weather conditions, the geotechnical and chemical characteristics of the extractive waste, its delivery rate, slurry concentration, volumetric storage capacity and the rate of rise of the deposit with time, water quality and dust control.
- Segregation of extractive waste from mineral processing can be applied when it contains a substantial coarse fraction.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).
- Savings in capital and operating costs for extractive waste transportation can be achieved if the extractive waste management site (including the EWF) is located in relatively close proximity to the mineral processing plant.

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements, according to Directive 2006/21/EC and related Commission Decisions and also according to national/local legislation.
- Economic benefits from the reduction of costs for the extractive waste management.

9. Example sites

- Preston New Road (UK)
- LKAB Kiruna Iron ore Mine (SE)
- LKAB Malmberget Iron ore Mine (SE)
- Zinkgruvan Mining AB (SE)

- Boliden Tara Mines (IE)
- Steirischer Erzberg (AT)
- Wolfram Bergbau und Huetten AG (AT)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Kisladag Gold Mine (TR)
- Roseacre Wood (UK)

10. Reference literature
(UK EA 2016)
(EC-JRC 2009)
(ICOLD 2011b)
(Kerr and Ulrich 2011)
(UK EA 2015a)
(Williams 2014)

4.1.2.3 Environmental Risk and Impact Evaluation

4.1.2.3.1 Hazards and risk elements identification

1. Description
This technique consists of identifying the hazards and risk elements, including source-pathway-receptor linkages (also physical failure modes), associated with extractive waste characteristics and extractive waste site and management options.

2. Technical description
Identification of potential hazards and risk elements represents the first step of an Environmental Risk and Impact Evaluation (see Section 4.1.2.3.2).
Operators identify a list of site-specific hazards or risk elements considering for example:
- the extractive waste management activities carried out on site;
- the reagents and auxiliary materials used for the management of extractive waste;
- the extractive waste deposition area including extractive waste facilities and temporary storage facilities.

A potential source-pathway-receptor chain is usually identified for each potential hazard/risk element, considering for example:
- the technical characteristics of the extractive waste deposition area including extractive waste facilities and temporary storage facilities;
- the geographical location of the site selected for the management of extractive waste;
- the local environmental conditions.

The concept of the source-pathway-receptor chain is also mentioned in Commission Decision 2009/337/EC.

The technique is implemented in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Hazards and risk elements are identified.
- *Operational (construction, management and maintenance) phase*
  Hazards and risk elements are reviewed in the case of changes influencing the management of extractive waste (see management of changes in Section 4.1.1.1), based on findings from the monitoring of the following:
    - o extractive waste characteristics (see Section 4.1.2.1.2);
    - o physical stability of the extractive waste and extractive waste deposition area (including the EWF) (see Section 4.2.1.3.6.3);
    - o emissions to soil and groundwater (see Section 4.3.1.5.1);
    - o emissions to surface water (see Section 4.3.2.2.7.2);

  - emissions to air (see Section 4.3.3.4.2);
  - other parameters considered relevant for the hazards and risk elements identification.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Determining the potential environmental hazards/risk elements brought about as a result of the management of extractive waste.
- Helping to prevent the risk of failure and better mitigating the possible consequences of adverse events.

4. Environmental performance and operational data
Different tools can be used to carry out hazards and risk elements identification.
Examples of tools particularly suitable for hazards and risk elements identification are (ISO 2009c):
- brainstorming;
- cause-and-effect analysis;
- checklists;
- consequence/probability matrix;
- Delphi method;
- environmental risk assessment;
- failure mode analysis;
- hazard analysis and critical control point (HACCP);
- hazard and operability (HAZOP) studies;
- human reliability analysis;
- primary hazard analysis;
- reliability-centred maintenance;
- scenario analysis;
- structured "what if?" technique (SWIFT);
- structured or semi-structured interviews.

The result of the potential hazards and risk elements identification, and the associated potential source-pathway-receptor chain, are usually presented in a tabular form. An example of such a table is presented below.

Table 4.4: Examples of potential hazards and risk elements resulting from the management of extractive waste along with the associated potential source-pathway-receptor chain

Potential hazards / risk elements	Potential source*	Potential pathway	Potential receptor
Loss of structural integrity	Physical movement of extractive waste, water and embankments, including basal structure breakage	Movement over land, and transport by surface water bodies, groundwater and air (fugitive dust)	Humans and the downstream environment (terrestrial environment, groundwater, surface water)
Incorrect operation	Inappropriate planning, design, construction, maintenance, closure and after-closure of the EWF which may lead to the physical or chemical instability of the EWF and the extractive waste	Air, soil, groundwater, surface water	Humans, the environment and EWF structures
Hazardous extractive waste	The extractive waste itself (direct exposure and fugitive dust), leachate from the waste	Air, soil, groundwater, surface water	Humans and the environment, in particular surface water and groundwater
Dangerous substances/preparations contained in the extractive waste	The aqueous phase of the extractive waste	Soil, groundwater, surface water	Humans and the environment, in particular surface water and groundwater

** Note that the table shows the source but not the underlying cause of a potential accident.*
Source: Adapted from (EC-DG ENV 2012)

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- The level of detail and nature of the hazards and risk elements identification are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention and improvement of occupational safety.
- Legal and environmental requirements according to Directive 2006/21/EC and related Commission Decisions, particularly Decision 2009/337/EC.
- Reduction of costs during the whole life cycle.

9. Example sites

- Welton GC (UK)

10. Reference literature

(EC-DG ENV 2012)
(ISO 2009a, b, c)

4.1.2.3.2 Environmental Risk and Impact Evaluation

1. Description

Environmental Risk and Impact Evaluation consists of a structured, dynamic and often iterative process, which is part of the risk management, where all the environmental risks and impacts brought about as a result of the extractive waste management (including all EWFs) are identified, analysed and evaluated over the whole life cycle.

2. Technical description

Extractive waste management is based on consideration of safety aspects and environmental impacts (EC-JRC 2009; UNECE 2014). Therefore, as part of the planning of an extractive waste site (including the EWF), it is often necessary to carry out an evaluation of potential environmental risks and impacts.

The Environmental Risk and Impact Evaluation may be integrated into existing procedures on EIA, including screening, for those activities falling under Directive 2011/92/EU amended by Directive 2014/52/EU.

The classification of an EWF as Category A or not Category A is, among others, based on a risk assessment (see Annex III to Directive 2006/21/EC and Commission Decision 2009/337/EC).

A suitable way to manage environmental risk and impacts is to follow a risk management process which can identify the potential impacts and risks for a specific extractive waste site (including the EWF).

The objective of any environmental risk and impact management process is to identify the risks and impacts and to ensure that appropriate levels of risk/impact reduction are applied to prevent or reduce as far as possible any adverse effects on the environment and resultant risks to human health. According to IEC/ISO 31 010:2009, risk assessment is part of the risk management which consists of a structured, dynamic and often iterative process that identifies how objectives may be affected, and analyses the risks in terms of consequences and their probability before deciding whether further treatment/management measures are required. Risk assessment attempts to answer the following fundamental questions:

- What can happen and why (by risk identification)?
- What are the consequences?
- What is the probability of future occurrence?
- Are there any factors that mitigate the consequences of the risk or that reduce the probability of the risk?
- Is the level of risk tolerable or acceptable and does it require further treatment/measures?

Risk assessment provides an improved understanding of risks that could affect the achievement of objectives, and of the adequacy and effectiveness of controls/monitoring already in place. This in turn provides a basis for decisions about the most appropriate approach to be used to treat the risk.

Environmental Risk and Impact Evaluation is a key part of the management of all the life cycle phases of the extractive waste management (including the EWF). An appropriate and comprehensive Environmental Risk and Impact Evaluation considers the full spectrum of specific hazards and risk sources for a given extractive management site (including the EWF).

Environmental Risk and Impact Evaluation processes include structured, disciplined and transparent demonstration that proposed measures are based, *inter alia*, on the BAT, but taking into account the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.

The size, the complexity and the geographic location of the EWF are just some of the parameters that are included in the Environmental Risk and Impact Evaluation.

Methodology

- *Environmental Risk and Impact Evaluation* and related management process
  The objective of an Environmental Risk and Impact Evaluation is to identify risks and impacts brought about as a result of the extractive waste management (including the EWF)

over the whole life cycle with regard to any adverse effects on the environment, in particular water, ambient air, soil, biodiversity (such as fauna, flora) and landscape or places of particular interest, and any resultant risks to human health (see Article 1 of Directive 2006/21/EC).
The next step is to identify appropriate measures (BAT or other suitable alternative techniques) to manage those environmental risks and impacts.

- *Collection of information about extractive waste and extractive waste site and management options*
  The Environmental Risk and Impact Evaluation is based, among others, on information related to the initial characterisation of the extractive waste (see Section 4.1.2.1) and to the extractive waste site and management options (see Section 4.1.2.2). The extractive waste characterisation includes the following categories of information: background information, geological background of deposit to be exploited, nature of the extractive waste and its intended handling, geotechnical behaviour and geochemical characteristics of the extractive waste.
  The extractive waste site and management options are related to the identification of extractive waste site options (see Section 4.1.2.2.1) and to the identification of extractive waste handling/transport, treatment and deposition options (see Section 4.1.2.2.2).

- *Environmental Risk and Impact Evaluation*
  The hazards and risk elements associated with the extractive waste management, including sources, pathways and receptors, are identified. According to ISO 31000:2009, risks are typically assessed by means of an overall process consisting of the following:
    - <u>Risk identification</u>: a process of finding, recognising and describing risks. Risk identification involves the identification of the risk sources, events, their causes and their potential consequences.
    - <u>Risk analysis</u>: a process to comprehend the nature of risk and to determine the level of risk, which consists of the magnitude of a risk, or of a combination of risks, expressed in terms of the combination of consequences (outcome of an event affecting objectives) and their likelihood (chance of something happening).
    - <u>Risk evaluation</u>: a process of comparing the results of a risk analysis (see previous point) with risk criteria (terms of reference against which the significance of a risk is evaluated) in order to determine whether the risk and/or its magnitude is acceptable or tolerable.

  The environment, human health and safety are prioritised.

  The level of risk and impact to be considered acceptable or tolerable may be defined in the legislation at Community and Member State level. For example, Commission Decision 2009/337/EC specifies when the potential for loss of life or danger to human health due to the loss of structural integrity or incorrect operation shall be considered to be negligible or not serious (see Article 4(2)) and the potential danger for the environment due to the loss of structural integrity or incorrect operation shall be considered to be not serious (see Article 4(3)).

  According to IEC/ISO 31010:2009, the manner in which risk assessment is applied is dependent not only on the context of the risk management process but also on the method and techniques used to carry out the risk assessment. A comparison of the risk assessment techniques is provided in IEC/ISO 31010:2009, including the applicability of different tools in Annex A and a detailed description of the different techniques in Annex B.

- *Application of the generic and the risk-specific BAT candidates*
  Depending on the outcome of the evaluation of the environmental risk and impact sources, one or more generic and/or risk-specific BAT candidates are applied to minimise each overall risk and impact level associated with the extractive waste management (including

the EWF). In some cases, however, measures might not be necessary if the risk and impact is deemed irrelevant.

- *Conclusions and response*
  At this point, a synopsis of the whole procedure of the Environmental Risk and Impact Evaluation and the related management process is produced to identify which measures to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of extractive waste should be included in the project design.

The technique is implemented in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  An initial evaluation of environmental risks and impacts is carried out in order to identify these and gather the necessary information and data to properly plan and design the extractive waste management, and to plan appropriate accident prevention and mitigation measures where necessary.
- *Operational (construction, management and maintenance) phase*
  The Environmental Risk and Impact Evaluation is reviewed in the case of changes influencing the management of extractive waste (see management of changes in Section 4.1.1.1), based on findings from the monitoring of the following:
    - extractive waste characteristics (see Section 4.1.2.1.2);
    - physical stability of the extractive waste and extractive waste deposition area (including the EWF) (see Section 4.2.1.3.6.3);
    - emissions to soil and groundwater (see Section 4.3.1.5.1);
    - emissions to surface water (see Section 4.3.2.2.7.2);
    - emissions to air (see Section 4.3.3.4.2);
    - other parameters considered relevant for the hazards and risk elements identification.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Determining the potential environmental risks and impacts brought about as a result of the management of extractive waste.
- Helping to prevent the risk of failure and better mitigating the possible consequences of adverse events.

4. Environmental performance and operational data
An example of risk-specific objectives and potential hazards and risk/impact elements from the management of extractive waste (including the EWF) is given Table 4.5.

Table 4.5: Example of risk-specific objectives and potential hazards and risk/impact elements from the management of extractive waste

Risk-specific objectives		Potential hazards and risk elements	
General category	**Specific category**	**General category**	**Possible hazards and risk elements due to inappropriate…**
Safety	Structural stability of the extractive waste deposition area	Short-term and long-term structural instability	… design for closure approach
			… use of additional Organisational and Corporate Management tools
			… ground investigation
			… dam construction materials selection
			… dam/embankment construction methods

			… heap construction methods
			… water balance analysis
			… design flood
			… free water management
			… drainage systems
			… geotechnical analysis of the extractive waste deposition area (including the EWF)
			… monitoring of the physical stability of the extractive waste deposition area (including the EWF)
			… containment of extractive waste in underground extractive waste deposition areas
			… monitoring of the fracture propagation and seismicity in the underground extractive waste deposition area
	Physical and chemical stability of extractive waste	Extractive waste physical instability	… solid/liquid control of extractive waste
			… stabilisation of extractive waste for placing back into excavation voids
			… compaction, consolidation and deposition of extractive waste
		Extractive waste chemical instability	… prevention or minimisation of pollutant leaching
			… prevention or minimisation of Acid Rock Drainage (ARD)
			… prevention or minimisation of self-ignition of extractive waste
		Extractive waste containing dangerous substances	… reduction of the cyanide concentration in the pond
			… reduction of hydrocarbon concentrations in drilling muds and other drilling wastes
Prevention and minimisation of water status deterioration, air and soil pollution	Prevention and minimisation of groundwater status deterioration and soil pollution	Emissions to soil and groundwater	… basal structure
			… water streams management
			… covering
			… groundwater and soil pollution remediation
			… monitoring of emissions to soil and groundwater
	Prevention and minimisation of surface water status deterioration	EWIW generation	… prevention or minimisation of EWIW generation
		Emissions to surface water	… drainage of EWIW
			… removal of suspended solids or suspended liquid particles
			… removal of dissolved substances
			… neutralisation of EWIW prior to discharge
			… monitoring of emissions to surface water
	Prevention and minimisation of air pollution	Emissions to air	… prevention or minimisation of dusting from exposed surfaces of extractive waste
			… prevention or minimisation of dusting from extractive waste handling and transport
			… prevention or minimisation of emissions of VOCs and other air pollutants from drilling muds and other extractive wastes from oil and gas exploration and production
			… monitoring of emissions to air
Others	Prevention and minimisation of any other adverse effects on human health, flora and fauna	Noise emissions	… prevention or minimisation of noise emissions from the management of extractive waste
		Odour emissions	… prevention or minimisation of odour emissions from the management of extractive waste
		Visual / Footprint impacts	… prevention or minimisation of visual and footprint impacts from the management of extractive waste
		Inefficient resource consumption	… minimisation of resource consumption from the management of extractive waste
		Presence of NORMs	… prevention or minimisation of impacts related to the management of extractive waste containing NORMs

A risk-based preselection protocol for the inventory of closed EWFs, as required by Article 20 of Directive 2006/21/EC, is proposed by Stanley G., Jordan G. and Hamor T. (EC-DG ENV 2011). Even though it refers to closed EWFs, the proposed methodology may be considered a good reference for developing similar protocols for new or operational EWFs.

Simplified guidance for the risk assessment on closed/abandoned EWFs has been developed by the Spanish Ministry (MAPAMA 2016) and takes into account the risks causing:
- deterioration of surface water;
- deterioration of groundwater;
- air pollution;
- soil pollution;
- structural instability of heaps and dams.

A detailed methodology for the definition of consequences and likelihood, in order to determine the level of risk in the scenarios analysed, is provided.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- The level of detail and nature of the Environmental Risk and Impact Evaluation are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.

7. Economics
- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation
- Risk prevention and improvement of occupational safety.
- Legal and environmental requirements according to Directive 2006/21/EC and related Commission Decisions, particularly Decision 2009/337/EC.
- Reduction of costs during the whole life cycle.

9. Example sites
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature
(Azam and Li 2010)
(UK EA and DEFRA 2016)
(EC-DG ENV 2011, 2012, 2014, 2015, 2016)
(EC-JRC 2009)
(EEA 2016)
(ICOLD 2011b)
(ICMM 2016)
(ISO 2009a, b, c)
(MAPAMA 2016)
(Rico *et al.* 2008a)
(UNECE 2014)
(Xin *et al.* 2011)

4.1.3 Waste hierarchy

Techniques presented in this section belong to the organisational management and can be considered generic and overarching techniques. They ensure compliance with the waste hierarchy principles, i.e. to prevent or reduce as far as possible extractive waste generation and to re-use or recycle extractive waste.

4.1.3.1 Techniques to prevent solid extractive waste generation

4.1.3.1.1 Pre-sorting and selective handling of extractive materials that in principle qualify as by-products/products

1. Description
This technique consists of pre-sorting extractive materials that in principle qualify as by-products/products and selectively handling these materials.

2. Technical description
This BAT candidate is particularly relevant for heterogeneous extractive materials.

This technique consists of pre-sorting extractive materials that in principle qualify as by-products/products and selectively handling these materials. This may include selective separation of solid extractive materials, e.g. based on visually, physically or chemically detected properties. Some examples are listed below:

- Selective separation of solid extractive materials based on automated optical detection (digital sorting using cameras, lasers and/or sensor based-systems). The separated fraction, which in principle qualifies as by-product/product, might be used as construction material for internal (e.g. dam construction materials) or external purposes.
- Physical/mechanical separation of solid and liquid streams: using hydro-cyclones, shale shakers and/or screens, it is possible to isolate targeted materials that in principle qualify as by-products/products and could be used as construction materials or re-used in the process, thus preventing the generation of extractive waste. Some examples of mechanical pre-sorting are as follows:
  - *Two-stage cycloning of flotation extractive materials from mineral processing that in principle qualify as by-products/products:*
    This technique is applied for producing extractive materials to be placed back into excavation voids, in order to separate the fine fraction, which is pumped to the EWF for deposition, from the coarse fraction that can be, for example, hydraulically placed back into excavation voids or used for dam construction.
  - *Separation of coal and aggregates that in principle qualify as by-products/products:*
    This technique consists of processing coal residues to separate coal and aggregates according to the following procedure:
    - raw material delivery and pre-sorting;
    - classification of material for washing process: screening, coarse fraction crushing, fine fraction washing;
    - sludge fraction (0-2 mm) processing by means of classification cyclones, hydro-classification, centrifugation;
    - fine fraction (class 2-40 mm) processing by hydro-cyclones to separate coal from aggregates; coal is then dewatered and stockpiled; aggregates are sieved, piled and sold as construction materials or used for rehabilitation.
  - *Use of shale shakers to separate drill cuttings from the drilling muds or other drilling extractive wastes in oil and gas exploration and production:*
    The liquid part can be re-used in the drilling process.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- <u>Planning and design phase</u>
  Pre-sorting and selective handling are included in the design.

- <u>*Operational (construction, management and maintenance) phase*</u>
  Pre-sorting and selective handling are carried out.

3. Achieved environmental benefits

- Implementation of the waste hierarchy principles by:
  - preventing the generation of solid extractive waste.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.

4. Environmental performance and operational data

Pre-sorting of extractive materials that in principle qualify as by-products/products from other extractive residue streams is not always possible and depends on the site-specific conditions. Figure 4.3 presents the site-specific relative amount of pre-sorted extractive materials that in principle qualify as by-products/products (blue bars), calculated as a percentage of the total amount of extracted materials, based on information reported by operators via the questionnaires. The site-specific relative amount of extractive residues (red bars) is also presented and is also expressed as a percentage of the total amount of extracted materials. As contextual information, the extracted mineral resources, from which the extractive residues originate, are presented on the vertical axis. Most of the operators that provided data on the amounts of extracted materials, by-products/products and extractive wastes reported some amounts of pre-sorted extracted materials that in principle qualify as by-products/products.

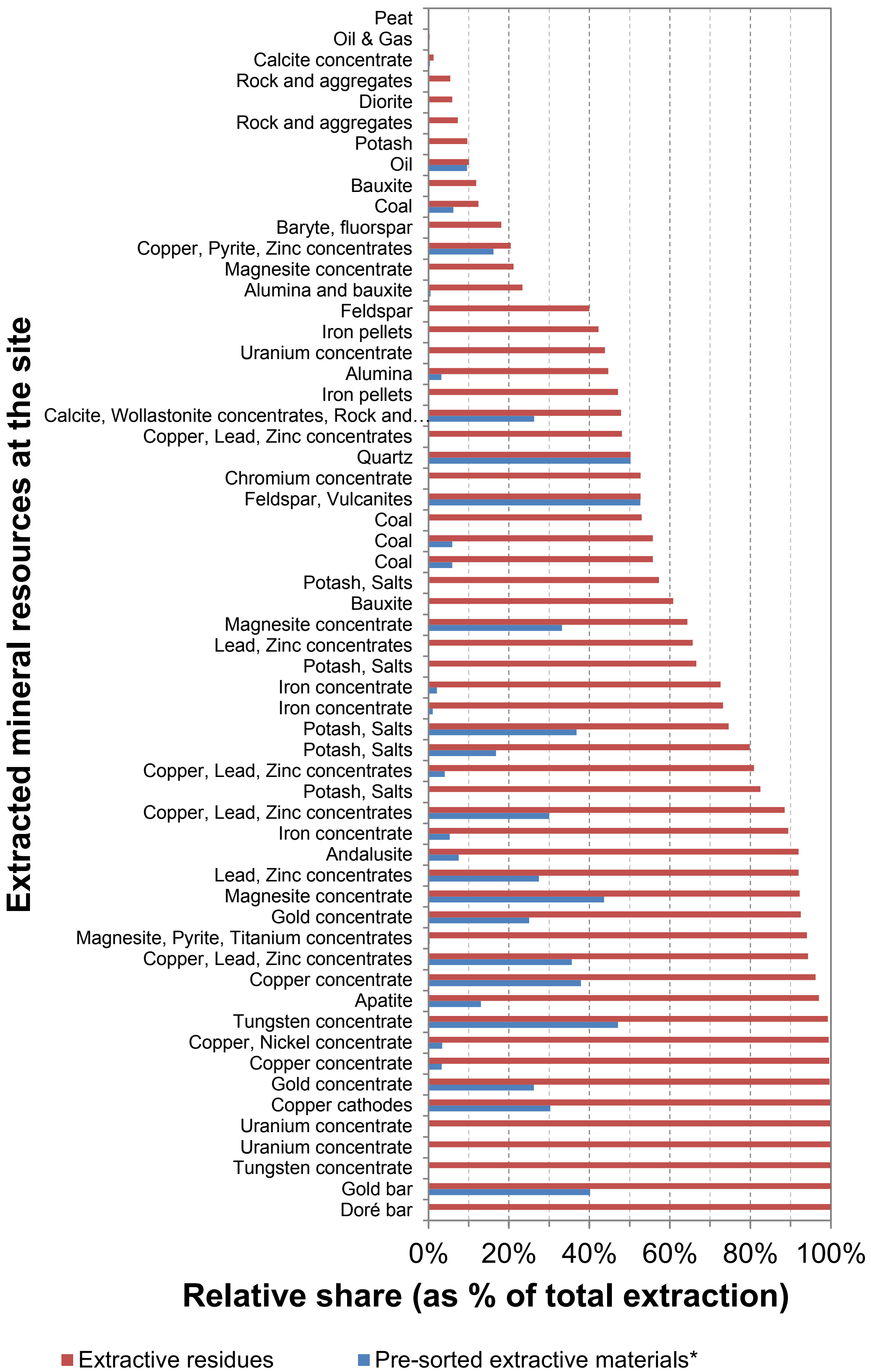
On the one hand, at 26 sites out of the 58 that provided data, operators responsible for the management of extractive waste did not report pre-sorting of extractive materials that in principle qualify as by-products/products (no blue bars) even though they reported the management of an extractive residues stream (red bars).

On the other hand, at the other 32 sites out of the 58 that provided data, operators did report pre-sorting of extractive materials that in principle qualify as by-products/products. The relative share varies greatly from site to site. A few operators reported the pre-sorting of almost all the extractive residues, indicated by the fact that the relative share of pre-sorted extractive materials in blue is close to the relative share of extractive residues in red. For most of the operators that reported pre-sorting of extractive materials, the share of pre-sorted materials represented ~ 5 % to 50 % of the total extraction, which represented ~ 20 % to 50 % of the extractive residues.

Obviously, the relative share of pre-sorted extractive materials that in principle qualify as by-products/products varies from site to site and depends on the possibility to use the pre-sorted materials for internal or external purposes.

Some of the reported uses of such materials are:

- construction materials;
- site rehabilitation materials;
- materials to be placed back into excavation voids for rehabilitation or construction purposes.



**Materials that in principle qualify as by-products/products.*

NB: Calculation based on the information reported by operators via the questionnaires. The extracted mineral resources are indicated on the vertical axis.

Figure 4.3: Calculated site-specific relative share of pre-sorted extractive materials and extractive residues, expressed as a percentage of total extraction

5. Cross-media effects

- Concentration of pollutants in the waste stream after the pre-sorting of valuable extractive materials that in principle qualify as by-products/products.
- Energy and water consumption in the pre-sorting and selective handling operations such as optical treatment or physical-mechanical treatment.

6. Technical considerations relevant to applicability

- Pre-sorting and selective handling are generally applied for the management of extractive materials that in principle qualify as by-products/products.
- The choice between different techniques will depend on the site-specific conditions and the nature of extractive materials that in principle qualify as by-products/products, e.g.:
    - selective manual separation for coarse fractions such as extractive materials from excavation (e.g. materials valuable for construction purposes are separated manually from non-valuable waste-rock);
    - selective separation for dry solid material by automated optical detection (e.g. valuable materials for construction purposes are separated automatically from non-valuable waste-rock with an optical device such as a camera);
    - shale shakers for drilling muds (coarse solid fractions of shale and sand are separated from the liquid stream);
    - hydro-cyclones for extractive materials from mineral processing that in principle qualify as by-products/products or drilling muds.

7. Economics

- No information provided.

8. Driving force for implementation

- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of extractive waste produced.
- Efficient use of materials.
- Legal and environmental requirements, particularly Article 5 of Directive 2006/21/EC.
- Economic benefits: prevention of extractive waste management costs.
- When applied before mineral processing, improvement of the processing efficiency by avoiding the processing of inappropriate fractions, and reduction of the use of chemicals or energy for mineral processing.
- Maximisation of the lifetime of the extractive waste deposition area (including the EWF).

9. Example sites

- Wolfram Bergau un Huetten AG (AT)
- Hellenic Copper Mines, Skouriotissa (CY)
- Grecian Magnesite (EL)
- Ternamag, Mantoudi (EL)
- ICL Iberia, Súria (ES)
- Matsa a Mubadala and Trafigura Company, Mina de Aguas Teñidas (ES)
- Boliden Tara Mines (IE)
- Minerali industriali, Sondalo and Lozzolo (IT)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Aitik Mine (SE)
- Ridgeway (US)

10. Reference literature

(EC-JRC 2009)

4.1.3.1.2 Placing extractive materials that in principle qualify as by-products/products back into excavation voids

1. Description
This technique consists of placing extractive materials that in principle qualify as by-products/products, combined or not with water and cementitious binders, back into excavation voids, e.g. for structural and/or rehabilitation purposes.

2. Technical description
Extractive waste generation is prevented by placing extractive materials that in principle qualify as by-products/products (such as extractive materials from excavation or mineral processing), combined or not with water and cementitious binders, into excavation voids, e.g. for structural and/or rehabilitation purposes. These activities form an integral part of the extraction operation.

The term excavation voids includes both surface and underground excavation voids from mineral resources extraction.

If extractive materials from excavation cannot be placed back directly into excavation voids, they are usually temporarily stored.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The placing back of extractive materials that in principle qualify as by-products/products into excavation voids is planned and designed. This enables the reduction of the amount of extractive waste to be deposited in the extractive waste deposition area (including the EWF).
- *Operational (construction, management and maintenance) phase*
  The technique is implemented.
- *Closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

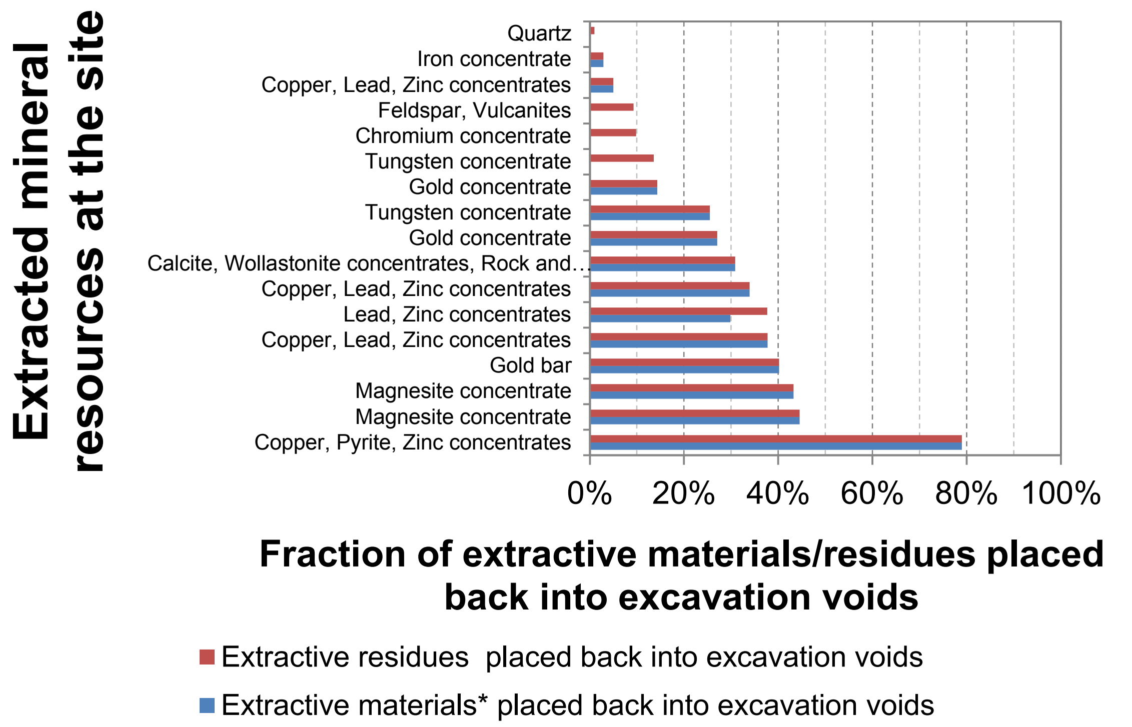
3. Achieved environmental benefits

- Implementation of the waste hierarchy principles by:
  - preventing the generation and handling of extractive waste, increasing the ore recovery, maximising the ore reserves and facilitating the mineral extraction.
- Reducing transport of materials, when these are placed back directly into underground or surface excavation voids.
- Elimination of the need to import materials.
- Helping to ensure the short-term and long-term structural stability of the excavation voids by allowing the wall rock to retain load-bearing capacities.
- Avoidance of temporary storage, as well as prevention of erosion and dusting by means of progressive site rehabilitation during operation.
- Prevention or minimisation of visual, footprint or land-use impacts from the management of extractive waste by:
  - rehabilitating extraction and deposition sites/areas, allowing the recreation of pieces of land with new uses.

4. Environmental performance and operational data
Figure 4.4 presents the calculated fractions of extractive residues and extractive materials that in principle qualify as by-products/products that the operators reported placing back into excavation voids. The fractions have been calculated based on the reported amounts of extractive residues (including extractive materials that in principle qualify as by-products/products) and the reported amounts of extractive residues placed back into excavation voids (including extractive materials that in principle qualify as by-products/products). As

contextual information, the extracted mineral resources, from which the extractive residues originate, are presented on the vertical axis.

Most of the operators responsible for the management of extractive waste that reported data on placing extractive materials back into excavation voids reported the placing back of extractive materials that in principle qualify as by-products/products. At 13 (blue bars) out of the 17 (red bars) sites for which operators reported placing extractive residues back into excavation voids, the operators reported placing extractive materials that in principle qualify as by-products/products back into excavation voids. At 8 sites, operators reported placing only extractive materials that in principle qualify as by-products/products (blue bar equals red bar) back into excavation voids.



**Materials that in principle qualify as by-products/products.*

NB: Calculation based on the information reported by operators via the questionnaires. The extracted mineral resources at each site are indicated on the vertical axis.

Figure 4.4: Calculated site-specific ratios of extractive residues and extractive materials that in principle qualify as by-products/products, placed back into excavation voids, expressed as a percentage of total extraction (run-of-mine)

Based on the data reported by operators, Figure 4.4 reveals that one operator reported an unusually high fraction of extractive residues placed back into excavation voids, ~ 80 % of the extractive residues, whereas most of the operators that provided data reported a fraction in the range of ~ 10 % to 45 % of extractive residues being placed back into excavation voids (including the placing back of extractive materials that in principle qualify as by-products/products). In theory, a maximum volume of extractive residues that can be placed back into excavation voids can be defined and depends, among others, on the volume expansion of extractive materials due to the size reduction process (e.g. crushing, milling), which means that it is not possible to place all the extractive residues back into the same excavation void. The need for a suitable particle size distribution may also limit the maximum fraction of extractive residues that can be placed back into excavation voids.

The following examples further illustrate some cases of placing extractive materials that in principle qualify as by-products/products back into excavation voids:

- At the Pyhäsalmi site, extractive materials are mixed with cementitious binders (blast furnace slag and lime) to produce a cemented slurry, with a solids content of ~ 62 %, to be placed back hydraulically into the empty stopes. The target for the compressive strength of the consolidated material is 2 MPa after two months curing time. According to the data provided by operators via the questionnaire, ~ 80 % of the extractive materials that in principle qualify as by-products/products were placed back into excavation voids in 2014.
- At the Boliden Tara site, a high fraction (~ 40 %) of the extractive residues resulting from the mineral processing is placed back into the excavation voids. The pre-sorted coarse fraction of extractive residues resulting from the mineral processing was reported to qualify as by-product/product. The total amount of such extractive materials qualifying as by-products/products that are placed back into excavation voids represents ~ 30 % of the extractive residues.
- At the KGHM Polska Miedź S.A. Żelazny Most tailings pond, based on the information exchanged, the gangue which has to be extracted underground is not brought to the surface, but is placed back into underground excavation voids or is used for underground road construction. Due to the different shape of the deposit in each mine, the amount of extractive materials which qualify as by-products/products varies. Annually, the three mines produce ~ 6-7 Mt of extractive materials qualifying as by-products/products, which are placed back into excavation voids or used for construction purposes directly underground. This represents 11-13 % of the total amount of extractive waste residues.
- At the Kittilä Mine site, extractive materials qualifying as by-products/products are placed back into excavation voids by means of the following deposition techniques: placing dry extractive materials, placing cemented extractive materials (5 % cement) and placing paste extractive materials.
  In 2014, ~ 40 % of the extractive residues qualified as by-product/product materials and were placed back into excavation voids. About 60 % of the extractive residues resulting from excavation were used as coarse materials qualifying as by-products/products (this corresponded to a third of the total extractive materials placed back into excavation voids) and ~ 20 % of the extractive residues resulting from flotation were used as paste materials qualifying as by-products/products (this corresponded to two thirds of the total extractive materials placed back into excavation voids).
- At the Efemçukuru Gold Mine, approximately 50 % of the extractive residues from mineral processing are placed back into excavation voids. The remaining 50 % are dewatered to a (geotechnical) moisture content of ~ 16-20 % and deposited as extractive waste on the surface in an engineered EWF.

The placing back of extractive materials that in principle qualify as by-products/products has also been reported for by-products/products resulting from the extraction of:
- magnesite;
- fluorspar (EC-JRC 2009);
- feldspar (EC-JRC 2009);
- gypsum (as long as this does not create any dissolution or leaching issue);
- potash;
- coal and lignite.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- Placing extractive materials that in principle qualify as by-products/products back into excavation voids is generally applicable as a part of the extraction method (particularly for underground extraction, but also for surface extraction) (EC-JRC 2009).

- The placing back of extractive materials that in principle qualify as by-products/products back into excavation voids may have site-specific technical considerations that limit the possibility of placing back materials, e.g.:
  - o extraction site characteristics;
  - o local hydrogeology;
  - o geochemical and geotechnical characteristics of the extractive materials.

7. Economics
- See heading 7 in Section 4.2.2.1.4.3.

8. Driving force for implementation
- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of produced extractive waste.
- Safety and stability purposes.
- Efficient use of materials.
- Land rehabilitation.
- Legal and environmental requirements, particularly Article 5 of Directive 2006/21/EC, and national legislation (such as the Finnish Government Decree 190/2013 and Spanish legislation).
- Economic benefits: minimisation of operational, closure and after-closure costs and maximisation of the ore recovery, due to the stabilisation of the mine which allows further excavation.

9. Example sites
- FQM Kevitsa Pyhäsalmi Mine Oy, Pyhäjärvi (FI)
- Ternamag, Mantoudi (EL)
- Grecian magnesite, Yerakini (EL)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Matsa Trafigura, Mina de Aguas Teñidas (ES)
- Boliden Tara Mines, Randalstown (IE)
- Zinkgruvan Mining AB, Svappavaara Mine (SE)
- Nordkalk Oy Ab, Lappeenranta Mine (FI)
- Efemçukuru Gold Mine (TR)
- Wolfram Bergbau und Huetten AG, Mittersill (AT)
- Endomines Oy, Pampalo, Ilomantsi, (FI)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature
(EC-JRC 2009)
(Engels 2016b)
(Hambley 2011)
(INAP 2014h)
(ITRC 2010g)
(MEND 1995)
(Punkkinen *et al.* 2015a)
(Rauche 2015)
(Tornivaara 2015c)

4.1.3.1.3 Using extractive materials that in principle qualify as by-products/products for internal or external purposes

1. Description
This technique consists of using extractive materials that in principle qualify as by-products/products for internal or external purposes.

2. Technical description

Using extractive materials that in principle qualify as by-products/products for internal or external purposes covers a wide range of possible applications, which may include the following:

Use of extractive materials that in principle qualify as by-products/products for internal purposes within the extractive industry

- *Site rehabilitation* (e.g. extraction site or extractive waste management site).
- *Construction purposes* (e.g. means of access for machinery, ramps, safety barricades, berms, dams).
- *Placing extractive materials that in principle qualify as by-products/products back into excavation voids* (see Section 4.1.3.1.2).
- *ARD management* (e.g. use of extractive materials with alkaline properties, such as dolomitic materials, as buffer materials).
- *Use of muds in the drilling process.*
- *Use in mineral processing.*

Use of extractive materials that in principle qualify as by-products/products for external purposes outside the extractive industry

- *Selling on the market as construction products* when complying with Regulation (EU) No 305/2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC. According to the MTWR BREF (EC-JRC 2009), possible examples are:
    - earthworks and infrastructure construction, i.e. as aggregate or filler in specific applications such as:
        - dams and embankments for roads, noise protection walls and other ancillary infrastructures construction;
        - ground and foundation improvement (exchange of soil and mechanical soil improvement);
        - soil fortification by applying extractive materials from coal mineral processing and hydraulic binders;
        - other earth construction segments (e.g. dykes, pipeline ditch refill, landscape modelling, landscaped buildings);
        - liners for landfill construction (e.g. surface sealing liners for landfills as well as liners of well shafts);
    - hydraulic engineering:
        - filling material for abandoned harbour basins;
        - dyke construction along rivers;
        - extension and safety measures of canal system.
- *Selling on the market as raw materials in different applications* such as:
    - cement production (e.g. by using bauxite residues, baryte fine extractive materials from mineral processing that in principle qualify as by-products/products);
    - bricks manufacturing (e.g. by using extractive materials from coal mineral processing or alumina refining, etc. that in principle qualify as by-products/products);
    - ceramic industry (e.g. by using extractive materials from coal mineral processing or alumina refining, etc. that in principle qualify as by-products/products);
    - as a colorant (e.g. by using extractive materials from alumina refining that in principle qualify as by-products/products);
    - as a source of iron oxide or other valuable metals or oxides (including gallium, rare earth elements);
    - as materials sold on the market.
- *Use for agricultural purposes*, e.g. use of calcite materials that in principle qualify as by-products/products or silt that in principle qualify as by-products/products as soil improvers.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The use of extractive materials that in principle qualify as by-products/products for internal or external purposes is planned and designed. This enables the reduction of the amount of extractive waste to be deposited in the extractive waste deposition area (including the EWF).
- *Operational (construction, management and maintenance) phase*
  The technique is implemented.
- *Closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

3. Achieved environmental benefits

- Implementation of the waste hierarchy principles by:
  - preventing the generation of extractive waste.
- Saving natural resources.
- Prevention or minimisation of visual and footprint impacts from the management of the extractive waste.

4. Environmental performance and operational data

According to the data provided by operators via the (87) completed questionnaires (see Figure 1.9), the alternative uses most reported, apart from placing back materials into excavation voids, are the following:

- Construction: reported by more than 40 operators for internal purposes and 9 for external uses (sold on the market). Extractive materials from excavation that in principle qualify as by-products/products (e.g. waste-rock) and extractive materials from mineral processing that in principle qualify as by-products/products (e.g. tailings) were the main materials used for construction.
- Site rehabilitation: reported by 11 operators. Valuable soil (e.g. topsoil, till) is mainly used for this purpose.
- Buffer material for ARD management.
- Re-use in the extractive process (e.g. drilling process) or in the mineral processing. Water-based extractive materials that in principle qualify as by-products/products are also reported to be reinjected in wells when it comes to the extraction of oil and gas.
- Agricultural applications (e.g. fertilisers or lime).
- Other industrial applications (e.g. pigments for ceramic industries).

The relative share of non-waste extractive residues used for alternative uses varies greatly from site to site.

5. Cross-media effects

- Fuel consumption for transporting the extractive materials that in principle qualify as by-products/products.

6. Technical considerations relevant to applicability

- Technical requirements for the use of extractive materials that in principle qualify as by-products/products for internal or external purposes may be restrictive:
  - extractive materials can be used if satisfying both geotechnical and environmental criteria, according to the Closedure project (Karlsson and Kauppila 2015b);
  - extractive materials with contaminant leaching potential (acidity, alkalinity and metals) or radioactivity are stabilised and treated prior to their use.
- In addition, site-specific conditions may also limit the applicability, e.g.:
  - the extractive materials' characteristics (e.g. mineralogy, particle size distribution and chemical properties);
  - the mineral resources extraction method (e.g. underground, surface);
  - the possibility to use the extractive materials for other purposes such as construction and rehabilitation purposes including placing them back into the excavation voids.

- Economic considerations relevant to applicability include different factors such as:
  - the market demand for such extractive materials;
  - the market location;
  - the price;
  - the transportation cost.

7. Economics

The cost of processing extractive materials that in principle qualify as by-products/products used for internal or external purposes varies from one material to another.

- For example, processing of bauxite residue can cost normally from EUR 4 to EUR 8 per tonne, depending on site specificities.
- However, the use of extractive materials that in principle qualify as by-products/products is less costly than disposal.
- Furthermore, high-quality materials produced may generate revenues. For example, according to the information provided in a questionnaire, recovering separately all constituents (such as alumina, titanium oxide, rare earth elements) from the hydrometallurgical process in the alumina refining process requires large investments but the payback time can be as short as two years.

The costs of using extractive materials that in principle qualify as by-products/products are influenced by the transportation distances.

8. Driving force for implementation

- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of extractive waste produced.
- Re-use or recycling targets are set by national/local authorities. For example, the target of Alcoa Kwiniana is to re-use 15 % of the total produced bauxite residue by 2020 and 30 % by 2030.
- Efficient use of materials.
- Saturation of extractive waste deposition areas (including EWFs) and lack of land availability.
- Economic benefits by generating revenues.
- Use of extractive materials that in principle qualify as by-products/products for public works, whenever applicable.

9. Example sites

- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Kiviõli Chemical Plant (EE)
- Yara Suomi Oy, Siilinjärvi Mine (FI)
- Mange Garri Alteo Gardanne (FR): 300 000 t used in 10 years for covering EWFs
- VKG Kaevandused OÜ, Kohtla-Järve (EE)
- FQM Kevitsa Pyhäsalmi Mine Oy, Pyhäjärvi (FI)
- SHESA, Bilbao (ES)
- Sydvaranger Gruve AS, Kirkenes (NO)
- RAG, Shöttelheide (DE)
- RAG, Haniel (DE)
- AoG (EL): use of extractive materials that in principle qualify as by-products/products as a raw material for cement
- Rusal Nikolaiev (Ukraine): more than 250 000 t/yr of extractive materials that in principle qualify as by-products/products used as a raw material for cement
- Kwiniana (Australia): use of red sand as an alternative material to quarry material

10. Reference literature

(EC-JRC 2009)
(Karlsson and Kauppila 2015b)

(Klauber *et al.* 2009)
(Power *et al.* 2009)

4.1.3.2 Techniques to reduce non-inert extractive waste and hazardous extractive waste generation

4.1.3.2.1 Management of extractive waste accumulated during exploration/prospecting

This BAT candidate is relevant for extractive waste from exploration/prospecting activities other than oil and gas exploration and production activities.

According to the information provided by operators and guidance documents available (SveMin 2005, 2012), plans are in place for the extractive waste generated during exploration/prospecting to be appropriately managed and stored on site or to be sent off site for appropriate treatment and/or disposal.

This technique is carried out during exploration and prospecting, which are parts of the *planning and design phase*.

The applicability of this technique depends on the characteristics and quantity of extractive waste, and site-specific conditions.

4.1.3.2.2 Sorting and selective handling of extractive waste

1. Description
Sorting and selective handling of extractive waste enable the appropriate separation of hazardous, non-hazardous non-inert and inert extractive waste streams, followed by selective handling of each stream.

2. Technical description
This BAT candidate is particularly relevant for heterogeneous extractive waste.

Sorting and selective handling of extractive waste are aimed at appropriately separating hazardous, non-hazardous non-inert and inert extractive waste streams. It is performed with the techniques described in Section 4.1.3.1.1, mainly selective separation of solid extractive waste streams or solid-liquid extractive waste streams, e.g. based on visually, physically or chemically detected properties.

For illustration purposes, information about the selective management of PAG and NAG extractive waste from excavation is provided here, according to the MTWR BREF (EC-JRC 2009):

- Sulphide ore deposits often exhibit zonation, with an elevated pyrite content in the layers near the ore. In open-pit mining, in some cases it is possible to manage excavation residues selectively using the geochemical properties as a criterion. Careful geological mapping and follow-up analyses using drilling chips are a means to provide the information required for classification. Based on this, it is then possible to separate the NAG extractive waste from excavation from the PAG extractive waste from excavation.
- The operating and decommissioning requirements for extractive waste from excavation depend on the net ARD generation potential. Excavation waste that does not have the potential to produce ARD will require less extensive decommissioning measures than extractive waste from excavation with ARD generation potential.
- The selective management of extractive waste from excavation does not call for advanced technology, merely prompt routines for information gathering and management of the material according to these results. If no selective handling is applied, the entire extractive

waste from excavation will need to be prevented from generating ARD. By applying selective handling, the fraction of PAG extractive waste from excavation is more easily manageable due to the reduced amounts (compared to the total amount of extractive waste from excavation).
- Low-sulphur extractive residues from excavation may meet the criteria for construction material and aggregates, avoiding the use of primary raw materials (see Section 4.1.3.1.3).

The technique is implemented in the life cycle phases of the extractive waste management listed below:
- Planning and design phase
  The planned and designed extractive waste management technique will influence the choice of sorting and selective handling technique.
  Sorting and selective handling are usually included in the planning and design of extractive waste management for waste which exhibits an ARD risk.
- Operational (construction, management and maintenance) phase
  Sorting and selective handling is used.

3. Achieved environmental benefits
- Implementation of the waste hierarchy principles by:
  - reducing the generation of extractive waste and its harmfulness;
  - reducing the generation of non-inert extractive waste and its harmfulness.
- Possible uses for internal or external purposes for the non-reactive fraction of the extractive waste.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD and thereby reducing the metal content in the EWIW discharge.
- Reduction or minimisation of visual and footprint impacts from the management of extractive waste.
- Reduction or minimisation of impacts related to the management of extractive waste containing NORMs.

4. Environmental performance and operational data
Sorting and selective handling of extractive waste streams is a technique usually applied in metal extraction with PAG and NAG extractive waste, based on the evaluation of the acidification potential ratio (NP/AP). For that purpose, a management system for extractive waste from excavation is applied. It generally includes the following:
- *A preliminary classification* of the extractive waste based on drilling samples.
- *Extractive waste classification during the extraction phase* through analytical results of drilling/other geological samples, geological data and models. This includes the evaluation of the neutralisation potential (NP) and acidification potential (AP) and consequently of the acidification potential ratio (NP/AP).
- *Monitoring and updating the geological model* according to the NP/AP ratio.
- *The segregation* of extractive waste streams into two categories:
  - NAG extractive waste;
  - PAG extractive waste.

  It has to be considered that, if the extractive waste has a low or limited neutralisation capacity to buffer acidity, even small concentrations of sulphide sulphur may cause ARD. The minimum level of AP, sulphide sulphur or acidic sulphide sulphur capable of causing ARD depends on the magnitude of the effective NP (Price 2009).
  Limit values for the sulphide sulphur content are provided in Commission Decision 2009/359/EC completing the definition of inert extractive waste: a maximum sulphide sulphur content of 0.1 % *or* a maximum sulphide sulphur content of 1 % and an NP/AP ratio greater than 3. In CEN/TR 16376, an NP/AP ratio greater than 3 is also indicated as a rule of thumb to identify NAG extractive waste.
  Another indicator that can be used to identify PAG and acid-generating extractive waste is the net neutralisation potential (NNP = NP – AP). If the NNP is higher than 20 tonnes of

$CaCO_3$ equivalent per thousand tonnes of extractive waste then the waste is NAG. If the NNP is lower than -20 tonnes of $CaCO_3$ equivalent per thousand tonnes of extractive waste then the extractive waste is considered PAG. Otherwise (-20 tonnes of $CaCO_3$ equivalent per thousand tonnes of extractive waste $\leq$ NNP $\leq$ 20 tonnes of $CaCO_3$ equivalent per thousand tonnes of extractive waste), further characterisation is required.
NAG and PAG extractive waste categories are thus defined by specifying the effective NP or by using the limit values as identified in Commission Decision 2009/359/EC.
According to the information reported by an operator in the questionnaire of the Kittilä Mine, a sulphur sulphide content greater than 0.5 % and an NP/AP ratio lower than 3 are used to classify the NAG and PAG extractive waste streams.

- *A systematic management process* that allows the extractive waste to be traced back to its original position in the bedrock.
- *Placing NAG extractive waste on the heap's surface* in order to reduce the potential acid formation.
- *Monitoring of the seepage water* within the extractive waste heap (for example by means of lysimeters).

In some cases, such as the Barneys Canyon gold mine, the presence of 5 % PAG extractive waste decreased the pH to 2.6 in the surface rock. However, in this case, the surface rock pH can be raised to 7.3 by selective handling and isolation of ARD materials (Rio Tinto 2011).

5. Cross-media effects
- Concentration of pollutants in the hazardous extractive waste or non-inert non-hazardous extractive waste streams after the separation from the inert extractive waste.
- Energy and water consumption in the sorting and selective handling operations such as manual or automated separation, and physical-mechanical treatments.

6. Technical considerations relevant to applicability
- The choice between different techniques will depend on the characteristics of the extractive waste.

7. Economics
- Sorting and selective handling of extractive waste involve increased costs during operation. At closure, however, the rehabilitation costs may be reduced thanks to the segregation of PAG extractive waste.

8. Driving force for implementation
- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of extractive waste produced.
- Legal and environmental requirements, particularly Article 5 of Directive 2006/21/EC and Commission Decision 2009/359/EC.
- Efficient use of materials.
- Economic benefits: reduction of the extractive waste management costs.
- When applied before mineral processing, improvement of the processing efficiency by avoiding the processing of inappropriate fractions, and reduction of the use of chemicals or energy for mineral processing.
- Maximisation of the lifetime of the extractive waste deposition area (including the EWF).

9. Example sites
- Extractive waste facility Panewniki (PL)
- Boliden Tara Mines (IE)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Aitik Mine (SE)
- Kisladag Gold Mine (TR): separate management of PAG extractive waste (sulphide) and NAG extractive waste (oxide) at the EWF
- Barneys Canyon gold mine, Utah (US)

10. Reference literature
(CEN 2012a)
(Comarmond 1997)
(EC-JRC 2009)
(MEND 2009)
(Rio Tinto 2011)
(Price 1997)
(Soregaroli 2011)

4.1.3.3 Techniques to reduce the volumes of extractive waste to be deposited

4.1.3.3.1 Techniques to prepare for re-use and to recycle flowback and produced water classified as extractive waste from oil and gas exploration and production

4.1.3.3.1.1 Preparing for re-use of liquid extractive wastes

1. Description
The preparing for re-use of flowback and produced water classified as extractive wastes from oil and gas exploration and production stages.

2. Technical description
This BAT candidate is relevant for flowback and produced water from oil and gas exploration and production.

Flowback and produced water may represent a useable water resource.
The volume of flowback water can represent approximately 25-75 % (Royal Society 2012), or 10-80 % (DE UBA 2014), of the injected *fracturing fluids* in the case of high-pressure high-volume well stimulation. If the well is not stimulated, no flowback will be produced.

The volume of produced water will vary greatly from site to site.

Flowback and produced water flowing out of the well are treated as follows:
- They pass through a special device called a *choke manifold*, which allows pressure control.
- At the inlet of the separator there is a sandtrap (see the reduced emissions completion system in Section 4.3.3.3.1) that removes the sand from the flow stream, allowing mainly the natural gas and water to move onto the next separation stages. The collected sand is periodically discharged to a disposal container.
- The flow stream then enters a *phase separator* (see the reduced emissions completion system in Section 4.3.3.3.1). The separation of flowback and produced water creates the following phases:
    - the solid phase which will consist predominantly of sand returning from the hydraulic fracture;
    - the condensate and gaseous phase which come from dissolved natural gas and free-flowing natural gas;
    - the liquid phase which will contain natural minerals and salts from the formation as well as Technically Enhanced Naturally Occurring Radioactive Material (TE-NORM).
- In order to prevent or reduce emissions to air, soil and water, the flowback and produced water are sent to temporary tanks for measurement and appropriate storage until they are partially re-used in the subsequent hydraulic fracturing process, whenever possible, or treated off site in an authorised waste treatment facility. These tanks are located on the well pad membrane, providing additional containment. Once hydraulic fracturing is complete, flowback and produced water are sent to off-site treatment and disposal facilities.

- Either vacuum suction tankers or road barrel containers fitted with a hose will transport the fluid from site storage containers into the haulage containers for off-site disposal.

The flowback water can, as a precaution, be disinfected in order to help maintain the productivity of the fractures and to reduce the risk of bacteria causing souring of the natural gas. UV disinfection can be applied to replace biocide additives within the early stages of exploration.

The technique is mainly implemented in the operational phase of the extractive waste management, although it is also planned in the design phase:

- *Planning and design phase*
  On sites where multiple well drilling activities will be carried out, operators can, in some cases, plan to prepare the flowback and produced water for re-use when planning and designing their extractive waste management. In that case, water storage facilities will be planned and designed along with the extractive waste management.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, the preparing for re-use of flowback and produced water classified as extractive waste enables the reduction of the final amount of extractive waste to be deposited and reduces fresh water intakes.

3. Achieved environmental benefits

- Implementation of the waste hierarchy principles by:
  - minimising the overall generation of liquid extractive waste from oil and gas exploration and production;
  - reducing water consumption and preventing extractive waste disposal.
- Prevention of natural gas fugitive methane emissions through the use of reduced emissions completion.
- Reduction in transport of waste fluids and subsequent impacts associated with emissions to air and noise.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- TE-NORMs concentration in sands to be disposed of according to the applicable regulations.

6. Technical considerations relevant to applicability

- The technique is applicable where the water quality and quantity match the requirements for future use.
- Thresholds on TDS may be applied to define whether the flowback and produced water need to be diluted before being re-used. For example, at the Preston New Road site, if TDS > 250 g/l, the friction reducer does not work and the flowback and produced water are then diluted by mains water. If after dilution TDS is still > 250 g/l, the flowback and produced water are disposed of.

7. Economics

- The preparing for re-use of flowback and produced water between hydraulic fracturing stages and re-use for subsequent wells on a single pad will provide a return on investment by preventing the need to treat, transport and dispose of extractive waste. This will save ~ EUR 69-207 (GBP 50-150, year 2015) per tonne for the transport and treatment.

8. Driving force for implementation

- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of extractive waste produced.
- Efficient use of materials.

- Legal and environmental requirements and local legislation.
- Economic benefits: reduction of costs and optimisation of the oil and gas exploration and production process.

9. Example sites
- Preston New Road (UK)

10. Reference literature
(CH2Mhill 2015)
(Cuadrilla 2014a, b)
(DE UBA 2014)
(Royal Society 2012)
(UK EA 2016)
(UK EA 2015a)
(UK EA 2015b)

4.1.3.3.1.2 Desalinisation of liquid extractive wastes

1. Description
This technique involves the desalinisation of liquid extractive wastes by physical/chemical means.

2. Technical description
This BAT candidate is relevant for flowback and produced water from oil and gas exploration and production.

<u>Physical/chemical separation technologies</u> are used for desalination of produced water and include:
- *MultiStage Flash distillation (MSF)*, where the feed water is heated, the pressure is lowered, and the water "flashes" into steam this process constitutes one stage of a number of stages in series, each operating at a lower temperature and pressure; or
- *Multiple-Effect Distillation (MED)*, where the feed water passes through a number of evaporators in series; or
- *Vapour Compression Distillation (VCD)*, where the feed water evaporates, the vapour is compressed and the heat of condensation is recovered; or
- hybrids of more than one desalination technology; by using hybrid thermal technologies, zero liquid discharge can be achieved through a brine concentrator and crystalliser (CSM 2009); or
- *membrane filtration* (e.g. reverse osmosis).

The technique is mainly implemented in the operational phase of the extractive waste management, although it is also planned in the design phase:
- <u>*Planning and design phase*</u>
  When the preparing for re-use of flowback and produced water is not possible, e.g. due to technical requirements such as water quality, the operator may already consider the recycling of flowback and produced water during the planning and design phase.
- <u>*Operational (construction, management and maintenance) phase*</u>
  During the operational phase, recycling of flowback and produced water classified as extractive waste enables the reduction of the final amount of extractive waste to be deposited and reduces fresh water intakes.

3. Achieved environmental benefits
- Implementation of the waste hierarchy principles by:
  - minimising the overall generation of liquid extractive waste from oil and gas exploration and production.

- In the case of MSF, MED, VCD and hybrids of more than one technology, there is no need to add biocides as the elevated process temperatures will automatically sterilise the water.

4. Environmental performance and operational data
Technical performance data for distillation techniques are reported in Table 4.6.

Table 4.6: Technical performance of distillation of flowback and produced water

Technique	Product water quality	Product water recovery [a]	Typical lifetime [a]
MultiStage Flash Distillation (MSF)	TDS 2-10 mg/l[a]	10-20 %	20 years
Multiple Effect Distillation (MED)	2-10 mg/l[b, d]	Horizontal/Vertical tube: 20-35 % Stacked vertical tube: 67 %	20 years
Vapour Compression Distillation (VCD)	< 10 mg/l[c, d]	40 % for desalination	20 years

[a] *(CSM 2009)*
[b] *(Veolia 2006)*
[c] *(AquaSwiss 2017)*
[d] *(Murray 2017)*

Product water needs stabilisation due to the low TDS level. This may be achieved by lime bed contacting or by blending small amounts of filtered and sterilised feed water with the distillate (CSM 2009).

Operational data (CSM 2009)
- MSF: electricity 2.8-5.7 kWh/m^3 (0.45-0.9 kWh/bbl); thermal energy 21.2 kWh/m^3 (3.35 kWh/bbl).
- MED: electricity 3.03 kWh/m^3 (0.48 kWh/bbl); thermal energy 8.2-12 kWh/m^3 (1.3-1.9 kWh/bbl)]. The total energy consumption is lower than for MSF.
- The power consumption for VCD is lower than for MSF and MED.
- To achieve zero liquid discharge, the energy demand for concentrate evaporation and crystallisation is ~ 26.5-66.5 kWh/m^3 (4.2-10.5 kWh/bbl).

5. Cross-media effects
- Energy consumption for heating the feed water.
- Scale inhibitor and acid are needed (CSM 2009).

6. Technical considerations relevant to applicability
- Feed water requires screens and rough filtration to remove large suspended solids.
- MSF and MED are usually applicable to liquid streams with high TDS (for MSF up to 40 000 mg/l, for MED > 40 000 mg/l), and all types of water chemistry makeup.
- MSF and MED often require centralised design and construction of large-scale plants. VCD installations are small-scale plants.

7. Economics
- MSF:
  - CAPEX: EUR 1.18-1.70 per m^3/h (USD 250-360 per bpd (0.0066 m^3/h), year 2009);
  - OPEX: approximately EUR 0.55/m^3 (USD 0.12/bbl, year 2009);
  - total unit costs: EUR 0.87/m^3 (USD 0.19/bbl, year 2009) (CSM 2009).
- MED:
  - CAPEX: EUR 1.18-1.70 per m^3/h (USD 250-360 per bpd (0.0066 m^3/h), year 2009);

- OPEX: approximately EUR 0.50/m^3 (USD 0.11/bbl, year 2009);
- total unit costs: EUR 0.73 EUR/m^3 (USD 0.16/bbl, year 2009) (CSM 2009).

- VCD:
  - CAPEX for seawater desalination: EUR 0.66-1.18 per m^3/h (USD 140-250 per bpd (0.0066 m^3/h), year 2009);
  - OPEX: approximately EUR 0.34/m^3 (USD 0.075/bbl, year 2009);
  - total unit costs: EUR 0.36/m^3 (USD 0.08/bbl, year 2009) (CSM 2009).

8. Driving force for implementation
- No information provided.

9. Example sites
- Examples reported in the US (CSM 2009)

10. Reference literature
(AquaSwiss 2017)
(CSM 2009)
(Murray 2017)
(Veolia 2006)

4.1.3.3.1.3 Dehydration of liquid extractive wastes

1. Description
This technique involves the dehydration of liquid extractive wastes by means of freeze and thaw cycles or humidification and dehumidification cycles.

2. Technical description
This BAT candidate is relevant for flowback and produced water from oil and gas exploration and production.

Freeze/thaw dehydration is a process that combines freezing and thawing cycles with conventional dehydration technology for treating the flowback and produced water. When the air temperature is below 0 °C, the feed (saline) water is sprayed onto a freezing pad to create an ice pile. Relatively pure ice crystals form and an unfrozen solution (brine) with elevated concentrations of the dissolved constituents drains from the ice. The run-off can be diverted to a brine storage facility or back to the feed water storage facility for recycling. When the temperature rises, the ice melts and the run-off from the freezing pad is highly purified water (CSM 2009).

Dewvaporation is a process that involves humidification and dehumidification cycles for treating the flowback and produced water. It reduces the energy costs by using countercurrent heat exchange technology. Feed water is evaporated by heated air, which condenses as fresh water on the opposite side of a heat transfer wall. Screens (> 300 microns) are required if debris is present in the produced water to protect the pumps and valves in the incoming lines (CSM 2009).

The technique is mainly implemented in the operational phase of the extractive waste management, although it is also planned in the planning and design phase:
- *Planning and design phase*
  When re-use of flowback and produced water is not possible, e.g. due to technical requirements such as water quality, the operator may already consider the recycling of flowback and produced water during the planning and design phase.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, recycling of flowback and produced water classified as extractive waste enables the reduction of the final amount of extractive waste to be deposited and reduces fresh water intakes.

3. Achieved environmental benefits

- Implementation of the waste hierarchy principles by:
    - o minimising the overall generation of liquid extractive waste from oil and gas exploration and production;
- Produced water requires minimal pretreatment.
- The electricity requirement is low because dewvaporation operates at ambient pressure and a low temperature.
- No chemicals are used (CSM 2009).

4. Environmental performance and operational data

Technical performance data are reported in Table 4.7.

Table 4.7: Technical performance of dehydration of flowback and produced water

Technique	Water quality after treatment[a]	Removal efficiency [a]	Water recovery [a]	Expected lifetime [a]
Freeze/thaw dehydration	TDS 1 000 mg/l	90 % of TSS, TDS, TRPH, VOC, SVOC, heavy metals	50 % in winter No water recovered in other seasons	20 years
Dewvaporation	TDS 20-100 mg/l	High removal rate of heavy metals, organics, and radionuclides	~ 90 %	NI*

** NI stands for No Information.*
[a] (CSM 2009)

The freeze/thaw evaporation process generates waste streams: oil from the oil water separators (if present) and concentrated brine.

Product water needs remineralization due to the low TDS level. This may be achieved by lime bed contacting or by blending small amounts of filtered feed water with the distillate. The 10 % brine stream is transported off site

5. Cross-media effects

- Energy consumption.

6. Technical considerations relevant to applicability

- High energy consumption might be a limiting factor for its applicability if no waste heat or cheap energy sources are available.
- Freezing operations only take place when ambient temperatures are below freezing point (0 °C).
- In the freeze/thaw dehydration, the TDS content of the feed water could be > 40 000 mg/l. Produced water with a high methanol concentration cannot be treated. This technique is excellent for zero liquid discharge of produced water, but it may be limited by land availability and climatic conditions.
- Dewvaporation is applicable for a TDS content of up to 40 000-60 000 mg/l and a broad variety of water chemistry makeup. No special infrastructure is required.

7. Economics

Freeze/thaw evaporation is strongly application- and location-specific.

- According to CSM (CSM 2009), a 6.6 m^3/h (1 000 bpd) facility will require:
    - o total installed CAPEX: EUR 1.1-1.4 million (USD 1.75-2 million, year 2009) for a turnkey operation;
    - o annual OPEX: EUR 3.4-4.5/m^3 (USD 0.75-1.00/bbl, year 2009).
- Data are not available for dewvaporation.

8. Driving force for implementation
- No information provided.

9. Example sites
- Examples reported in the US (CSM 2009)

10. Reference literature
(CSM 2009)

4.1.3.3.2 Techniques to prepare drilling muds and other drilling extractive wastes from oil and gas exploration and production for off-site treatment and/or disposal

1. Description
This technique consists of preparing drilling muds and other drilling extractive wastes from oil and gas exploration and production for off-site treatment and/or disposal.

2. Technical description
This BAT candidate is relevant for drilling muds and other drilling extractive waste from oil and gas exploration and production.

Based on literature information ((UK EA 2016) and (IOGP 2016)), drilling muds and other drilling extractive wastes from oil and gas exploration and production are prepared for off-site treatment and/or disposal through the following activities:
- the separation of drill cuttings from the drilling muds by means of solid/liquid control techniques (e.g. shale shakers or equivalent) (see Section 4.2.2.1.1.1);
- the further removal of the finer fraction of drill cuttings from the drilling muds by means of e.g. mud cleaners, hydro-cyclones and centrifuges (see Sections 4.2.2.1.1.2 and 4.2.2.1.1.4);
- the characterisation of the drill cuttings (see Section 4.1.2.1.1);
- the re-use of the recovered drilling muds for the drilling operation;
- the sorting and selective handling of drill cuttings derived from the use of water-based muds from drill cuttings derived from oil-based muds;
- the temporary storage of drill cuttings not releasing VOCs or other potential air pollutants into open containers (e.g. skips) designated for either oil-based cuttings or water-based cuttings and separate from any spent drilling muds pending collection;
- the temporary storage of drill cuttings releasing VOCs or other potential air pollutants into closed containers/tanks designated for either oil-based cuttings or water-based cuttings and separate from any spent drilling muds pending collection (see Section 4.3.3.3.2);
- the sorting and selective handling of hazardous and non-hazardous waste (see Section 4.1.3.2.2);
- the covering of open containers for the temporary storage of drill cuttings, to prevent the ingress of water;
- the reduction of the hydrocarbon concentrations in drill cuttings (see Section 4.2.2.3.2); or the removal of drill cuttings from the site, followed by off-site treatment and/or disposal (see also Section 4.3.3.3.2).

The technique is implemented in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  The preparation of drilling muds and other drilling extractive wastes from oil and gas exploration and production for off-site treatment and/or disposal is planned and designed.
- *Operational (construction, management and maintenance) phase*
  The technique is implemented.

3. Achieved environmental benefits

- Implementation of the waste hierarchy principles by:
    - minimising the overall amount of extractive waste from oil and gas exploration and production to be deposited.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- No information provided.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of extractive waste produced.
- Legal and environmental requirements and local legislation.

9. Example sites

- No information provided.

10. Reference literature

(IOGP 2016)
(UK EA 2016)

4.1.3.3.3 Techniques for the recovery of extractive waste

This BAT candidate is relevant for solid extractive waste containing valuable resources that can be re-used or recycled.

Re-processing of extractive waste is encouraged in order to recover valuable resources.

Examples of extractive waste re-processing exist for extractive waste from coal extraction (such as in the EWF Panewniki) and metal extraction (such as in the Alteo Gardanne site). Re-processing of extractive waste depends on various factors but is mainly linked to the economic viability. If an adequate re-processing technique is available and the economic context is favourable, extractive waste may become a deposit and re-processing may be planned, designed and carried out.

In some cases, re-processing of extractive waste can be seen as an opportunity to properly remediate and rehabilitate an old extractive waste management site.

The following steps are used for recovery of coal and aggregates from the extractive waste resulting from coal extraction at Panewniki (Poland):
1. Raw material delivery and first classification.
2. Classification of material for washing process.
Three grain classes are separated:

- a coarse fraction (40-100 mm), which is pre-sorted, crushed and used for site rehabilitation;
- an intermediate fraction (2-40 mm), which is re-processed using a wet treatment process to recover coal and aggregates;
- a fine fraction (0-3 mm), which is also re-processed.

The following steps are used for the management of red muds at Alteo, Gardanne (France):

1. after the Bayer process, red muds are filtered using filter press;
2. residual water is filtered using a diastar filter to remove suspended matter;
3. dried red muds are stored as secondary materials for potential further use;
4. planned further uses are e.g. construction industry, ARD treatment or pigment production.

4.2 Risk-specific BAT candidates to ensure safety

4.2.1 Short-term and long-term structural stability of the extractive waste deposition area (including the EWF)

General information on the construction and management principles of the extractive waste deposition areas (including EWFs) can be found in Section 4.1 of the MTWR BREF (EC-JRC 2009).

4.2.1.1 Design for closure approach

A design for closure approach, sometimes denoted as Life Cycle Management (LCM), consists of continuously adapting and improving the management of deposition areas (including EWFs) and extractive waste, based on the outcomes of the O&CMS tools and the monitoring results during the whole life cycle of the extractive waste deposition area (including the EWF), i.e. from the planning and design phase, the operational (construction, management and maintenance) phase, until the end of the closure and the after-closure phase.

The design for closure approach implies a commitment of the operator to the appropriate and enforced application of available engineering and monitoring techniques in the life cycle phases. The design for closure approach consists of continuously adapting the management of the extractive waste deposition area (including the EWF) during the different phases of the whole life cycle, in order to achieve a safe and environmentally sound closure, taking into consideration that:

- operators constantly calibrate and adapt the extractive waste management strategy based on:
  - monitoring of flows and chemistry of the run-off, seepage and drainage water;
  - impacts recorded on the quality of the surface water and the groundwater, the air quality and biodiversity;
  - specific safety parameters;
- in some cases, such as large ponds, construction and operation can occur at the same time, as dams might be constructed in several stages including operations;
- progressive rehabilitation can be carried out in some areas of the EWF while other areas are still in the operation and maintenance phase;
- the management of water is usually an integral part of the entire life cycle of the mineral resources exploitation and the extractive waste management.

4.2.1.1.1 Design for closure

1. Description
This technique consists of applying a design for closure and after-closure approach by including an initial closure and after-closure planning for the extractive waste deposition area (including the EWF) and by reviewing it during the whole life cycle.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps (permanent and temporary).

The design for closure technique helps ensure short- and long-term safe deposition of the extractive waste, *in particular by considering, during the design phase, management during the operation and after-closure of a waste facility and by choosing a design which:*

- *requires minimal and, if possible, ultimately no monitoring, control and management of the closed waste facility;*
- *prevents or at least minimises any long-term negative effects, for example attributable to migration of airborne or aquatic pollutants from the waste facility; and*

- *ensures the long-term geotechnical stability of any dams or heaps rising above the pre-existing ground surface.*

(Article 5(2)(c) of Directive 2006/21/EC)

To achieve environmentally responsible management of extractive waste, it is important that the extractive waste deposition is planned and designed for closure from the very beginning and that appropriate attention is given to quantification of the long-term environmental behaviour and stability of the extractive waste deposition area (including the EWF). The long term can be as long as 1 000 years or more (up to 2 000 years in the US) in the case of large ponds containing extractive waste (ICOLD 2011a; UNECE 2014).

A further consideration to be kept in mind when defining the closure design lifetime is the probability of exceeding an extreme design flood or earthquake event. The return periods for the design criteria to be applied for the design life can be estimated on the basis of assuming a probability of exceedance. The probability of exceeding the design value during the design lifetime may be calculated assuming that the occurrence of seismic or flood events follows a Poisson process: $P = 1 - e^{-t/T}$. For example, using a closure design life of 1 000 years, the return period calculated for a probability of exceeding the design value of 10 % would result in approximately 10 000 years (ICOLD 2011a).

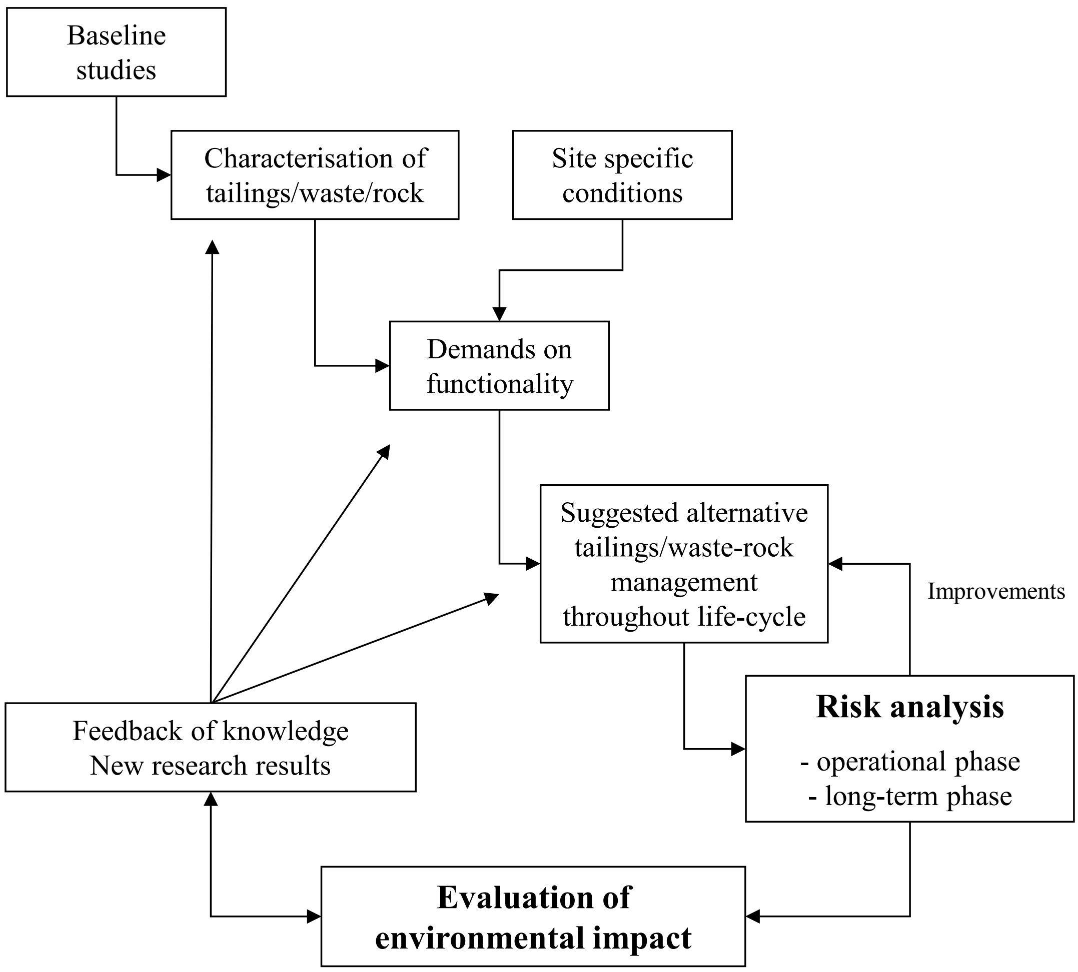
The design for closure principle implies that decisions on the design of an extractive waste deposition area (including the EWF) are based on targeted performance in the after-closure phase in order to minimise closure costs and environmental impacts.

Closure and after-closure planning of the extractive waste deposition area (including the EWF) is developed at the planning and design phase and may include the following (ICOLD 2011a; IFC 2007):

- a preliminary identification of the covering techniques (see Section 4.3.1.3);
- a preliminary identification of the techniques to prevent and control water and wind erosion (see Section 4.2.1.3.5, Section 4.3.3.1);
- an assessment of costs related to the proposed and alternative closure strategies, including a cost-benefit analysis;
- an Environmental Risk and Impact Evaluation;
- a specific indication of the closure process to be followed, specifying how the rehabilitation will be progressively carried out during the operation phase, unless progressive rehabilitation is not possible, in which case it will be entirely carried out in the closure phase; in the latter case, the initial closure and after-closure planning explicitly states if a dry or wet cover will be implemented and provides details on the final landform and surface rehabilitation;
- a design of the EWF that takes into consideration possible premature closure;
- long-term stability analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2);
- a proposal for the control and monitoring procedures to be carried out during the after-closure phase (see Sections 4.1.2.1.2, 4.2.1.3.6.3, 4.3.1.5.1, 4.3.2.2.7.2 and 4.3.3.4.2).

If possible, the closure and after-closure planning for the extractive waste deposition area (including the EWF) is integrated into the periodic extraction plans.

Figure 4.5 illustrates the information flow for a design for closure.



Source: (EC-JRC 2009)

Figure 4.5: Illustration of the information loop for a design for closure

By definition, operators responsible for the management of extractive waste implement a design for closure at the planning and design phase of the extractive waste management. A review of the planned and designed extractive waste management is carried out during all the life cycle phases of the extractive waste management, e.g. depending on changes and new data and information.

- *Planning and design phase*
  Implementation of the design for closure.
- *Operational (construction, management and maintenance) phase*
  Possible review and modification of the planned and designed extractive waste management strategy including the closure and after-closure phase, particularly when progressive rehabilitation is carried out during operation.
- *Closure and after-closure phase*
  Possible review and modification of the planned and designed closure and after-closure phase. The final closure plan is provided.

3. Achieved environmental benefits

- Helping to ensure the long-term structural stability of the extractive waste deposition area (including the EWF).
- Improvement of the overall environmental performance of the extractive waste management.
- Integrated approach taking into consideration long-term and cumulative effects.

- Prevention or minimisation of resource consumption from the management of extractive waste.

4. Environmental performance and operational data
According to Rico and co-authors (Rico *et al.* 2008b), poor management is the third identified cause of dam incidents after unusual rain and seismic liquefaction. It includes inappropriate dam construction procedures, improper maintenance of drainage structures and inappropriate long-term monitoring programmes.

According to the studies of Rico and co-authors (Rico *et al.* 2008b) and Azam and Li (Azam and Li 2010), in which different dam failure databases are analysed, all failures of European dams retaining extractive waste have occurred in dams of less than 45 m in height, of which about a third were in dams of 20-30 m in height and containing a maximum volume of extractive waste from mineral processing of $5x10^6$ m^3 (29 % for pre-2000 cases and 40 % for post-2000 cases).

5. Cross-media effects
- None identified, as by definition the design for closure takes into consideration all aspects of the extractive waste management in order to minimise or reduce as far as possible all negative impacts and the cross-media effects.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- Applying a design for closure approach can considerably reduce the final closure and after-closure costs as the possible closure challenges will be anticipated.

- According to the SME Handbook (Orman *et al.* 2011), proper planning and design are imperative to avoid clean-up and remediation costs due to EWF failures, which can reach several hundred million euro (e.g. Aznalcóllar ~ EUR 240 million, Mount Polley ~ EUR 150 million, Baia Mare EUR 190 million (Kossoff *et al.* 2014), Samarco ~ EUR 5 000 million (Boadle and Eisenhammer 2016). Furthermore, in the Samarco failure, the Brazilian Court imposed a daily fine of EUR 0.25 million until the measures to fully contain the seepage from the burst dam containing extractive waste were implemented (BR MPMG 2016).

8. Driving force for implementation
- Accounting for long-term failure risks and the cumulative effects of repeated occurrence of extreme events or progressive processes such as internal erosion, which can degrade the dam stability over time.
- Risk prevention. The design for closure can be part of the RMS and also of the EMS.
- Legal and environmental requirements, *inter alia* Article 12 and Article 14 of Directive 2006/21/EC.
- Depending on national legislation, provision for closure can be gradually based on results gathered from monitored performance parameters.
- Economic benefits: reduction of costs during the whole life cycle, including closure and after-closure costs.

9. Example sites
- Galmoy Mines (IE)
- An illustrative case study on a BAT proposal for a minimum-impact mineral processing concentrator is presented in Annex 3.

10. Reference literature
(Azam and Li 2010)

(Boadle and Eisenhammer 2016)
(BR MPMG 2016)
(Chambers and Higman 2011)
(Davies 2001)
(EC-JRC 2009)
(ICOLD 2001a, 2011a, b)
(IFC 2007)
(Kossoff *et al.* 2014)
(Orman *et al.* 2011)
(Rico *et al.* 2008b)

The primary databases for dam failures are:
- United Nations Environmental Protection (UNECE 2014; UNEP 1996);
- International Commission On Large Dams (ICOLD) (ICOLD 2017);
- World Information Service of Energy (WISE 2016);
- United States Commission On Large Dams (USCOLD 1994);
- United States Environmental Protection Agency (US EPA 1997).

4.2.1.2 Additional Organisational and Corporate Management tools

Systematic corporate management systems are, in general, good techniques to be implemented before or at least during operations (see Section 4.1). Additional management techniques and tools for the extractive waste management are developed further in this section.

4.2.1.2.1 Quality Assurance and Quality Control (QA/QC) system

1. Description
A QA/QC system consists of documenting and keeping records of planning, design, construction, operation, maintenance, and rehabilitation works carried out during the life cycle of the extractive waste management.

2. Technical description
Operators responsible for the management of extractive waste implement a systematic QA/QC system in order to provide assurance that quality requirements are fulfilled.

The QA/QC system can be part of a formal Quality Management System (QMS).

As for any O&CMS, operators responsible for the management of extractive waste can adhere to QA/QC systems before the planning and design phase of the extractive waste management.

QA/QC implies that at least the following information has been gathered, considered and archived:

- *Planning and design phase*
    - Extractive waste characterisation (see Section 4.1.2.1).
    - Extractive waste site and management options (see Section 4.1.2.2).
    - Environmental Risk and Impact Evaluation (see Section 4.1.2.3).
    - Extractive waste deposition area (including the EWF) design (see Section 4.2.1.3).

- *Operational (construction, management and maintenance) phase*
  The QA/QC system is implemented by documenting the following information relating to the:
    - construction phase:
        - records of any deviation and change from the original design;

        - records of the results of test work carried out before and during construction;
        - "as-built" documentation;
    - operational phase:
        - OSM manuals for dams (see Section 4.2.1.2.3);
        - internal and/or external (independent) auditing plans and reports, and/or inspection reports, conformity/non-conformity reports;
        - documented corrective measures and results;
        - monitoring reports.

- *Closure and after-closure phase*
  The QA/QC system is implemented by documenting the following information:
    - "as-built" documentation and adjustments of the closure plan, highlighting the long-term closure objectives including physical, chemical and biological stability and subsequent land use;
    - specific closure issues for:
        - heaps;
        - ponds, including:
            - water-covered ponds;
            - dewatered ponds;
            - water management facilities.

Information, including reports, collected and documented for other purposes may be re-used to this end.

3. Achieved environmental benefits
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
    - preventing or reducing inappropriate QA/QC of processes.
- Improvement of the overall environmental performance of the extractive waste management.
- Timely detection and implementation of corrective measures to ensure the optimum functioning of the extractive waste management site (including the EWF).

4. Environmental performance and operational data
As an example, 62 out of 87 sites were operated with a QMS, of which 42 were certified by a third party, based on information reported by operators via the questionnaires.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation
- Accounting for long-term failure risks and the cumulative effects.
- Risk prevention.
- Legal and environmental requirements.
- Economic benefits: reduction of costs during the whole life cycle.

9. Example sites

- Generally applied in Europe. Operators adhere to a QMS in many sites that participated in the questionnaire exercise (62 out of 87).

10. Reference literature

(EC-JRC 2009)

4.2.1.2.2 Management of changes

For some extractive waste deposition areas (including EWFs) the distinction between construction and operational phases is not so clear, because often construction continues or reoccurs during operation (e.g. raising of the dam). Construction of the extractive waste deposition area (including the EWF) will be well documented and follows the construction plan established in the design phase. "As-built" documentation is provided highlighting any changes compared to the construction plan.

A Management of Changes system will define the procedures to follow when changes in the design/construction/personnel occur in comparison to the initial plan and includes the systematic documentation of these changes. Such a system can be part of an O&CMS and may be in place at the level of the organisation before the planning and design phase of the extractive waste management. A review of the management systems is carried out during the life cycle phases of the extractive waste management listed below.

- *Operational (construction, management and maintenance) phase*
  Operators responsible for the management of extractive waste adhere to a Management of Changes system.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

4.2.1.2.3 Operation, Supervision and Maintenance manual for dams

1. Description

The Operation, Supervision and Maintenance (OSM) manual is a dam safety manual, which is a living document that compiles all the relevant information related to the dam.

2. Technical description

This BAT candidate is relevant for ponds with dams where free water has to be properly managed.

According to the MTWR BREF (EC-JRC 2009), the OSM manual may include the following:

- *Dam safety organisation*: the dam safety organisation consists of one dam safety manager appointed at each site and supported by one safety co-ordinator. For operation, supervision and maintenance, the manager will also utilise people in his own organisation, often the same staff responsible for the environmental sampling and supervising the extractive waste deposition area (including the EWF).
- *Emergency planning* including the emergency plan specifically required for Category A EWFs according to Article 6 of Directive 2006/21/EC, and information from the external emergency plan insofar as it is available to the operator.
- *Environmental Risk and Impact Evaluation*: classification according to the dam failure consequences (according to Directive 2006/21/EC and the related Commission Decisions).
- *Dam design and construction*: from the starter dam to its present height, a full description is recorded of the type of construction and material used, the name of the contractor, any

problems that occurred during construction, the type of spillway, the volume of extractive waste and water being deposited, etc. In this way, at any time, all information required about the dam that is relevant for safety can be easily found.

- *Design of the water-related structures and free water management* (see Section 4.2.1.3.4).
- *Operation*: detailed up-to-date instructions are given on the way the facility is operated to meet design requirements, respond to extractive waste properties, and to fulfil the demand for process water and react to climatic conditions. Everybody working on the dam is trained on these instructions.
- *Systematic review and verification of the extractive waste characteristics (see Section 4.1.2.1.2) and of the physical stability of the extractive waste deposition area* (see Section 4.2.1.3.6.3): supervision and correct operation of the extractive waste deposition area (including the EWF) are probably the most important requirements to obtain a high level of dam safety. Supervision requires suitable instrumentation, which in turn requires competent staff to evaluate the results and to draw the correct conclusions from them. Regular monitoring is carried out by means of routing site conformance checks by operators, supervision, inspection and external audits.
- *Environmental monitoring plan* (see Sections 4.3.1.5, 4.3.2.2.7 and 4.3.3.4).
- *Closure and after-closure planning*.
- *Permits*: it is common practice to compile all permits given for the extractive waste deposition area (including the EWF) to make it easy to check how operations are faring with the given permits.
- *Additional information regarding safety*: after completion of the safety manuals, considerable effort has to be made to implement the OSM manuals on site and to educate staff working at the facility. Implementation of OSM manuals and the education of staff are an ongoing project, connected with the yearly inspection. The result of the inspection is presented to all relevant staff, and further education may be linked to this.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- <u>Operational (construction, management and maintenance) phase</u>
  Operators responsible for the management of extractive waste deposition areas (including EWFs) designed and constructed with dams usually develop a specific manual for the OSM of such an EWF. The manual is a living document which gathers all the relevant information and documents related to the dam.
- <u>Closure and after-closure phase</u>
  The OSM manual is maintained and reviewed.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
    - ensuring the availability of effective additional Organisational and Corporate Management tools;
    - ensuring easy access to all relevant information if any incident/accident occurs.
- Prevention and reduction of negative environmental impacts.
- Mitigation of accidents.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics
- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

- It is not possible to give reliable cost figures for the manpower required for the creation and maintenance of the manuals. However, the cost is comparable to that of other management systems. Two factors that will influence the cost are the amount of information already compiled in the design phase of the site and the size of the operation, according to the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation
- Improved risk management and safety, with particular regard to the occupational safety.
- Surveillance and early warnings.

9. Example sites
- LKAB Kiruna Iron ore Mine (SE)
- Pyhäsalmi Mine Oy (FI)

10. Reference literature
(EC-JRC 2009)
(UNEP 2001)

4.2.1.2.4 Mitigation of accident procedures including emergency planning

1. Description
"Mitigation of accident procedures" consists of a system for documenting all information related to accidents and incidents, including follow-up procedures. It may include emergency planning, the internal emergency plan specifically required for Category A EWFs, information from the external emergency plan insofar as it is available to the operator, investigation of accidents and incidents, and suggestions on how to prevent the event from happening again. It may also include warning systems and a plan for uncontrolled discharge of extractive waste or EWIW resulting for example from EWF failure due to the loss of structural integrity or the breakage of the basal structure.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps (permanent and temporary) and for excavation voids where extractive waste is placed back.

Operators responsible for the management of extractive waste develop systematic procedures for the mitigation of accidents including accident planning. These procedures can be part of O&CMS (see Section 4.1.1.1) such as an EMS (see Section 4.1.1.2) and/or a RMS. These procedures are usually implemented within the standardised management system, such as ISO 18001 and ISO 14001.

Mitigation of accident procedures is usually put in place in the operational phase and closure and after-closure phase. The data and information collected during the site characterisation and the Environmental Risk and Impact Evaluation are used, among others, as input information to develop these procedures.

When an incident occurs, it is reported and documented, e.g. what happened and why it happened. At the same time, suggestions on how to prevent the event from happening again are developed together with the names of the persons responsible for performing the suggested action and a deadline for when the action should be achieved by. If the system is computerised, it is easy to keep track of measures that were/are performed to prevent a recurrence of an incident.

Emergency planning may include warning systems and a plan for uncontrolled discharge of extractive waste or EWIW resulting for example from EWF failure due to the loss of structural integrity or the breakage of the basal structure. Emergency planning is usually coordinated with the municipal rescue services and other actors to handle accidents.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- *Operational (construction, management and maintenance) phase*
  Procedures are put in place and may be reviewed. Warning systems can be also put in place.
- *Closure and after-closure phase*
  The documentation is maintained and reviewed.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term stability of the extractive waste deposition area (including the EWF) by:
  - ensuring the availability of proper emergency planning and procedures for the mitigation of accidents.
- Prevention and reduction of negative environmental impacts.
- Mitigation of accidents

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- Improved risk management and safety, with particular regard to the occupational safety.

9. Example sites

- Galmoy Mines (IE)

10. Reference literature

(EC-JRC 2009)

4.2.1.3 Extractive waste deposition on surface areas (including EWFs)

4.2.1.3.1 Ground investigation

1. Description

This technique consists of investigating the geotechnical and hydrogeological properties of the supporting strata before the construction of the extractive waste deposition area (including the EWF).

2. Technical description

This BAT candidate is relevant for ponds with dams and for heaps.

The geotechnical and hydrogeological site investigations for the construction of extractive waste deposition areas (including new EWFs or extensions of existing EWFs that will cover new land surface) are carefully planned in the initial concept design and further specified in the detailed design.

According to the SME Handbook (Kerr and Ulrich 2011), the *key objectives* of site investigations and laboratory testing are to:

- confirm potential natural hazards identified during the delineation phase or advanced exploration stage;
- characterise foundation materials through sampling and laboratory tests;
- characterise existing groundwater conditions through drilling investigations;
- determine the geotechnical and hydrogeological properties of the foundation rock and soils and determine the characteristics of quaternary sediments and bedrock topography in glaciated areas;
- confirm the availability and suitability of materials to construct the EWF (dam, embankment, basin liner, drainage system, etc.), including extractive waste from excavation.

Tools for site investigations include:

- test pits for analysing potential construction materials and shallow foundations;
- drill holes for analysing dam/embankment/heap foundations;
- geophysics analysis techniques such as seismic refraction and electrical conductivity;
- pump tests for determining hydrogeological conditions.

A qualified geotechnical engineer supervises site investigation and drilling activities to ensure sampling and testing are completed at appropriate locations, following appropriate methods.

Standards on ground investigation and testing, such as Eurocode 7-2 (EN 1997-2: 2007 - Part 2) (CEN 2007), when relevant, or other ISO, national or international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards, are followed. Eurocode 7-2 provides rules relating to:

- planning and reporting of ground investigations with a specific focus on the locations and depths of the investigation points;
- general requirements for a number of commonly used laboratory and field tests;
- establishment of derived values (values obtained from test results by theory, correlation or empiricism) of geotechnical parameters and coefficients.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- <u>*Planning and design phase*</u>
  Ground investigation is carried out.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The geotechnical and hydrogeological properties of the supporting strata are verified.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing a lack of information about the geotechnical properties of supporting strata;
  - preventing the inappropriate selection of foundations for ponds, dams and heaps.
- Prevention and reduction of negative environmental impacts.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation
- Risk prevention.
- Safety requirements.
- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of produced extractive waste.
- Legal and environmental requirements.
- Quality of the products: standards application (for example Eurocode 7-2 or equivalent).

9. Example sites
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature
(CEN 2007)
(EC-JRC 2009)
(Kerr and Ulrich 2011)

4.2.1.3.2 Dam construction materials selection

1. Description
This technique consists of defining the suitability of materials for the dam construction with reference to geotechnical and environmental characteristics.

2. Technical description
This BAT candidate is relevant for dams.

The materials used in the dam construction are selected based on them fulfilling both geotechnical and environmental criteria.

The suitability of materials for the dam construction with reference to geotechnical and environmental characteristics is defined in accordance with standards such as Eurocode 7-2 (EN 1997–2: 2007 - Part 2) (CEN 2007), when relevant, or other ISO, national or international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.

If extractive waste coarse fractions are to be used for the construction of the embankments/dams, their characteristics are evaluated in the design by means of laboratory tests and verified in the construction phase (see Section 4.1.2.1.1).
- The prime considerations when choosing the dam construction material are that the materials are competent, do not weaken under operational or climatic conditions and do not contain PAG minerals and compounds. Dam construction materials have to present homogeneous characteristics, which also depend on the construction techniques used (see Section 4.2.1.3.3.1).
- The natural ground below the dam and the pond is usually stripped of all vegetation and humic soils in order to provide an appropriate foundation for the structure. This stripped surface needs to be examined for the presence of any springs or groundwater which then needs to be dealt with by a suitable drainage system (e.g. trenches equipped with land drainage pipes surrounded with graded stone and protected with artificial membranes), according to the MTWR BREF (EC-JRC 2009).

- Construction materials are selected to resist weathering and weakening caused by internal and external erosion. They have to be resistant to frost erosion, particularly in boreal and subarctic climates.

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- <u>*Planning and design phase*</u>
  The planned and designed dam construction material required characteristics and the selection procedure are defined.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The suitability of the selected materials for dam construction is verified prior to use.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o preventing the inappropriate selection of dam construction materials.
- Prevention and reduction of negative environmental impacts.

4. Environmental performance and operational data

Average properties of dam construction materials according to the data reported in the questionnaires are shown in Table 4.8.

Table 4.8: Properties of dam construction materials according to the information reported by operators via the questionnaires

Dam construction method	Type	γ_s (kN/m^3)		D_{10} (mm)		D_{50} (mm)		D_{90} (mm)		F.C. (%)	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Upstream	Core	17	22	1	85	25	95	60	100	1	10
	Filter	20				15					
	Shell	17	19	< 0.02		< 0.09		< 0.3		40	
Downstream	Core	21	22	0.01	0.06	0.2	8	5	50	32	
	Filter	22	24	< 4		< 4				1	
	Shell	22	28	1	8	12	600	150	275	6	95
Centreline	Core										
	Filter										
	Shell	20									
Combination	Core	18		0.01		0.06		0.15		52	
	Filter	18		0.45		1		2	1.6		
	Shell	20									

NB:
γ_s = specific gravity.
D_x = x % passing D greater than (x = 10 %; 50 %; 90 %).
F.C. = percentage of fines less than 63 µm sieve.

At the <u>Zinkgruvan site</u>, after being deposited on the beach, extractive waste from mineral processing is drained for 2-3 months before being used as construction materials.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention.
- Safety requirements.
- Compliance with the waste hierarchy principles: to prevent, re-use, recycle and subsequently reduce the amount of produced extractive waste.
- Legal and environmental requirements.
- Quality of the products: standards application (for example Eurocode 7-2 or equivalent).

9. Example sites

- Zinkgruvan Mining AB (SE)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature

(CEN 2007)
(EC-JRC 2009)
(Kerr and Ulrich 2011)

4.2.1.3.3 Construction techniques for dams and heaps

4.2.1.3.3.1 Dam/embankment construction methods

The basal structure has to be designed in order to prevent seepage to groundwater and the risk of soil and groundwater contamination (see Section 4.3.1.1).

The basics of dam construction techniques are included in Section 2.4.3.2.

The most important difference between water supply reservoir dams and dams retaining extractive waste (water and/or solids) concerns their construction, service lives and materials used. A dam retaining extractive waste is constructed in several stages that can last over decades and final stability may only be achieved in the closure phase. There is a wide variation in current acceptable design life periods internationally. The planned closure design life of the dam retaining extractive waste is usually as long as 1 000 years or more (up to 2 000 years in the US) in the case of large storage ponds (ICOLD 2011a; UNECE 2014).

4.2.1.3.3.1.1 General dam/embankment construction methods

4.2.1.3.3.1.1.1 Water and solids retention dam construction method

1. Description

A water and solids retention dam is an impermeable dam completely built before the extractive waste is deposited into the pond. It encompasses one stage or various stages raised throughout the lifetime of the dam, where every individual stage is completed before extractive waste deposition begins and deposition ceases before construction of the next stage.

2. Technical description

This BAT candidate is relevant for water and solids retention dams. It is relevant for non-inert extractive waste, including PAG extractive waste.

The basics of water and solids retention dam techniques are included in Section 2.4.3.2.

A water and solids retention dam is an impermeable dam, whose structure (foundations, core, filters and initial shoulders) is completely built before the extractive waste is deposited into the pond. It encompasses one stage or various stages raised throughout the lifetime of the dam.

Water and solids retention dams are designed as dams with low-hydraulic-conductivity upstream layers, filters and drainage systems and a dam basal structure to prevent or reduce seepage.

The following construction materials can be used: natural soils, blasted rock and extractive materials from excavation (including materials from excavation that in principle qualify as by-products/products), concrete, etc.

The technique is implemented in all the life cycle phases of the extractive waste management.

- *Planning and design phase*
  The size and characteristics of the water and solids retention dam are planned and designed.
- *Operational (construction, management and maintenance) phase*
  Construction, monitoring and maintenance of the water and solids retention dam are carried out. Management systems are applied and design for closure is implemented.
- *Closure and after-closure phase*
  In the closure phase, monitoring and maintenance of the water and solids retention dam are carried out. Management systems are applied and design for closure is implemented.
  In the after-closure phase, monitoring and maintenance of the water and solids retention dam are carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing the inappropriate construction of dams;
  - good seismic resistance and stability.

The benefits of using a one-stage dam retaining water and solids consist of:

- construction of the dam takes a short period of time with a good quality control;
- minimal supervision of the dam is required during operation;
- protection against pollution by water and wind erosion.

The benefits of using a staged dam retaining water and solids consist of allowing for design adjustments in the latter stages, gaining experience and accounting for changing conditions (for example land use changes), according to the SME Handbook (Kerr and Ulrich 2011).

4. Environmental performance and operational data

Dams retaining extractive waste have a failure rate that is significantly higher than that of water supply reservoir dams (on average 0.01 % (Davies 2001)). According to literature information (Chambers and Higman 2011; Davies 2001; Kossoff *et al.* 2014), the failure rate of dams retaining extractive waste varies from 0.06 % to 0.14 %. According to Azam and co-authors (Azam and Li 2010), this rate over the last 100 years is estimated to be 1.2 %.

5. Cross-media effects

- Construction materials have to be borrowed from an external site unless extractive residues from the extraction site can be used in the shoulder fill.

6. Technical considerations relevant to applicability

- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management (see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- According to the MTWR BREF (EC-JRC 2009), it is applicable when:

  - a pond is required for the storage of water, usually on a seasonal basis, and extractive waste during the whole life cycle; or
  - retention of water is needed over an extended period; or
  - the site is in a remote and inaccessible location; or
  - the natural inflow into the pond is large or subject to high variations, and water storage is then needed for its control.
- In the case of dams built in stages, the quality of the construction may vary from stage to stage if different contractors, materials and/or QA/QC procedures are used, according to the SME Handbook (Kerr and Ulrich 2011).

7. Economics
- Compared to a one-stage dam, the one built in stages has a lower initial capital cost as the construction is carried out in staged, meaning that the costs are spread more evenly over the period of deposition.

8. Driving force for implementation
- Local conditions that require the construction of a water and solids retention dam.
- Safety requirements and less monitoring requirements.

9. Example sites
- Galmoy Mines (IE)

10. Reference literature
(ANCOLD 2012)
(Azam and Li 2010)
(Chambers and Higman 2011)
(Davies 2001)
(EC-JRC 2009)
(Kerr and Ulrich 2011)
(Kossoff *et al.* 2014)
(Niemeläinen *et al.* 2015b)

4.2.1.3.3.1.1.2 Starter dam for total solids retention and partial water retention dam construction method

1. Description
A total solids retention and partial water retention dam is constructed with a starter dam (usually with a low-hydraulic-permeability core) and can be raised with extractive materials using the appropriate raising method.

2. Technical description
The BAT candidate is relevant for total solids retention and partial water retention dams. It is relevant for inert and non-inert extractive waste.

Total solids retention and partial water retention dams are constructed with a starter dam (usually with a low-hydraulic-permeability core) and can be raised with extractive materials (including extractive materials that in principle qualify as by-products/products) using the appropriate raising method.

Filters and drainage zones are included in the design to permit the safe drainage of the dam, along with the EWIW collection and management systems

The technique is implemented in all the life cycle phases of the extractive waste deposition area:
- *Planning and design phase*

The size and characteristics of the total solids retention and partial water retention dam are planned and designed.

- Operational (construction, management and maintenance) phase
  Construction, monitoring and maintenance of the dam are carried out. Management systems are applied and design for closure is implemented.
- Closure and after-closure phase
  In the closure phase, monitoring and maintenance of the final dam structure, comprised of the starter dam and raised embankments, are carried out. Management systems are applied and design for closure is implemented.
  In the after-closure phase, monitoring and maintenance of the final dam structure, comprised of the starter dam and raised embankments, are carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing the inappropriate construction of dams.

4. Environmental performance and operational data

- In the KGHM Polska Miedź S.A. Żelazny Most tailings pond, the extractive residues from the flotation process (14-20 % solids content) are transported by pipelines to the pond. They are first pumped to the dam crest and then distributed by pipelines forming a ring around the pond. Two additional pumping stations are located at the dam crest in order to support the distribution of the extractive residues by means of parallel pipes placed every 20 m. The coarse fractions of the extractive residues from the flotation process are used for the construction of the dam raises. The dam construction by stages guarantees the proper drainage of the extractive waste and the presence of a stable phreatic surface within the dam body. The discharged extractive residues create a beach with a minimum length of 200 m where their segregation occurs: the coarser fractions settle on the beach, while the finer fractions (0.05-0.002 mm) are transferred into the pond. The longitudinal beach inclination varies from 6.5 ‰ close to the dam to approximately 4.5 ‰ at a distance of 100 m.
  Carbonate-type fine extractive residues are produced by flotation of the ore extracted in the Polkowice-Sieroswice mine and are discharged into the centre of the pond to seal its bottom. The spigotting cycle in every section usually takes ~ 15 weeks. For longer time breaks, the surface of the beach in every section is stabilised by a bituminous water emulsion, sprinkled from a helicopter, aiming at avoiding wind erosion and dusting. The bituminous temporary cover is then removed, when necessary, by heavy equipment.

5. Cross-media effects

- No information provided.

6. Technical considerations relevant to applicability

- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management (see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).

7. Economics

- No information provided.

8. Driving force for implementation

- Local conditions that require the construction of a total solids retention and partial water retention dam.

9. Example sites
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature
(ANCOLD 2012)
(EC-JRC 2009)

4.2.1.3.3.1.2 Dam raising methods

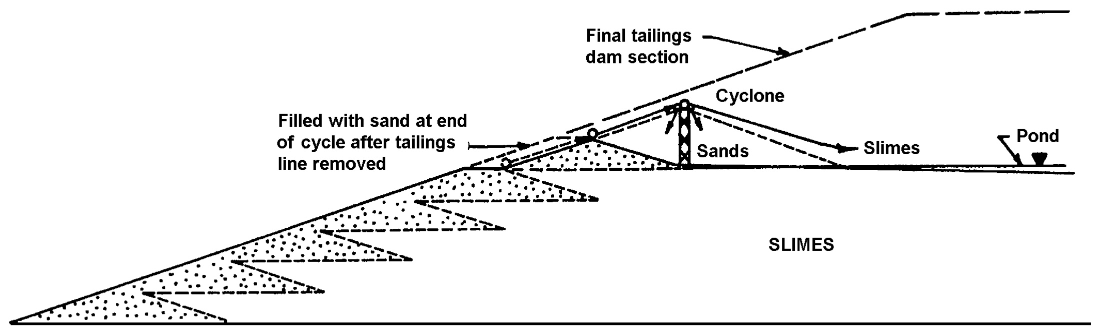
4.2.1.3.3.1.2.1 Upstream raising method

1. Description
An upstream dam is constructed in stages by building embankments on the beach of the previous stage. The centreline of the embankment crest moves upstream with each stage.

2. Technical description
This BAT candidate is relevant for slurried extractive waste retention dams.

The basics of the upstream method are included in Section 2.4.3.2.

Extractive materials used as construction materials are coarse fractions of extractive residues from mineral processing and/or extractive residues from excavation, and may be combined with natural materials. They can be produced by segregation from the fine fraction through a hydro-cyclone or spigotting deposition system. Extractive materials for construction are generated progressively during the EWF lifetime and used for dam construction, i.e. dam raises and lateral expansions, according to the SME Handbook (Kerr and Ulrich 2011). Geotechnical standards on dam construction materials are complied with (see Section 4.2.1.3.2).



Source: (EC-JRC 2009)

Figure 4.6: Upstream method using cycloned extractive materials

The dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events (see Section 4.2.1.3.4.4), and that the phreatic surface is controlled.

The design usually includes filters and drainage zones to permit the safe drainage of the dam, along with the EWIW collection and management systems.

Care is taken in the design stage to control the phreatic surface. This can be achieved by providing a wide enough beach and applying correct drainage and operation. Allowing the phreatic surface to move downstream and intersect the downstream slope of a dam is extremely dangerous (ICOLD 2011b).

Factors negatively influencing the position of the phreatic surface in upstream dams are:

- short distance to the supernatant pond and small length of the beach;
- poor grain size segregation on the beach;
- low permeability in the foundation;
- the decrease of the permeability of extractive residues with depth;
- presence of slime layers;
- not including underdrains.

Key design features to help ensure upstream dam stability include:

- a wide beach to allow for good drainage of the dam (Kossoff *et al.* 2014);
- compaction of beaches to a minimum width to provide a stable dam shell (Davies *et al.* 2002);
- underdrainage (e.g. finger drains or horizontal bored drains) to lower the phreatic level in the dam (Davies *et al.* 2002; ICOLD 2011b);
- a slope angle of 3:1 (H:V) or flatter, depending on the other measures incorporated into the long-term design; steeper slopes, without an appropriately drained and/or compacted beach, create the potential for spontaneous static liquefaction (Davies *et al.* 2002) (see Section 4.2.1.3.6.1);
- an extra dyke on a closed pond containing extractive waste (ICOLD 2011b).

In every case, expert evaluation and assessment, e.g. independent design reviews, are required.

The technique is implemented in all the life cycle phases of the extractive waste management:

- <u>*Planning and design phase*</u>
  In the planning and design phase, the raising method is selected.
- <u>*Operational (construction, management and maintenance) phase*</u>
  During the operational phase, operators raise the dam following the planned design and specifications. QA/QC is performed to ensure that the objectives are met. Design for closure techniques are applied. If necessary, remediation measures are put in place.
- <u>*Closure and after-closure phase*</u>
  In the closure phase, monitoring and maintenance of the final dam structure, comprised of a starter dam and raised embankments built with an upstream method, are carried out. Management systems are applied and design for closure is implemented.
  In the after-closure phase, monitoring and maintenance of the final dam structure, comprised of a starter dam and raised embankments built with an upstream method, are carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Increase of the space availability in the pond.
- Decrease of the footprint of dam embankments.
- Less construction materials required compared to other raising methods.
- Reduction of the need for supplementary natural materials and transport.

4. Environmental performance and operational data

Historical statistics show a higher number of incidents for dams raised with the upstream method than dams raised with other methods, i.e. downstream or centreline (Davies *et al.* 2002; Rico *et al.* 2008a; Rico *et al.* 2008b). In Europe, a total number of 7 and 6 incidents related to dams raised with upstream and downstream methods were reported respectively, whereas worldwide the upstream raising method is associated with almost 60 incidents and the downstream method with ~ 10.

However, it should be noted that the majority of incidents reported in Europe and worldwide refer to unknown dam construction methods, 11 and 70 respectively. Furthermore, the share of the different construction methods, both in Europe and worldwide, is also unknown and this makes it difficult to properly compare the performance of the different raising methods.

For the upstream raising method, a raising rate lower than 5 m/year is generally recommended to avoid insufficient consolidation. For thickened extractive residues from mineral processing, such as red muds, this rate would be in the order of 1-2 m/year.

Average upstream dam characteristics based on site-specific data reported by operators via the questionnaires are provided in Table 4.9.

Table 4.9: Upstream raise characteristics based on site-specific data reported by operators via the questionnaires

Raising method	Number of raises			Total height (m)			Crest width (m)			External slope (°)			Internal slope (°)		
	Min	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*
Upstream*	1	6	13	5	20	67	3	12	90	18	29	60	14	32	70

** Based on 10 questionnaires that reported data on upstream raised dams*

5. Cross-media effects
- Increase of the phreatic surface level and significant seepage through the dam.
- ARD potential of exposed extractive waste on the beaches.

6. Technical considerations relevant to applicability
- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management (see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- This method of construction is not applicable in areas where the slightest risk of liquefaction has been identified after seismic evaluation of (small and large) dams according to ICOLD Bulletin 139 (ICOLD 2011b) and to ICOLD Bulletin 148 (ICOLD 2016) (referred to in BAT 22.a), applied equally to all kinds of upstream dams (ICOLD 2001a; Kossoff *et al.* 2014) (for the definition of large dams see Section 4.2.1.3.6.1, heading 2).
- An additional problem of this method consists of relying entirely on the strength of the extractive residues deposited upstream of the berm. In any case, the dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, and the phreatic surface is strictly controlled, i.e. keeping the phreatic level out of the dam, according to the SME Handbook (Kerr and Ulrich 2011).
- It is not applicable when permanent free water storage is necessary.
- Extractive materials used as construction materials fulfil the requirements of Eurocode 7 or other equivalent standards. Changes in extractive residues' characteristics along the whole life cycle of the EWF have to be carefully considered.
- Regular/continuous monitoring of pore pressure, phreatic surface, consolidation, settlements and liquefaction is mostly required for upstream dams.

7. Economics
- The upstream method is cheaper than the downstream or the centreline methods, due to the lower amount of construction materials needed. By means of a staged construction of the dam, initial capital costs are minimised.

8. Driving force for implementation
- Reduction of costs.
- Reduction of the dam footprint.

9. Example sites
- Zinkgruvan Mining AB (SE)
- Yerakini Mine (EL)
- Wolfram Bergbau und Huetten AG (AT)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Pampalo Mine and Rämepuro Mine (FI)
- Pyhäsalmi Mine Oy (FI)
- Cetățuia II tailing pond (RO)

10. Reference literature
(Davies *et al.* 2002)
(EC-JRC 2009)
(ICOLD 2001a, 2011b, 2016)
(Kerr and Ulrich 2011)
(Kossoff *et al.* 2014)
(Niemeläinen *et al.* 2015a)
(Rico *et al.* 2008a; Rico *et al.* 2008b)
(US EPA 1994)

4.2.1.3.3.1.2.2 Downstream raising method

1. Description
A downstream dam is constructed in stages in such a way that the centreline of the embankment crest moves downstream with each stage.

2. Technical description
This BAT candidate is relevant for slurried extractive waste retention dams.

The basics of the downstream method are included in Section 2.4.3.2.

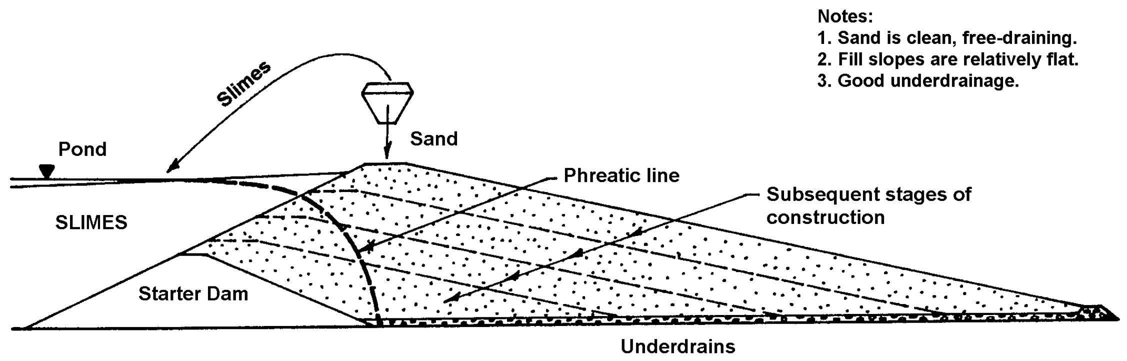
Coarse fractions of extractive residues from mineral processing are separated by hydro-cyclones and used as construction materials to build the dam. According to the MTWR BREF (EC-JRC 2009), where the proportion of the coarse fractions of extractive residues is insufficient to permit the dam to keep ahead of the rise of the pond level, the extractive residue zone may be supplemented by a zone of borrow natural material.

Extractive materials used as construction materials are coarse fractions of extractive residues from mineral processing and/or extractive residues from excavation, and may be combined with natural materials.

The dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events (see Section 4.2.1.3.4.4), and that the phreatic surface is controlled.

The design usually includes filters and drainage zones to permit the safe drainage of the dam along with the EWIW collection and management systems.

For the downstream raising method, an impermeable core keeps the free water in place. If the permeability and the leakage through the core increase, the stability of the dam may be compromised.



Source: (EC-JRC 2009)

Figure 4.7: Downstream construction of a dam using hydro-cyclones

The technique is implemented in all the life cycle phases of the extractive waste management:

- <u>*Planning and design phase*</u>
  In the planning and design phase, the raising method is selected.
- <u>*Operational (construction, management and maintenance) phase*</u>
  During the operational phase, operators raise the dam following the planned design and specifications. QA/QC is performed to ensure that the objectives are met. Design for closure is applied. If necessary, remediation measures are put in place.
- <u>*Closure and after-closure phase*</u>
  In the closure phase, monitoring and maintenance of the final dam structure comprised of a starter dam and raised embankments built with a downstream method are carried out. Management systems are applied and design for closure techniques are implemented.
  In the after-closure phase, monitoring and maintenance of the final dam structure, comprised of a starter dam and raised embankments built with a downstream method, are carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o preventing the inappropriate raising of dams;
  - o providing good seismic resistance.

4. Environmental performance and operational data
See Section 4.2.1.3.3.1.2.1.

Average downstream dam characteristics based on site-specific data reported by operators via the questionnaires are provided in Table 4.10.

Table 4.10: Downstream dam characteristics based on site-specific data reported by operators via the questionnaires

Raising method	Number of raises			Total height (m)			Crest width (m)			External slope (°)			Internal slope (°)		
	Min	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*
Downstream *	1	2	4	5	35	237	6	7	15	23	32	45	24	30	45

** Based on 9 questionnaires that reported data on downstream raised dams*

5. Cross-media effects
- Larger amounts of supplementary natural materials are needed compared to the upstream method to achieve the same height increase.
- Increase of the dam footprint.

6. Technical considerations relevant to applicability
- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management (see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- There are no raising rate restrictions.
- In general, downstream dams are much safer than those built using the upstream method, particularly when subject to seismic loads (Chambers and Higman 2011; ICOLD 2001a).
- The downstream method is not applicable when the dam is not rigorously designed using modern engineering principles to ensure that the embankments are adequately drained and the phreatic surface is controlled.
- The downstream method is not applicable when sufficient amounts of dam construction material are not available, according to the MTWR BREF (EC-JRC 2009).
- Monitoring of seepage and stability is required.

7. Economics
- The cost of the downstream method is higher than for the upstream method.

8. Driving force for implementation
- Risk prevention.
- Safety requirements.

9. Example sites
- Somincor Neves Corvo Mine (PT)
- Galmoy Mines (IE)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Kevitsa Mine (FI)
- Yara Suomi Oy Siilinjärvi Mine (FI)

10. Reference literature
(Chambers and Higman 2011)
(EC-JRC 2009)
(ICOLD 2001a)
(Kerr and Ulrich 2011)
(Niemeläinen *et al.* 2015a)

4.2.1.3.3.1.2.3 Centreline raising method

1. Description
The centreline dam is constructed in stages in such a way that the location of the centreline of the embankment crest does not change with each stage. The upstream toe of each embankment stage is constructed slightly over the beach, but the majority of each new stage is founded on the previous embankment stage.

2. Technical description
This BAT candidate is relevant for slurried extractive waste retention dams.

The basics of the centreline method are included in Section 2.4.3.2.

Centreline construction is a hybrid of downstream- and upstream-type dam construction. It is a good compromise between downstream and upstream methods, according to Chambers (Chambers and Higman 2011) and the Closedure project (Niemeläinen *et al.* 2015a).

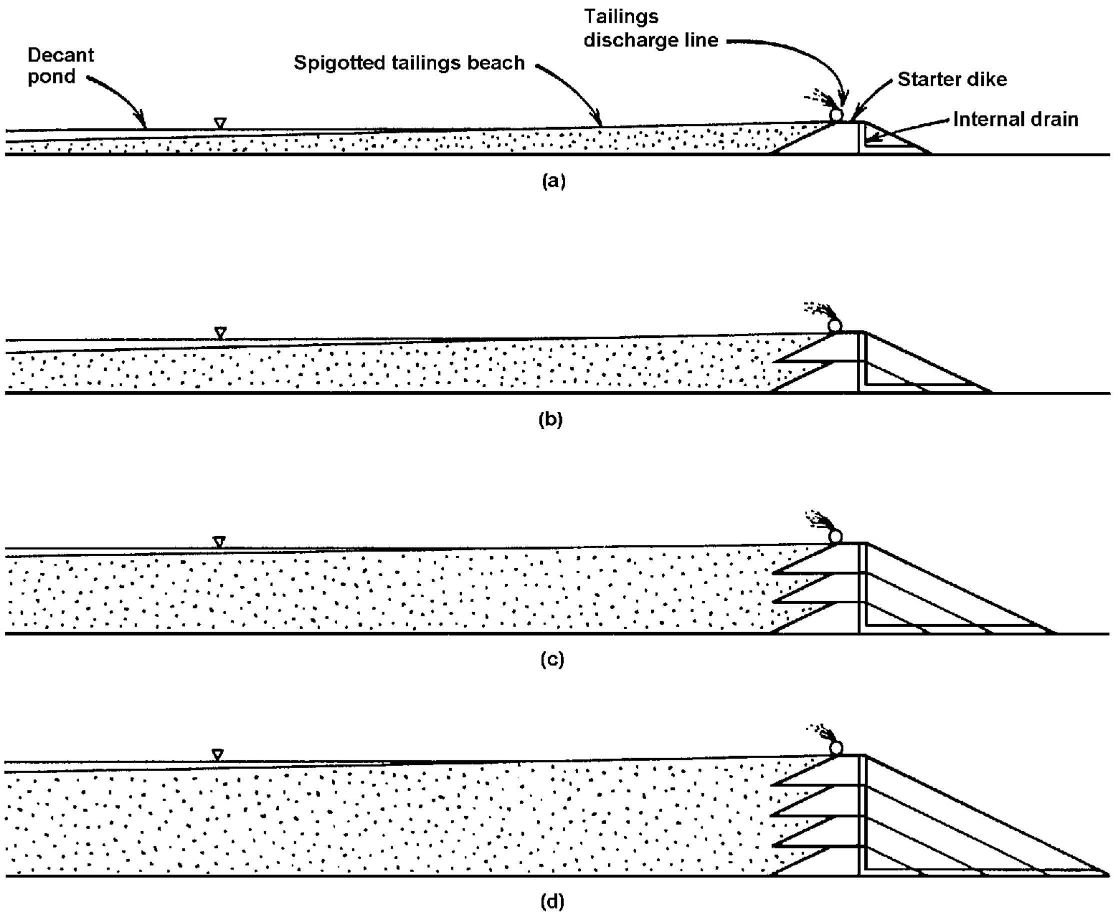
Possible liquefaction of extractive residues as a result of an earthquake loading could create some localised instability of the upstream slope of the most recent stage, but this would not result in significant damage to the dam, according to the SME Handbook (Kerr and Ulrich 2011).

The upstream portion of the dam may be composed of the beach of deposited extractive waste. The upstream face of the dam is progressively supported by the raise of extractive materials. A peripheral discharge system is needed.

The dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events (see Section 4.2.1.3.4.4), and that the phreatic surface is controlled.

The design usually includes filters and drainage zones to permit the safe drainage of the dam along with the EWIW collection and management systems.

Extractive materials used as construction materials are coarse fractions of extractive residues from mineral processing and/or extractive residues from excavation, and may be combined with natural materials.



Source: (EC-JRC 2009)

Figure 4.8: Centreline method

The technique is implemented in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  In the planning and design phase, the raising method is selected.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, operators raise the dam following the planned design and specifications. QA/QC is performed to ensure that the objectives are met. Design for closure techniques are applied. If necessary, remediation measures are put in place.
- *Closure and after-closure phase*
  In the closure phase monitoring and maintenance of the final dam structure comprised of a starter dam and raised embankments built with a centreline method are carried out. Management systems are applied and design for closure is implemented.
  In the after-closure phase, monitoring and maintenance of the final dam structure, comprised of a starter dam and raised embankments built with a centreline method, are carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
    - preventing the inappropriate raising of dams;
    - moderate seismic resistance.

4. Environmental performance and operational data

Dams built by the newer centreline method show relatively few incidents compared to the other methods. Only one incident has been reported in Europe and about five worldwide. However, significantly fewer dams of this type exist, compared with the number built using the upstream method (ICOLD 2011b).

For the centreline method, a maximum raising rate of 5 m/year is also recommended.

Average centreline dam characteristics based on site-specific data reported by operators via the questionnaires are provided in Table 4.11.

Table 4.11: Centreline raise characteristics based on site-specific data reported by operators via the questionnaires

Raising method	Number of raises			Total height (m)			Crest width (m)			External slope (°)			Internal slope (°)		
	Min	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*
Centreline*	1	2	4	6	19	50	4	14	30	19	26	37	14	25	36

** Based on 6 questionnaires that reported data on centreline raised dams*

5. Cross-media effects

- ARD potential of exposed extractive waste on the beaches.

6. Technical considerations relevant to applicability

- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management (see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- This technique is not applicable when:
    - due to its moderate susceptibility to liquefaction under seismic loading, the slightest risk of liquefaction has been identified after seismic evaluation of (small and large) dams according to ICOLD Bulletin 139 (ICOLD 2011b) and to ICOLD Bulletin

148 (ICOLD 2016) (referred to in BAT 22.a), applied equally to all kinds of centreline dams (ICOLD 2001a; Kossoff *et al.* 2014) (for the definition of large dams see Section 4.2.1.3.6.1, heading 2); or
  - construction materials with high plasticity are used; or
  - the water storage is permanent; or
  - the dam is not rigorously designed using modern engineering principles to ensure that the embankments are adequately drained and the phreatic surface is controlled.
- Temporary flood storage is acceptable with proper design.
- Height restrictions for individual raises may apply.
- Monitoring of seepage and stability is required for dams constructed and raised with a centreline raising method.

7. Economics
- The centreline method is often considered a compromise between the higher-cost downstream embankment and the higher-risk upstream embankment, according to the SME Handbook (Kerr and Ulrich 2011).

8. Driving force for implementation
- Risk prevention.
- Safety requirements.

9. Example sites
- Hahnwiese (DE)
- Nordkalk Oy Lappeenranta (FI)

10. Reference literature

(Chambers and Higman 2011)
(EC-JRC 2009)
(ICOLD 2011b, 2016)
(Kerr and Ulrich 2011)
(Niemeläinen *et al.* 2015a)

4.2.1.3.3.1.3 Basal systems for ponds and dams

4.2.1.3.3.1.3.1 Composite basal structure system

1. Description

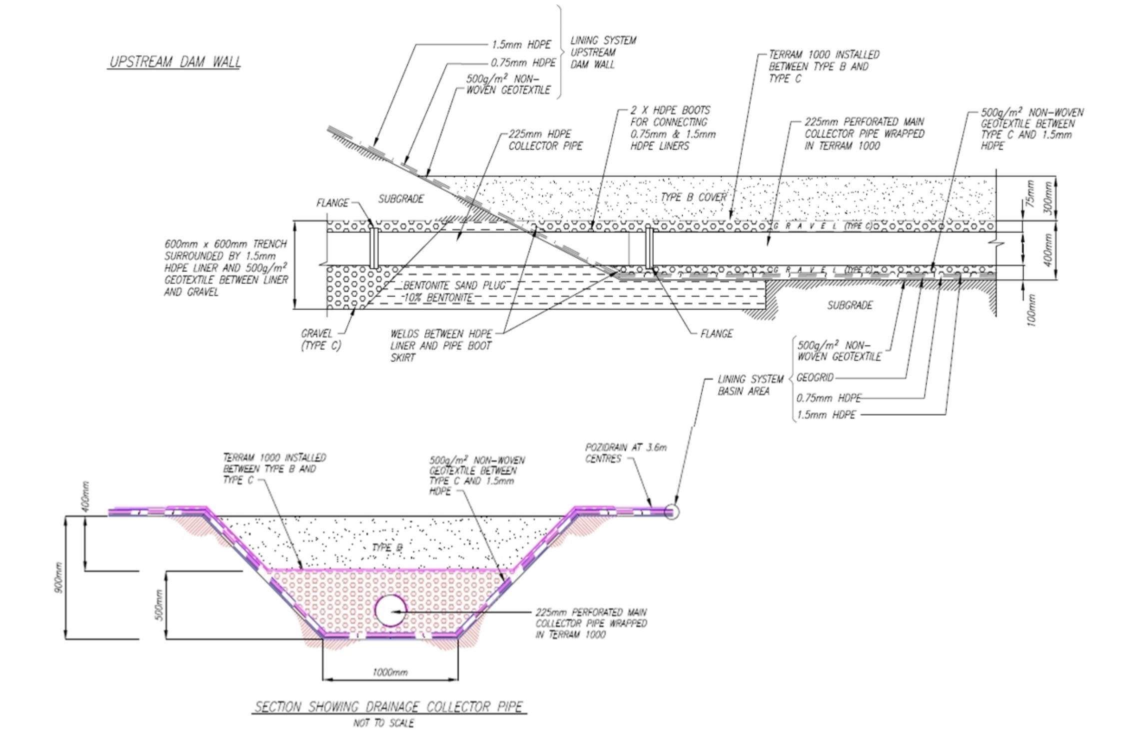
The technique consists of including in the pond/dam design an impermeable basal structure, in combination with a proper drainage system for ponds and dams.

2. Technical description

This BAT candidate is relevant for ponds and dams. It is relevant for non-inert extractive waste.

The technique consists of including in the integrated design an impermeable basal structure (see Sections 4.3.1.1.1 and 4.3.1.1.2), in combination with a proper drainage system for ponds and dams (see Section 4.2.1.3.5.1), designed based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see Section 4.1.2.1.1), the water balance (see Section 4.2.1.3.4.1 and Section 4.2.1.3.4.2) and based on the design criteria resulting from dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1). The basal structure has to be designed in order to prevent the risk of failure and soil and groundwater contamination.

An example of a composite basal structure system is shown in Figure 4.9.



Source: Galmoy Mine questionnaire

Figure 4.9: Example of a composite basal structure system

The technique is applied in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  An impermeable basal structure in combination with a proper drainage system is included in the design.
- *Operational (construction, management and maintenance) phase*
  The composite basal structure system is constructed and put into operation. QA/QC is performed to ensure that the objectives are met. Monitoring and maintenance are carried out.
- *Closure and after-closure phase*
  In the closure phase, monitoring of the composite basal structure system is carried out. Management systems are applied.
  In the after-closure phase, the composite basal structure system is monitored, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o preventing the inappropriate construction of dams and ponds.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- No information provided.

6. Technical considerations relevant to applicability

- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management

(see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- This technique is only applicable to new extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.

7. Economics
- No information provided.

8. Driving force for implementation
- Risk prevention.
- Safety requirements.

9. Example sites
- Galmoy Mines (IE)

10. Reference literature
(EC-JRC 2009)

4.2.1.3.3.1.3.2 Low-permeability natural soil basal structure

1. Description
This technique consists of including in the pond/dam design a low-permeability natural soil layer as the basal structure and partially allowing seepage through this basal structure.

2. Technical description
This BAT candidate is relevant for ponds and dams. It is relevant for inert extractive waste.

A low-permeability natural soil basal structure is included in the integrated design to partially allow seepage from the pond through the basal structure.

If the ground hydraulic conductivity cannot ensure proper drainage at all times, which could possibly lead to structural instability, an additional drainage system is included (see Section 4.2.1.3.5.1) based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see Section 4.1.2.1.1), the water balance (see Section 4.2.1.3.4.1 and Section 4.2.1.3.4.2) and based on the design criteria resulting from dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1).

The technique is implemented in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  The low-permeability natural soil basal structure is planned and designed.
- *Operational (construction, management and maintenance) phase*
  Construction and monitoring of the dam's basal structure is carried out. QA/QC is performed to ensure that the objectives are met.
- *Closure and after-closure phase*
  In the closure phase, monitoring of the low-permeability natural soil basal structure is carried out. Management systems are applied.
  In the after-closure phase, the low-permeability natural soil basal structure is monitored, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

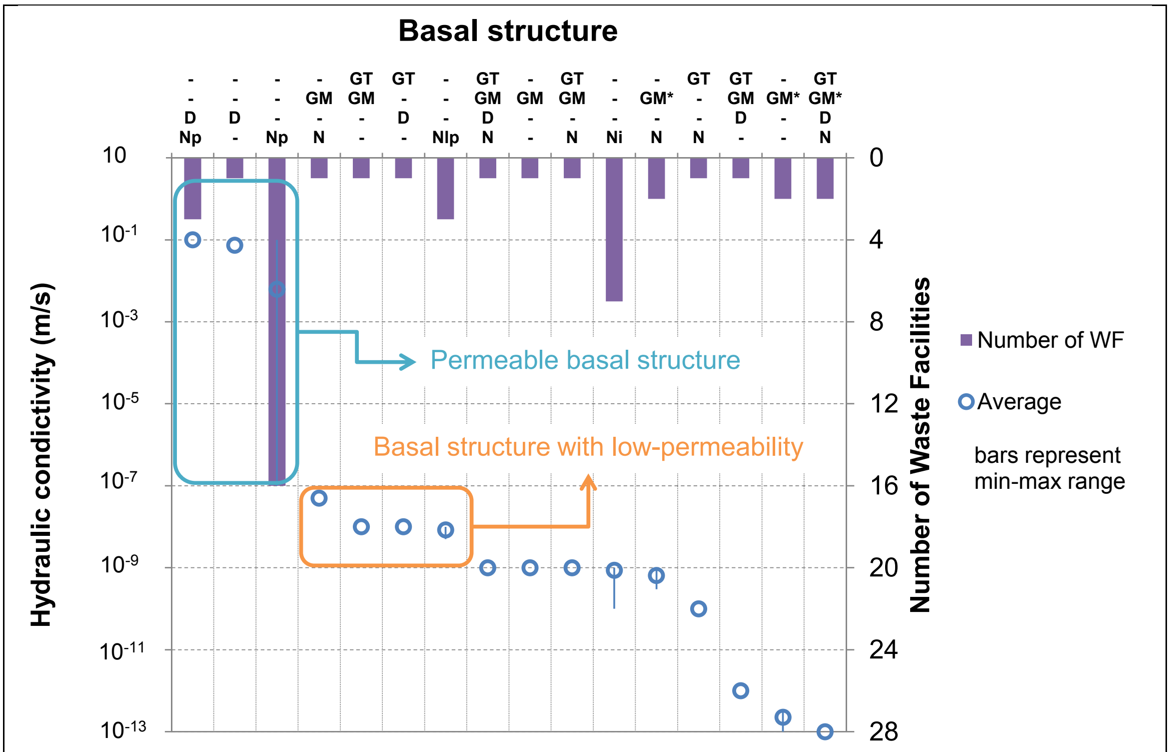
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing the inappropriate construction of dams and ponds.

4. Environmental performance and operational data

Extensive characterisation of extractive waste and soil mapping of the deposition area are essential to ensure that the low-permeability basal structure is suitable for the particular inert extractive waste type at the specific site. Natural soil is uniformly placed over the entire area to avoid unexpected differences in hydraulic conductivities.

Soil layers are often placed as parallel lifts (bathtub) or horizontal lifts (stair step) when constructing a basal structure. Slope angles steeper than 3:1 (H:V) can constitute a limiting factor for placing the soil layer.

According to the site-specific data reported by operators via the questionnaires, the permeable natural soil basal structure will usually have a hydraulic conductivity of 10^{-1} m/s to 10^{-3} m/s (see Figure 4.10) depending on the soil types and characteristics (clay, moraine, etc.). Six sites reported basal structures with low-permeability. Three sites reported to have a low-permability natural soil basal structure.



NB: N=Natural soil; Np=Permeable natural soil; Nlp=Low-permeability natural soil; Ni=Impermeable natural soil; D=Drainage layer; GM= Geomembrane; GM=Synthetic GM; GT=Geotextile.*
The orange box points out the basal structures with low-permeability.

Figure 4.10: Basal structure hydraulic conductivity values reported by operators via the questionnaires

5. Cross-media effects

No information provided.

6. Technical considerations relevant to applicability

- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2), design flood evaluation (see Section 4.2.1.3.4.3), free water management (see Section 4.2.1.3.4.4), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- A permeable or low-permeability natural soil basal structure is only applicable to inert extractive waste, according to Kauppila and co-authors (Kauppila *et al.* 2013) and to the Closedure project (Tornivaara 2015b).

7. Economics

- The costs are lower than in the case of impermeable basal structures because the construction is simple and there are no costs related to the liner systems.

8. Driving force for implementation

- Legal and environmental requirements.

9. Example sites

The technique is generally applied in Europe. A low-permeability natural soil basal structure is encountered in several sites that participated in the questionnaire exercise (6 out of 87).

10. Reference literature

(ICOLD 2011b)
(Kauppila *et al.* 2013)
(Kerr and Ulrich 2011)
(Tornivaara 2015b)

4.2.1.3.3.1.3.3 Impermeable basal structure

See Section 4.3.1.1.1 and Section 4.3.1.1.2.

4.2.1.3.3.2 Heap construction methods

Extractive waste heaps are constructed either top-down or bottom-up. Top-down methods usually refer to dumping whereas bottom-up methods refer to stacking (Orman *et al.* 2011).

4.2.1.3.3.2.1 Bottom-up construction method

1. Description

This technique consists of raising a heap by depositing the extractive waste in layers, followed by compaction if necessary and by the construction of benches when these can improve stability and facilitate further rehabilitation.

2. Technical description

This BAT candidate is relevant for heaps.

Bottom-up methods are also called ascending construction. In this case, extractive waste materials are piled from the bottom layer (the base) to the top using haul trucks, conveyors or a dragline. The extractive waste is generally compacted prior to the next lift. This type of heap construction usually provides more stable heaps (Orman *et al.* 2011; US EPA 1995).

Heaps are formed by extractive waste from excavation and/or coarse fractions of extractive waste from mineral processing.

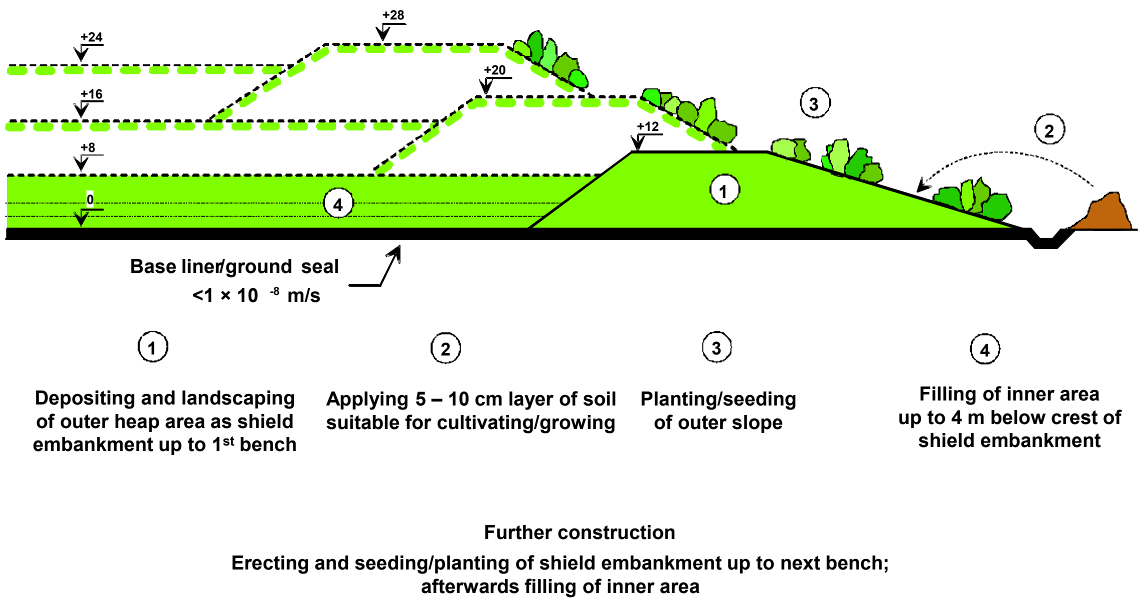
Proper design of a heap requires a thorough understanding of the following:

- extractive waste characteristics (e.g. geotechnical and geochemical properties) (see Section 4.1.2.1.1);
- site characteristics (e.g. foundation stability, topography, hydrogeology) and preliminary information on the intended construction methods, including the basal structure, foundations and possible future covers (see Section 4.1.2.2.2);
- heap stability (e.g. slope stability);
- water management (e.g. seepage and drainage, water erosion).

Extractive waste is deposited in layers with thicknesses that vary depending on the nature of the materials used, followed by compaction if fine materials are used.

Benches are built when these can improve the stability and facilitate the covering and further rehabilitation works. Benches with a horizontal inclination of 1-5 ° towards the drainage system are usually designed (Fleurisson and Cojean 2014).

The principles of erecting extractive waste heaps are illustrated in Figure 4.11. According to the MTWR BREF (EC-JRC 2009), first the ground and an outer wall are prepared. The wall is immediately revegetated and serves as a shield for the subsequent deposition in the inner zone. The slopes of the benches are then modelled, covered and revegetated. Then transfer ramps and working benches are created in the heap's inner area. This configuration is typical for the management of extractive waste resulting from coal extraction and destined for the slag heaps of the Ruhr, Saar and Ibbenbüren areas.



Source: (EC-JRC 2009)

Figure 4.11: Schematic drawing of extractive waste heap construction in the Ruhr, Saar and Ibbenbüren areas

Extractive waste heaps are usually rehabilitated by reshaping the slopes to form a dendritic surface drainage system for handling water run-off and by covering and revegetating the reshaped surfaces (see Section 4.3.1.3.3). The benches on the flattened slopes are designed to reduce the slope lengths and minimise the erosion potential, but have unnatural shapes. Alternatively, more natural landforms can be designed (see Section 4.3.2.1.4) (Williams 2014).

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  In the planning and design phase, the raising method is selected.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, operators raise the heap following the planned design and specifications. QA/QC is performed to ensure that the objectives are met. If necessary, remediation measures are put in place. Design for closure is applied.
- *Closure and after-closure phase*
  In the closure phase, monitoring and maintenance of the final heap built with a bottom-up method are carried out. Management systems are applied and design for closure is implemented.
  In the after-closure phase, the final heap built with a bottom-up method is monitored, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o preventing the inappropriate construction and raising of heaps.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- The environmental surroundings and conditions of the site are considered for proper heap design and management.
- The technique is not applicable to non-inert extractive waste as a stand-alone solution (i.e. without a basal structure or leaching/ARD prevention measures/techniques).

7. Economics

- According to the MTWR BREF (EC-JRC 2009), costs varying from ~ EUR 0.5 to EUR 1 per tonne of extractive waste from metal ores excavation are reported for the construction of heap deposits.

8. Driving force for implementation

- Risk prevention.
- Safety requirements.

9. Example sites

- Aguas Teñidas (ES)
- Schöttelheide (DE)
- Haniel (DE)
- Efemçukuru Gold Mine (TR)

10. Reference literature

(EC-JRC 2009)
(Fleurisson and Cojean 2014)
(Orman *et al.* 2011)
(Williams 2000)

Further information on heap construction can be found in:
(CAN BC 1991) Mined rock and overburden piles - Investigation and design manual;

(US EPA 1995) The design and operation of waste-rock piles at non coal mines;
(Hawley and Cunning 2017) Guidelines for mine and waste dump and stockpile design.

4.2.1.3.3.2.2 Top-down construction method

1. Description
This technique consists of raising a heap by depositing the extractive waste from the crest.

2. Technical description
This BAT candidate is relevant for heaps.

Top-down methods are also called descending construction. In this case, extractive waste materials are deposited from the crest.

Proper design of a heap requires a thorough understanding of the following:
- extractive waste characteristics (e.g. geotechnical and geochemical properties) (see Section 4.1.2.1.1);
- site characteristics (e.g. foundation stability, topography, hydrogeology) and preliminary information on the intended construction methods, including the basal structure, foundations and possible future covers (see Section 4.1.2.2.2);
- heap stability (e.g. slope stability);
- water management (e.g. seepage and drainage, water erosion).

Material segregation occurs during deposition as coarser particles flow down the slope and rest at approximatively the specific angle of repose of the material during operation, which usually varies from 25 ° to 40 °, depending on the heterogeneity and granulometry of the extractive waste.

In the closure phase, rehabilitation and closure of extractive waste heaps usually requires regrading to the angle of natural repose depending on the extractive waste characteristics (see Section 4.1.2.1.1) and resulting in a geomorphic shape (see Section 4.3.2.1.4) that, either in itself or after the placing of a cover, provides long-term stability (see Section 4.2.1.3.6.2) and adequate protection against wind and water erosion.

In top-down methods, the handling and deposition of extractive waste is usually done with conveyor belts, trucks or shovels. However, a greater control of the design is provided with conveyor belts, e.g. for the management of extractive waste resulting from potash extraction.

Slopes are generally not flattened and rehabilitated during the operational phase, but in the closure phase.

The technique is implemented in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  In the planning and design phase, the raising method is selected.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, operators raise the heap following the planned design and specifications. QA/QC is performed to ensure that the objectives are met. If necessary, remediation measures are put in place. Design for closure techniques are applied.
- *Closure and after-closure phase*
  In the closure phase, monitoring and maintenance of the final heap built with a top-down method are carried out. Management systems are applied and design for closure techniques are implemented.
  In the after-closure phase, the final heap built with a top-down method is monitored, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
    - o preventing the inappropriate construction and raising of heaps.

4. Environmental performance and operational data

- At the Kiruna site, heaps are designed in levels. Extractive waste is transported by trucks to the deposition area where the extractive waste is discharged. The deposition is carried out using loaders that push the extractive waste from a crest in order to create a starting layer with a height of 15 m (at base level) followed by raises with a height of less than 30 m. Between each new level, a horizontal distance of at least 10 metres is provided.

5. Cross-media effects

- Dusting from the extractive waste deposited from the crest.

6. Technical considerations relevant to applicability

- The technique is not applicable to non-inert extractive waste as a stand-alone solution (i.e. without a basal structure or leaching/ARD prevention measures/techniques).

7. Economics

- No information provided.

8. Driving force for implementation

- No information provided.

9. Example sites

- El Cogulló (ES)
- El Fusteret (ES)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)
- LKAB Kiruna Iron ore Mine (SE)

10. Reference literature

(EC-JRC 2009)
(Orman *et al.* 2011)

Further information on heap construction can be found in:
(CAN BC 1991) Mined rock and overburden piles - Investigation and design manual;
(US EPA 1995) The design and operation of waste-rock piles at non coal mines;
(Hawley and Cunning 2017) Guidelines for mine and waste dump and stockpile design.

4.2.1.3.3.2.3 Basal systems for heaps

4.2.1.3.3.2.3.1 Composite basal structure system

1. Description

The technique consists of including in the heap design an impermeable basal structure, in combination with a proper drainage system for heaps.

2. Technical description

This BAT candidate is relevant for heaps. It is relevant for non-inert extractive waste.

The technique consists of including in the integrated design an impermeable basal structure (see Sections 4.3.1.1.1 and 4.3.1.1.2), in combination with a proper drainage system for heaps (see Section 4.2.1.3.5.2), designed based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see Section 4.1.2.1.1), the water balance (see Section 4.2.1.3.4.1 and Section 4.2.1.3.4.2) and based on the design criteria resulting from the geotechnical analysis (see Section 4.2.1.3.6.2). The basal structure has to be designed in order to prevent the risk of failure and soil and groundwater contamination.

The technique is applied in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  An impermeable basal structure in combination with a proper drainage system is included in the design.
- *Operational (construction, management and maintenance) phase*
  The composite basal structure system is constructed and put into operation. QA/QC is performed to ensure that the objectives are met. Monitoring and maintenance are carried out.
- *Closure and after-closure phase*
  In the closure phase, monitoring of the composite basal structure system is carried out.
  In the after-closure phase, the composite basal structure system is monitored, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing the inappropriate construction of heaps.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), drainage systems techniques (see Section 4.2.1.3.5.2) and geotechnical analysis of heaps (see Section 4.2.1.3.6.2).
- This technique is only applicable to new extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.

7. Economics
- No information provided.

8. Driving force for implementation
- Risk prevention.
- Safety requirements.

9. Example sites
- No information provided.

10. Reference literature

(EC-JRC 2009)

4.2.1.3.3.2.3.2 Low-permeability natural soil basal structure

1. Description
This technique consists of including in the heap design a low-permeability natural soil layer as the basal structure and partially allowing seepage through the basal structure.

2. Technical description
This BAT candidate is relevant for heaps. It is relevant for inert extractive waste.

A low-permeability natural soil basal structure is designed in the integrated design to partially allow seepage through this basal structure.

If the ground hydraulic conductivity cannot ensure proper drainage at all times, which could possibly lead to structural instability, an additional drainage system is usually included (see Section 4.2.1.3.5.2) based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see Section 4.1.2.1.1), the water balance (see Section 4.2.1.3.4.1 and Section 4.2.1.3.4.2) and based on the design criteria resulting from the geotechnical analysis (see Section 4.2.1.3.6.2).

The technique is implemented in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The low-permeability natural soil basal structure is planned and designed.
- *Operational (construction, management and maintenance) phase*
  Construction and monitoring of the dam's basal structure is carried out. QA/QC is performed to ensure that the objectives are met.
- *Closure and after-closure phase*
  In the closure phase, monitoring of the low-permeability natural soil basal structure is carried out. Management systems are applied.
  In the after-closure phase, the low-permeability natural soil basal structure is monitored, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing the inappropriate construction of heaps.

4. Environmental performance and operational data
- See Section 4.2.1.3.3.1.3.2 (heading 4).

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- The technique is applicable in combination with design for closure (see Section 4.2.1.1.1), ground investigation (see Section 4.2.1.3.1), drainage systems techniques (see Section 4.2.1.3.5.2) and geotechnical analysis of heaps (see Section 4.2.1.3.6.2).
- A permeable or low-permeability natural soil basal structure is only applicable to inert extractive waste, according to Kauppila and co-authors (Kauppila *et al.* 2013) and to the Closedure project (Tornivaara 2015b).

7. Economics
- The costs are lower than in the case of impermeable basal structures because the construction is simple and there are no costs related to the liner systems.

8. Driving force for implementation
- Legal and environmental requirements.

9. Example sites
This technique is generally applied in Europe. A low-permeability natural soil basal structure is encountered at several sites that participated in the questionnaire exercise (26 out of 87).

10. Reference literature
(Kauppila *et al.* 2013)
(Tornivaara 2015b)

4.2.1.3.4 Water-related structure techniques

Although water management is not within the scope of this document, some of the environmental impacts resulting from the management of extractive waste are directly linked to the management of EWIW. It is thus important to ensure that the extractive waste deposition area (including the EWF) and the planned extractive waste management strategies are designed considering the interaction between extractive waste and EWIW.

4.2.1.3.4.1 Water balance analysis

1. Description
This technique consists of completing a detailed water balance analysis for the design of any surface extractive waste deposition area (including the EWF) that will be encountered in the operational phase, the closure phase and the after-closure phase.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps.

The water balance is used to predict the variation of volumes and quality of water entering, circulating and leaving the extractive waste deposition area (including the EWF). Models can be used to plan water management and assess potential environmental impacts, according to the Closedure project (Hentinen 2015).

The general hydrologic equation describing the water balance of a typical extractive waste deposition area (including the EWF) is given by:

$$P+Q-E-D=\Delta S$$

where:
P = precipitation on the extractive waste deposition area (including the EWF) and contributing catchment area;
Q = run-off inflows to the extractive waste deposition area (including the EWF), including run-off and water liberated from the extractive waste minus outflows from the surface water pond, consisting of reclaimed water to the plant and excess water discharges to water treatment (if necessary);
E = evapotranspiration (evaporation plus transpiration);
ΔS = change in storage in the extractive waste deposition area (including the EWF) and associated ponds;
D = deep percolation (unrecoverable by drains and/or vegetation at closure) including seepage.

According to Punkkinen and co-authors (Punkkinen *et al.* 2016), the water balance analysis may be based on monitoring data, such as monitoring of water levels (e.g. in ponds), drainage water flow rates and weather conditions. It may be reviewed based on the monitoring findings to prevent risk/emergency situations. Continuous online monitoring data are usually preferred. Furthermore, water balance analysis can be carried out using spreadsheet-based deterministic models or more advanced dynamic models. The latter may possibly be coupled with hydrological, hydrogeological and geochemical models for example. A detailed description is provided in the VTT guidelines (Punkkinen *et al.* 2016).

According to the MTWR BREF (EC-JRC 2009), the water balance will determine, for example:

- a suitable storage capacity of the pond over the whole life cycle;
- the discharge capacity of the pond and the need for emergency spillways;
- the required freeboard (if the water from the pond cannot be directly released into the receiving surface water body);
- the required water treatment capacity, if any;
- if there is water available and if it is of the right quality for re-use in the mineral processes;
- how to handle excess water;
- the amount of water escaping the drainage systems (seepage through the extractive waste to soil and groundwater); however, there is a degree of uncertainty associated with it, since several of the parameters are not measured but estimated.

Upon closure, the water balance is re-evaluated in order to carry out the final closure plan, and to evaluate the elemental mass loading from the extractive waste deposition area (including the EWF).

Some components of the water balance for a EWF are included in Figure 4.12.

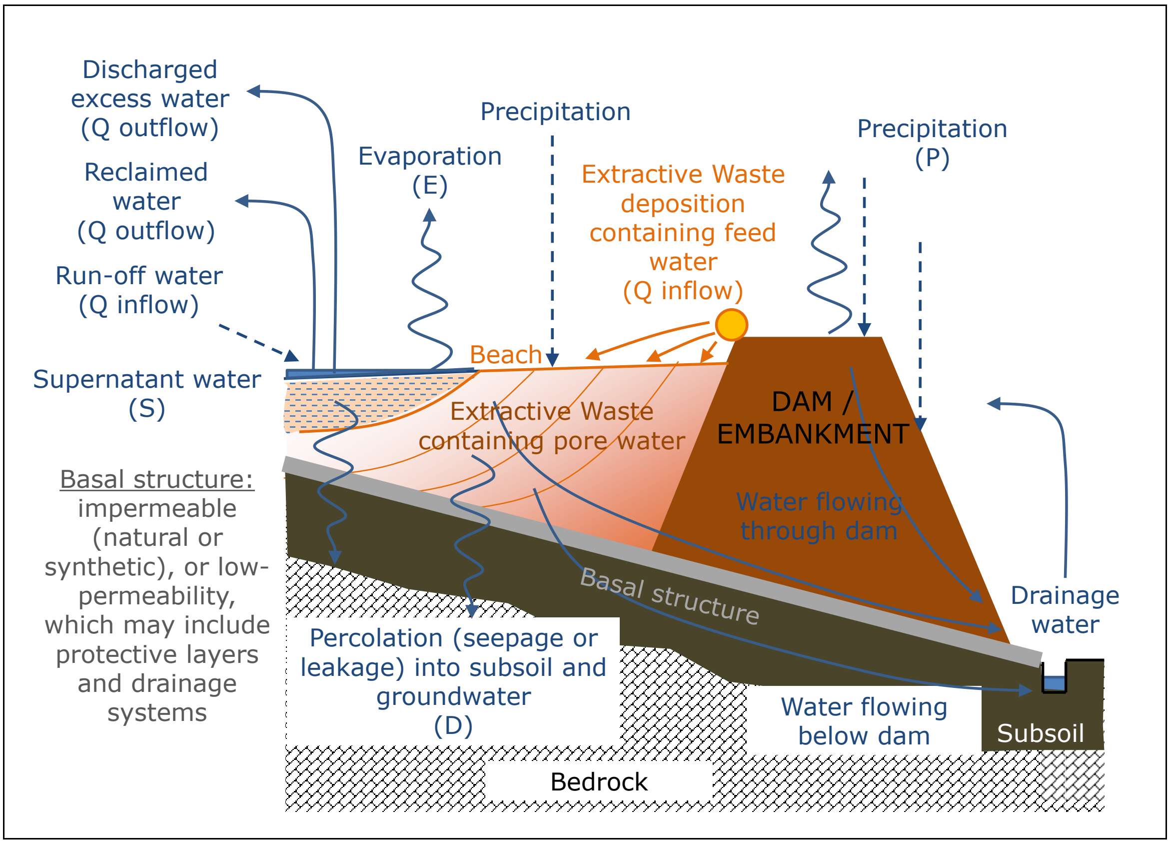


Figure 4.12: Illustration of the water balance

The technique is implemented in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Operators evaluate the water balance of the extractive waste deposition area (including the EWF).
- *Operational (construction, management and maintenance) phase*
  Operators monitor water inputs and outputs and evaluate water losses (e.g. seepage, evaporation). The water balance may be reviewed/corrected based on monitoring findings and measures can be taken to adapt the extractive waste deposition area (including the EWF) based on the new data and information.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - helping to establish the knowledge base needed to properly design the water-related systems ensuring:
    - better control of water resources, water re-use and recycling of water;
    - better drainage system design;
    - suitable extractive waste and EWIW storage capacity design;
    - appropriate design of water-related structures such as temporary deposition EWFs and water treatment facilities;
  - preventing or reducing the risk of failure and overtopping;
  - preventing or reducing water erosion.

4. Environmental performance and operational data

A water balance analysis contains predicted input and output volumes of water as described in the technical description.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified. However, the technique is usually carried out when extractive waste is managed in surface EWFs such as large ponds and heaps.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention.
- Safety requirements.
- Legal and environmental requirements and national/local legislation.
- Identifying the input data for the drainage system design.

9. Example sites

- Zinkgruvan Mining AB (SE)
- Minas de Aguas Teñidas (ES): integrated water management system (two water treatment plants, a water distribution system and three regulatory ponds)
- Lisheen Mine (IE)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

- Pyhäsalmi Mine Oy (FI)

10. Reference literature
(EC-JRC 2009)
(Hentinen 2015)
(Kauppila *et al.* 2013)
(Punkkinen *et al.* 2016)
(Kerr and Ulrich 2011)
(Turunen and Hentinen 2015)

4.2.1.3.4.2 Water management plan

1. Description
This technique consists of using the results of the water balance analysis for developing a water management plan.

2. Technical description
This BAT candidate is relevant for all ponds, dams and heaps. It is particularly important for the water management strategy, including the water treatment.

The results of the water balance analysis are used for developing a <u>water management plan</u>.
According to the MTWR BREF (EC-JRC 2009), this plan may consider the following aspects:

- *Hydrological and hydrogeological data*, including the delineation of site catchment area(s) and all potential water sources, both natural and process-related, which are used in the development of a water/contaminant balance and the design of the components of the extractive waste deposition area (including the EWF). Design parameters are first established and documented, then monitored to identify variances, validate projections and to anticipate potential problems.
- *Water balance* (see Section 4.2.1.3.4.1).
- *Design flood* evaluation (see Section 4.2.1.3.4.3).
- *Surface water/groundwater management plan* detailing appropriate designs and strategies, if required, which usually cover EWIW collection, reclaim/pump-back systems, treatment/discharge systems (including all water conveyance systems) and water retention and discharge strategy (including operating parameters).

In order to develop and review the water management plan, the following monitoring findings are considered:

- monitoring of weather conditions (Punkkinen *et al.* 2016);
- monitoring of water levels (e.g. in ponds) and drainage water flow rates (see Section 4.2.1.3.6.3);
- monitoring of emissions to soil and groundwater (see Section 4.3.1.5.2), including modelling (see Section 4.3.1.5.1);
- monitoring of emissions to surface water (see Section 4.3.2.2.7.2) including modelling (see Section 4.3.2.2.7.1).

If the EWIW issue is considered together with the water that comes from the extraction site, e.g. AMD, and is sent to the pond, an integrated water management plan may be developed (Punkkinen *et al.* 2016).

The technique is applied in all the life cycle phases of the extractive waste management:

- <u>*Planning and design phase*</u>
  Operators use the results of the water balance analysis to develop a water management plan.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The management plan is implemented and reviewed.

- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - helping to establish the knowledge base needed to properly design the water-related systems;
  - preventing or reducing the risk of failure and overtopping;
  - preventing or reducing water erosion.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation
- Risk prevention.
- Safety requirements.
- Legal and environmental requirements and national/local legislation.

9. Example sites
- Zinkgruvan Mining AB (SE)
- Minas de Aguas Teñidas (ES): integrated water management system (two water treatment plants, a water distribution system and three regulatory ponds)
- Lisheen Mine (IE)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Pyhäsalmi Mine Oy (FI)

10. Reference literature
(EC-JRC 2009)
(Punkkinen *et al.* 2016)

4.2.1.3.4.3 Design flood evaluation

1. Description
The design flood is the flood of suitable probability and magnitude adopted for the dam/pond design to ensure a high level of dam safety. It generally refers to the computed maximum inflow at the dam site, affected by the reservoir, for the sizing of the spillways and the pond storage capacity.

2. Technical description
This BAT candidate is relevant for ponds with dams.

The risk of overtopping is dependent on the local weather conditions and on the size of the catchment basin. During operation, closure and after-closure, the discharge capacity has to be able to handle predictable extreme flood events.

The lack of control of the hydrological regime, and consequently of the water balance, is one of the most common causes of failure related to overtopping, slope instability, seepage and dam erosion.

All ponds with dams retaining extractive waste need to be able to accommodate extreme hydrologic events, up to the PMF (Chambers and Higman 2011; ICOLD 2011b), considering also climate change scenarios.

PMF is, by definition, *the stormwater flow resulting from the most severe precipitation and/or snowmelt event considered as reasonably possible at a particular geographic location. It is a site-specific determination, based on the maximae of the possible range in meteorological and hydrological conditions. Variables include the duration, the catchment area and the time of the year* (ICOLD 2011b). A PMF is generated by the Probable Maximum Precipitation (PMP), which is defined as, theoretically, the greatest depth of precipitation for a given duration that is physically possible for a given size storm area at a particular geographic location at a certain time.

The criteria for design flood follow conventional risk assessment criteria such as those published by ICOLD or the Canadian Dam Association, depending on the consequences of failure.

Storage is required to either contain the design flood or to provide sufficient attenuation to allow the decant system or emergency spillways to handle the flows.

As a rule of thumb, the designed discharge capacity is usually 2.5 times the highest flow measured at any point, according to the MTWR BREF (EC-JRC 2009).

If a water cover solution (see Section 4.3.1.3.4.2) is chosen for the closure of a pond, the discharge facility (outlet) needs to be stable in the long term and constructed as a spillway in natural ground and not through the dam. The long-term stable outlet is able, with a sufficient safety margin, to handle any extreme flood event and at the same time manage the risk posed by clogging by ice, falling trees, branches, etc. without jeopardising the required discharge capacity. These requirements imply that a very wide outlet is designed and constructed for the after-closure phase.

The design flood also takes into consideration the following variables:
- meteorological conditions that can lead to anomalous situations, such as sudden snowmelt, extreme rainfall and climate change;
- periodic review of the site hydrology, including the effects on the PMF;
- failure of decants/diversion structures due to debris slides, landslides or snow/ice clogging;
- temporary failures of passive decant systems or pumps;
- water quality of the discharged water during extreme events (ICOLD 2011b).

The technique is implemented in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Operators evaluate the design flood of the extractive deposition area (including the EWF).
- *Operational (construction, management and maintenance) phase*
  The design flood evaluation is reviewed. It is ensured that the EWF continues to meet all flood design criteria (see Section 4.2.1.1.1, Section 4.2.1.2, Section 4.2.1.3.2 and Section 4.2.1.3.6.1).

- *Closure and after-closure phase*
  The design flood evaluation is monitored and verified. It is ensured that the EWF continues to meet all flood design criteria (see Section 4.2.1.1.1, Section 4.2.1.2, Section 4.2.1.3.2 and Section 4.2.1.3.6.1).

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o preventing or reducing the risk of overtopping of dams.

4. Environmental performance and operational data

Typical design flood values are reported in Table 4.12. They are used for the evaluation of the combined discharge capacity of the pond, decant systems and emergency spillways.

Table 4.12: Design flood values based on site-specific data reported by operators via the questionnaires or collected from literature

Source	Design Return Period (years)			Dam final height (m)
	Risk	Short-term design (operational phase)	Long-term design (closure and after-closure phase)	
(ICOLD 2011b)	Low	200 to 500	PMF	-
	Moderate	500 to 1 000	PMF	-
	High	1 000 to PMF	PMF	-
Sweden, RIDAS (EC-JRC 2009)	Low (3)	100		-
	High (1)	Similar to PMF procedure		-
Finland Dam Safety Degree (319/2010) (Dam Safety act 494/2009)	Low (3)	100-500		-
	Moderate (2)	500-1 000		-
	High (1)	5 000-10 000		-
Sweden (information from questionnaires)	1 000			~ 50-100
Austria and Germany (information from questionnaires)	100 or 1 000			-
Spain (information from questionnaires)	100 or 500			~ 50-150

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- The technique is applicable in combination with dam construction materials selection (see Section 4.2.1.3.2), water balance analysis (see Section 4.2.1.3.4.1), water management plan (see Section 4.2.1.3.4.2), free water management (see Section 4.2.1.3.4.4) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention.
- Safety requirements.
- Legal and environmental requirements.

9. Example sites

- None identified.

10. Reference literature

(Bergström *et al.* 2008)
(Chambers and Higman 2011)
(EC-JRC 2009)
(ICOLD 2001a, 2011b)
(Royet and Peyras 2013)
(SE SVK 2007)
(US FERC 2001)

4.2.1.3.4.4 Free water management

1. Description

This technique consists of managing free water in ponds with dams by means of removal systems, a minimum beach length, a sufficient freeboard and emergency discharge systems.

2. Technical description

This BAT candidate is relevant for ponds with dams.

The management and control of free water is one of the most important procedures for a pond with a dam.

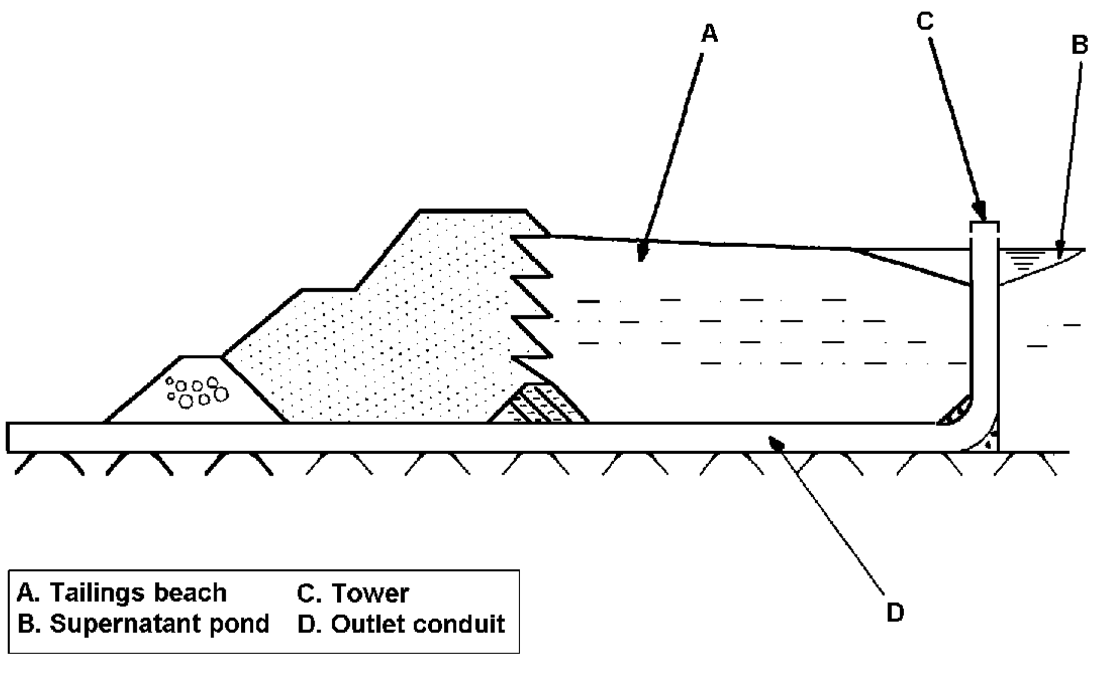
<u>Removal of free water</u>

In the evaluation of the free water amount in a pond, a compromise needs to be reached between keeping the free water level low enough for safety reasons and maintaining a sufficient water level to allow the settling of the fine fractions of the extractive waste and the decomposition of the process chemicals.

For a solids retention dam, particularly if raised by an upstream method (see Section 4.2.1.3.3.1.2.1) or a centreline method (see Section 4.2.1.3.3.1.2.3), it is essential that the free water volume in the pond is kept to a minimum and the freeboard is sufficiently high along the dam/embankments. According to the SME Handbook (Kerr and Ulrich 2011), free water monitoring systems are commonly installed.

The main requirement for successful removal of the free water is the provision of an outlet structure, or decant system, the effective level of which can be adjusted as the pond level progressively increases, or of a pump, which can perform a similar function. The removed water is either returned to the mineral processing plant and/or, usually after water treatment, discharged into receiving surface water bodies. The outlet structure is typically composed of two elements:

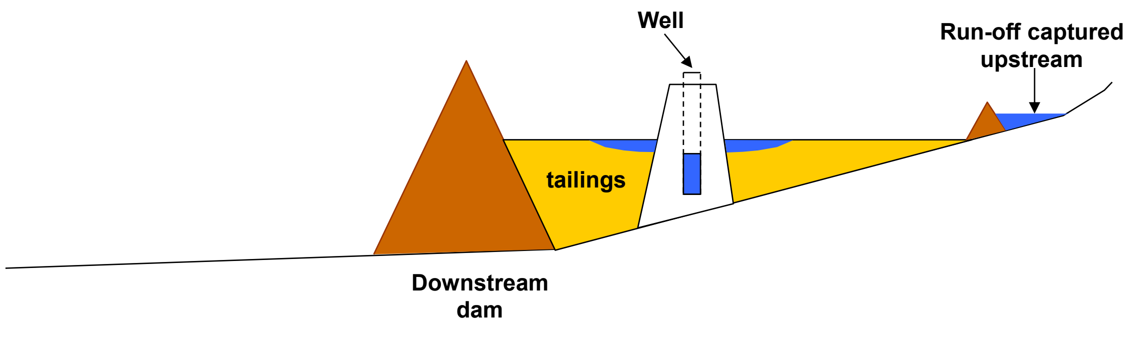
- <u>An extensible intake</u>, which may take the form of the following:
    - A *vertical decant tower*: this is a permanent system that removes the free water from the surface of the supernatant pond by gravity through an underlying conduit (see Figure 4.13). Decant towers have proven to work well under frosty conditions with a positive water balance. However, they have to be designed to resist the pressure of the extractive waste throughout the lifetime of the operation. Vertical decant towers are designed to accommodate total loads resulting from the deposited extractive waste during all relevant life cycle phases (see Section 4.2.1.3.2 and Section 4.2.1.3.6.1). Other associated structures (e.g. the conduit) are designed to accommodate total embankment loads during all relevant life cycle phases (see Section 4.2.1.3.2 and Section 4.2.1.3.6.1).



Source: (EC-JRC 2009)

Figure 4.13: Vertical tower decanting system

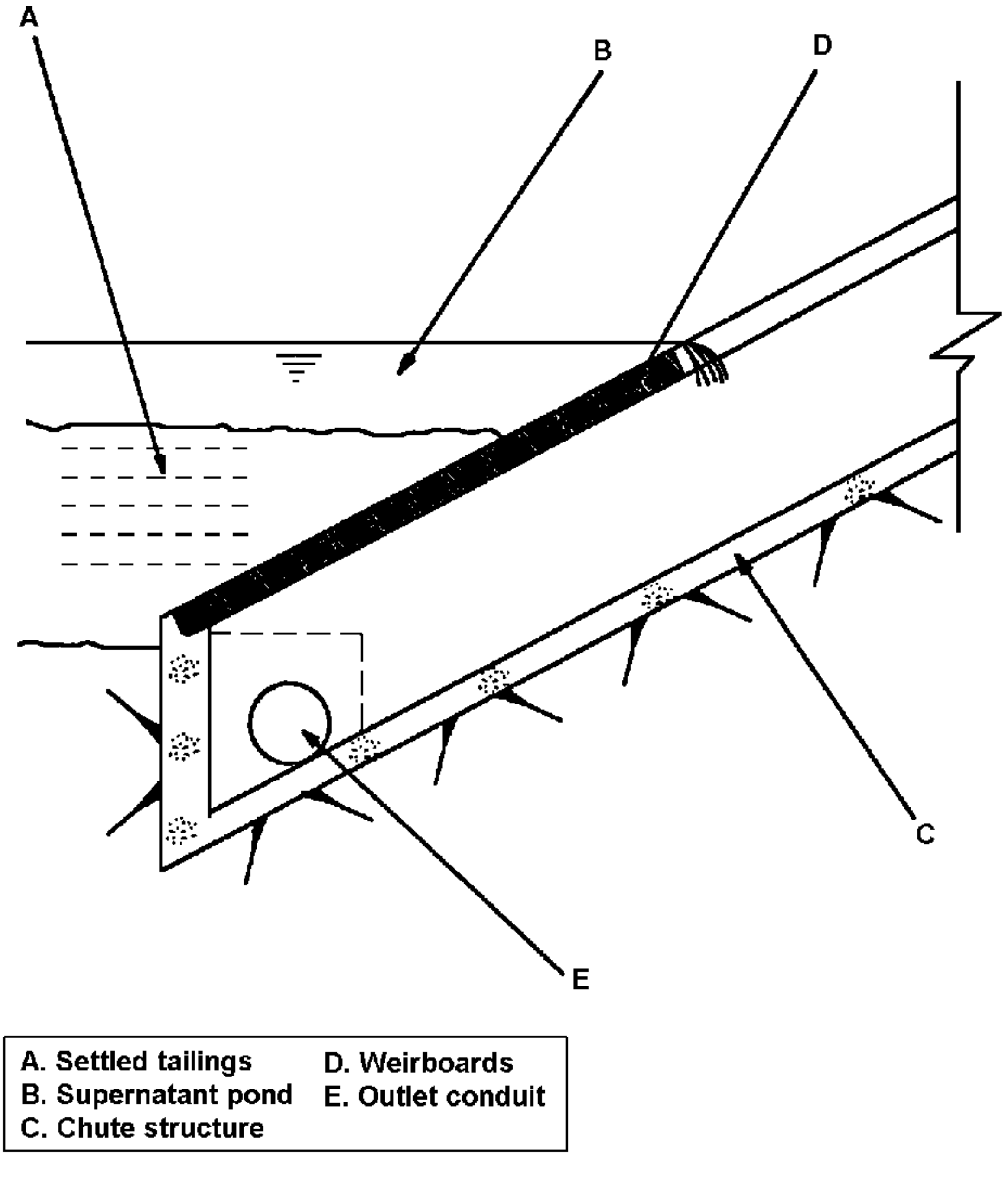
- A *decant well*: this is a permanent system that removes the free water from the surface composed of a perforated tube surrounded by rock-fill near the centre of the pond (see Figure 4.14). The gravel around the decant well acts as a stabiliser and a filter for water and aids retention of the fines. Additional features for this system are the drainage pipes laid over the bottom of the pond during construction in fish-bone configuration and connected to the tower in order to drain and consolidate the settled solid extractive waste. The decant well is a variation of a decant tower and is easily accessible. As opposed to discharge towers, there is no conduit/drain perforating the dam. The clarified water is pumped to the mineral processing plant. It is also necessary to divert any surface water run-off (see Section 4.3.2.1.2). Decant wells are designed to accommodate total loads resulting from the deposited extractive waste during all relevant life cycle phases (see Section 4.2.1.3.2 and Section 4.2.1.3.6.1).



Source: (EC-JRC 2009)

Figure 4.14: Decant well at Ovacık site

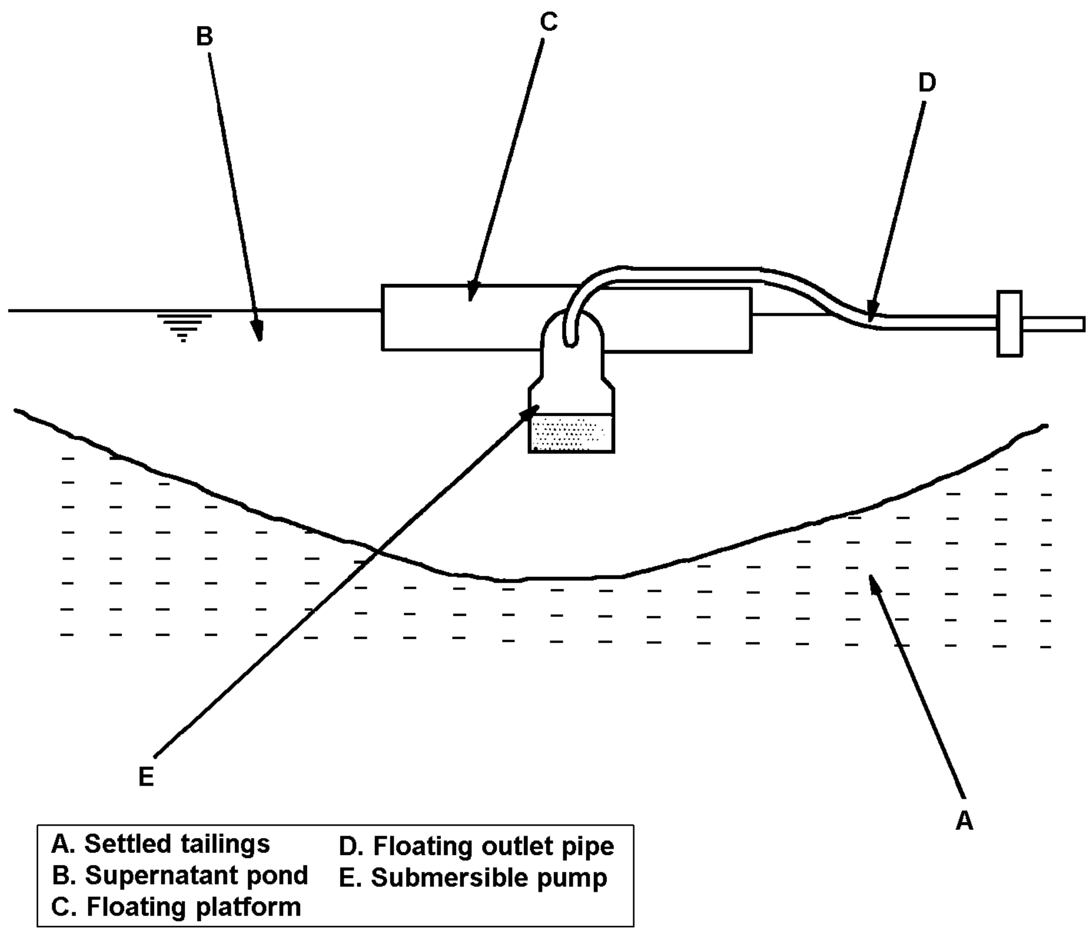
- A *decant chute or inclined decant:* this is a permanent system that is usually founded in natural ground on a flank of the pond and occasionally on the upstream face of the dam (see Figure 4.15). Decant chutes or inclined decants are designed to accommodate total loads resulting from the deposited extractive waste during all relevant life cycle phases (see Section 4.2.1.3.2 and Section 4.2.1.3.6.1).



Source: (EC-JRC 2009)

Figure 4.15: Chute decanting system

- A *floating decant system* (or barge system): this is a movable system that pumps the free water from the supernatant pond to the processing plant or the settling pond (see Figure 4.16). It is good practice to have standby pumps to use in case of emergency, for example a rapid inflow during a storm event, according to the SME Handbook (Kerr and Ulrich 2011).



Source: (EC-JRC 2009)

Figure 4.16: Floating decant system or pump barge system

  - o *Overflow systems* within the dam or around the dam.

- A conduit to convey the discharge away from the dam for emergency discharge. This normally passes beneath the pond and through/under the embankment(s).

Minimum beach length

According to the MTWR BREF (EC-JRC 2009), slurried extractive waste from mineral processing can be discharged off the crest of the dam in order to create a beach of extractive waste against the inner face of the retaining dam. This will normally result in the coarser fraction of the extractive waste settling out nearest to the embankment, with the fines settling nearer to the supernatant pond, effectively resulting in the segregation of the deposited extractive waste. The coarse fraction can then be used as construction materials. The beach will, upon closure, be covered with dry covers to prevent infiltration, aeration and weathering.

A minimum beach length is maintained for upstream and centreline dams, in order to maintain the segregated extractive waste coarse fractions emerged in the proximity of the dam crest. This allows an improvement of their strength characteristics to support the embankment, helps in keeping the phreatic level adequately low and enables stability to be controlled. The minimum beach length depends on the risk of the dam (see Section 4.1.2.3), the water content and the physical characteristics of the extractive waste and the local conditions.

According to DSC (DSC 2012), the supernatant pond cannot be closer to the embankments than a distance that is at least 10 times the height of the embankment.

Modern engineering principles are applied to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events, and that the phreatic surface is controlled.

Freeboard
The design freeboard is defined as the vertical height from the normal operating level of the free water in the supernatant pond to the current operational crest of the dam at its lowest elevation on the dam perimeter. This area of extractive waste will, usually upon closure, be covered with a layer of natural or artificial material to prevent infiltration, aeration and weathering (see Section 4.3.1.3.4).

During operation, the actual freeboard at any given time is the vertical height from the supernatant pond level to the current crest level.

Modern engineering principles are applied to ensure that the embankments are adequately drained, an appropriate freeboard is guaranteed at all times, including the minimum freeboard during extreme flood events, and the phreatic surface is controlled.

Emergency discharge
The design of the ponds containing extractive waste and discharge-water-related structures considers all predictable extreme events, such as extreme rainfall and snowmelt events, including climate change scenarios. Nevertheless, risk is further reduced by incorporating emergency discharge systems into the design. These systems are designed to work automatically if the water level reaches a predetermined critical level and to discharge any excessive water volume (that cannot be discharged through the normal discharge facilities) without hampering the integrity of the dam. In this way, emergency outlets can avoid overly elevated water levels within the dam or, in a very extreme scenario, overtopping, which otherwise may lead to a catastrophic dam failure, according to the MTWR BREF (EC-JRC 2009).

The most commonly used emergency discharge systems are as follows:

- *Large-dimension pipes* through the dam, which are installed at such a level so that the predetermined minimum freeboard will always be maintained.
- *Controlled overflows* over the dam body, which are designed to discharge any excessive water without hampering the integrity of the dam. For this system, erosion prevention is critical.
- A *spillway or an open channel in natural ground*, which are designed to work automatically and to discharge any excessive water without hampering the integrity of the dam. Also for this system, erosion prevention is critical.
- *Facilities for alternative discharge*, possibly into another pond.
- *Second decant facilities* (such as emergency overflow and/or standby pump barges), which are used in case of emergency, if the level of the free water in the pond reaches the predetermined minimum freeboard.

Most metal mines in northern Europe use a system of open channels in natural ground (e.g. Pyhäsalmi, Hitura, Zinkgruvan, Kiruna and Malmberget). The absence of emergency outlets in the design of the Baia Mare pond was the reason for its catastrophic failure. If an emergency outlet had been in place, only a small amount of CN-containing water would have been released, and no extractive waste would have been released, according to the MTWR BREF (EC-JRC 2009).

The technique is implemented in all the life cycle phases of the extractive waste management:

- Planning and design phase
  Free water management is designed and planned.

- *Operational (construction, management and maintenance) phase*
  The free water management systems are put in place. Monitoring and maintenance are carried out.
- *Closure and after-closure phase*
  The design flood evaluation is monitored and verified. It is ensured that the EWF continues to meet all flood design criteria (see Section 4.2.1.1.1, Section 4.2.1.2, Section 4.2.1.3.2 and Section 4.2.1.3.6.1).
  It is monitored and verified that embankments are adequately drained and the phreatic surface is controlled.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - ensuring the safe management of free water;
  - preventing or reducing the risk of failure and overtopping;
  - improving slope stability and reducing the potential for internal water erosion, as a consequence of the flat phreatic surface and flow lines, by means of long beach distances;
  - low energy consumption in the case of decant towers, since water flows by gravity.

4. Environmental performance and operational data

Minimum beach length

- According to the site-specific data reported by operators via the questionnaires, the indicative minimum length varies from 20 m to 120 m depending on the water content and physical characteristics of the extractive waste and the local conditions.
- At the Żelazny Most tailings pond, the minimum length of the beach is 200 m. The longitudinal beach inclination varies from 6.5 ‰ close to the dam to approximately 4.5 ‰ at a distance of 100 m.

Freeboard

Example values of freeboards reported by operators via the questionnaires or collected from literature are shown in Table 4.13.

Table 4.13: Example values of freeboards reported by operators via the questionnaires or collected from literature

Reference / site	Freeboard minimum thickness
(ICOLD 2011b)	1 m during the PMF event above the minimum required beach
Dam Safety Code of Practice (FI) (EC-JRC 2009; Niemeläinen *et al.* 2015a)	1.75 times the maximum wave height or according to the frost depth (10 years frost depth for class 1-2 and 5 years maximum for class 3)
(DSC 2012) (Australia)	• Operational minimum freeboard (vertical distance between the top of the extractive waste beach and the adjacent dam) varying from 0.3 m to 0.5 m according to the dam risk class • Minimum (total freeboard) defined according to the PMP with a critical duration
Aguas Teñidas (ES) (information from questionnaire)	Two warning levels are set and controlled: • normal freeboard that corresponds to the maximum level that water can reach in a normal operating regime; it corresponds to 1.5 times the maximum wave height expected, plus 20 cm • minimum freeboard that corresponds to the maximum level that water can reach
Żelazny Most (PL) (information from questionnaire)	1.5 m
Ovacık Gold Mine (EC-JRC 2009)	2 m
Kiruna and Malmberget mines (SE) (EC-JRC 2009)	1.2-2 m (based on RIDAS guidelines) For a class 2 dam, a one in a 100 years, 24-hour rainstorm event should be decanted without a raise in the water level
Sites for the management of extractive waste resulting from industrial minerals extraction (EC-JRC 2009)	1 m

From site-specific data reported by operators via the questionnaires, the most common freeboard is in between 1 and 2 metres, 1.5 m being the median value.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- Free water management techniques are applicable in combination with water balance analysis (see Section 4.2.1.3.4.1) and a water management plan (see Section 4.2.1.3.4.2).

Removal of free water

The MTWR BREF (EC-JRC 2009) reports the following:

- A *vertical decant tower* is effective in removing free water but its efficiency decreases with the increase of the deposited extractive waste amount. It is only applicable if continuously surrounded by water. Large filtering gravel supports of decant wells fill part of the pond, decreasing the available disposal space. The filtering capacity of these supports also decreases in time. Moreover, it cannot be relocated like the floating systems.
  It is generally applicable:
    - in climates without major precipitation-free periods with a positive water balance; or
    - in the case of paddock-style ponds.

  The conduit of a decant tower culvert perforates the embankment and may weaken the dam.
- A *decant well* is applicable:
    - in climates with major precipitation-free periods with a negative water balance; or
    - in the case of paddock-style ponds; or

    - if a high operating freeboard is maintained.
- A *decant chute* is generally applicable to manage free water in a pond.
- A *floating decant system* is located in easily accessible areas for maintenance and inspection. It is not applicable in the case of small ponds because it would necessitate moving the barge too often in order to pump free water, since the discharge points are changed frequently.
- These techniques are applicable in combination with dam construction materials selection (see Section 4.2.1.3.2), water balance analysis (see Section 4.2.1.3.4.1) and a water management plan (see Section 4.2.1.3.4.2), design flood evaluation (see Section 4.2.1.3.4.3) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).

Minimum beach length
- This technique is applicable in combination with dam construction materials selection (see Section 4.2.1.3.2), water balance analysis (see Section 4.2.1.3.4.1) and a water management plan (see Section 4.2.1.3.4.2), design flood evaluation (see Section 4.2.1.3.4.3), drainage systems techniques (see Section 4.2.1.3.5.1) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- It is not applicable for dry stacking.

Emergency discharge
- These techniques are applicable in combination with dam construction materials selection (see Section 4.2.1.3.2), water balance analysis (see Section 4.2.1.3.4.1) and a water management plan (see Section 4.2.1.3.4.2), design flood evaluation (see Section 4.2.1.3.4.3) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).
- A spillway in natural ground is not applicable in the case of paddock-style ponds.

7. Economics
- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

- The operational costs of a floating decant system are higher than the costs of decant towers and wells due to the pumping costs.

8. Driving force for implementation
- Risk prevention.
- Safety requirements.
- Legal and environmental requirements.

9. Example sites
- Minas de Aguas Teñidas (ES)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Aitik Mine (SE)
- Pyhäsalmi Mine Oy (FI)
- Zinkgruvan Mine
- LKAB Kiruna Iron ore Mine (SE)
- LKAB Malmberget Iron ore Mine (SE)
- Hitura
- Ovacık Gold Mine (TR)

10. Reference literature
(DSC 2012)
(EC-JRC 2009)
(ICOLD 2011b)
(Kerr and Ulrich 2011)

4.2.1.3.4.5 Lowering the phreatic surface at closure and after-closure

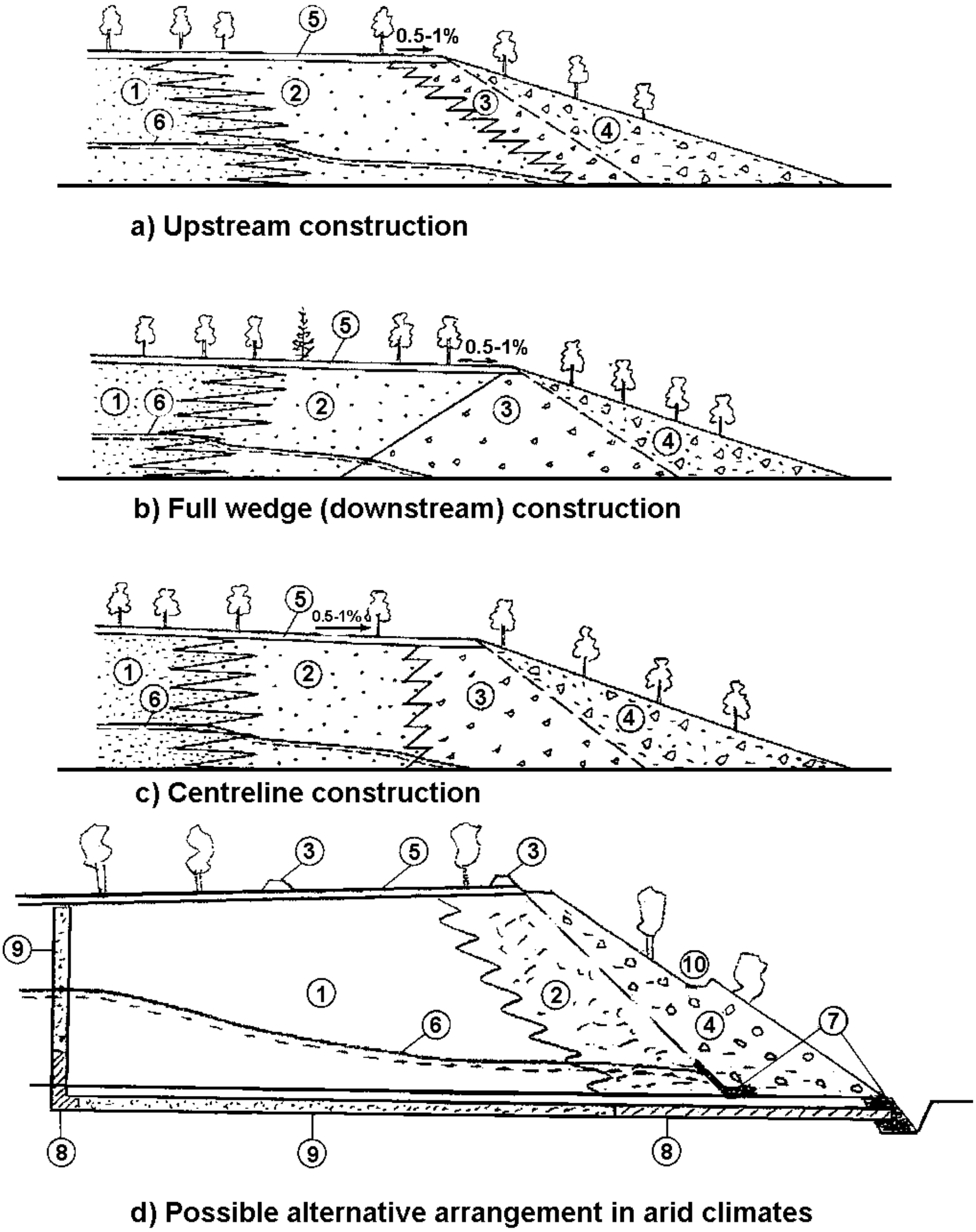
1. Description
This technique consists of permanently lowering the phreatic surface during the entire closure phase and for the long term in the case of dewatered ponds.

2. Technical description
This BAT candidate is relevant for ponds with dams.

Before the pond containing extractive waste is covered, it is dewatered so the dewatered extractive waste can consolidate. The consolidation can take a long time depending on the properties of the dewatered extractive waste. Consequently, it is sometimes necessary to apply a dust control cover on the extractive waste to prevent dusting during the consolidation phase. To prevent the accumulation of water, it is common practice to construct bypass ditches and to reshape the surface of the pond. Ideally the surface should decline 0.5-1.0 % towards the edges of the pond, according to the MTWR BREF.

In order to guarantee appropriate stability in the after-closure phase, EWIW has to be safely removed using modern engineering principles to ensure that the embankments are adequately drained and the phreatic surface is controlled.

Figure 4.17 shows some typical dams for dewatered ponds. Note that in this figure the coarse extractive waste is adjacent to the dam.



Source: (EC-JRC 2009)

Figure 4.17: Dams for dewatered ponds

The technique is implemented in the *closure and after-closure phase.*

3. Achieved environmental benefits

- Helping to ensure the long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o ensuring the safe management of free water;
  - o reducing the risk of internal erosion.
- Rehabilitation of the extractive waste deposition area (including the EWF).

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- This technique is applicable in combination with dam construction materials selection (see Section 4.2.1.3.2), water balance analysis (see Section 4.2.1.3.4.1) and a water management plan (see Section 4.2.1.3.4.2), design flood evaluation (see Section 4.2.1.3.4.3) and geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1).

7. Economics
- The costs for dewatering ponds reported in the MTWR BREF (EC-JRC 2009) range from EUR 0.7 to EUR 1.2 per m^2. A total cost for dewatering and closure of EUR 1.4 million (USD 1.8 million, year 2009) for the Ovacık Gold Mine was also reported in the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation
- No information provided.

9. Example sites
- Boliden Tara Mines (IE)
- Ovacık Gold Mine (TR)

10. Reference literature
(EC-JRC 2009)
(ICOLD 2011a)

4.2.1.3.5 Drainage system techniques

4.2.1.3.5.1 Drainage systems for ponds and dams

1. Description
This technique consists of designing a proper drainage system to capture and collect the EWIW originating from a pond or a dam in order to ensure the physical stability and to prevent or reduce seepage to the ground.

2. Technical description
This BAT candidate is relevant for ponds and dams.

Vertical filters are installed between the low-permeability core of the dam and the support fill. The downstream toe is equipped with a filter and can also be supported by coarse rocks. A ditch is constructed downstream of the toe to collect the water that infiltrates through the dam and to allow its flow and quality to be monitored.

Water that infiltrates through the dam may cause inner erosion, which is a common cause of damage to large dams. However, it is possible to prevent inner erosion if the inclination of the hydraulic gradient (i.e. the pore pressure line) is as low as in natural soil formations that are stable enough to prevent groundwater flow. Generally, as a rule of thumb, a soil slope is not susceptible to internal erosion if the inclination of the hydraulic gradient is less than half of the friction angle of the soil material, according to the MTWR BREF (EC-JRC 2009).

Other methods to counteract inner erosion are to use materials that ensure an inner stability and to design the transition between materials according to filter criteria.

It is essential that the EWIW is well controlled and managed both from a day-to-day environmental performance standpoint and as from an accident prevention point of view.

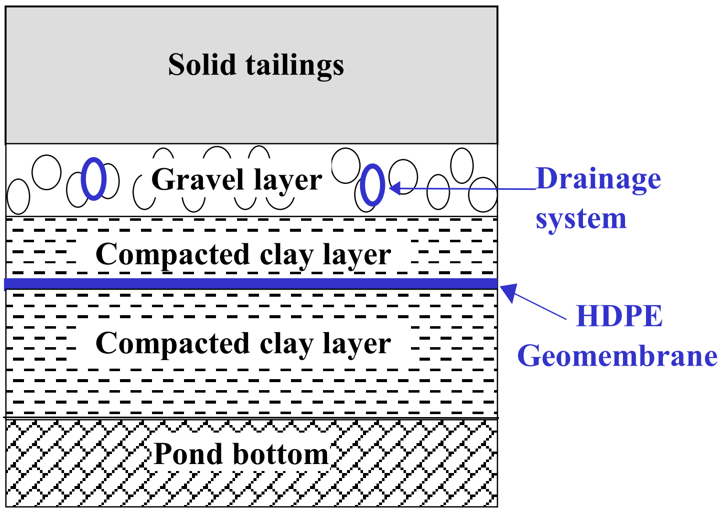
According to the MTWR BREF (EC-JRC 2009), drainage water control is used for the management of any dam construction. By monitoring the normal drainage water flow through the dam, in combination with good understanding of surrounding processes (meteorology, water level in pond, etc.), an early indication can be obtained as to whether any problems may occur with the dam. Increased flow, in combination with suspended particles in the drainage water, could mean that piping is starting to occur. Decreased flow could imply clogging of the drainage/filter.

Due to the prevailing hydraulic gradient (hydraulic pressure difference) between the pond and the surroundings, EWIW flows not only through the dam but also under the dam and in some cases (e.g. with inert extractive waste) also through the low-permeability basal structure that is used for confining the extractive waste. Differences in the hydrogeological setting between sites make it necessary to conduct a site-specific evaluation at each site.

Depending on the outcome of this hydrogeological investigation and the need to collect the EWIW or not, there are various prevention and collection options available. In many cases, a combination of options is preferred. Section 4.3.1 discusses water streams management and seepage control from an environmental point of view.

Different systems are usually applied and combined by means of:

- *drains* placed:
    - beneath the confining dam;
    - within the confining dam;
    - at the toe of the dam, where water is usually collected in a sump and pumped;
- *drains placed above the basal structure*, for example with a fishbone configuration (see Section 4.2.1.3.3.1.3.1 and Section 4.2.1.3.3.1.3.3);
- *a continuous gravel layer overlying the basal structure* (see Figure 4.18; see also Section 4.2.1.3.3.1.3.1, Figure 4.19 and Section 4.2.1.3.3.1.3.3); example values of drainage layer thickness are reported in Table 4.14.



Source: (EC-JRC 2009)

Figure 4.18: Example of a composite basal structure system scheme

Drainage water, i.e. EWIW collected in the drains, is generally evacuated by means of gravity through designed channels/drains or by using pumps according to the MTWR BREF (EC-JRC 2009).

The technique is implemented in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Drainage systems for ponds and dams are designed and planned.
- *Operational (construction, management and maintenance) phase*
  Drainage systems for ponds and dams are put in place. Monitoring and maintenance are carried out.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.
  It is ensured that the EWF continues to meet all flood design criteria (see Section 4.2.1.1.1, Section 4.2.1.2, Section 4.2.1.3.2 and Section 4.2.1.3.6.1).

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the dam by:
  - reducing the hydrostatic pressure;
  - increasing the extractive waste consolidation through dewatering:
  - preventing water erosion, which would negatively affect the structural stability of the dam;
  - preventing an anomalous presence of phreatic surface or infiltrated water within the dam, which would negatively affect the structural stability of the dam.
- Preventing or reducing the risk of failure and overtopping.
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate water collection.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the uncontrolled release of EWIW to surface water.
- As the alternative to the drainage system would be the construction of a bigger clarification area, this system may be a means of reducing the pond size and therefore the dam/pond footprint.

4. Environmental performance and operational data

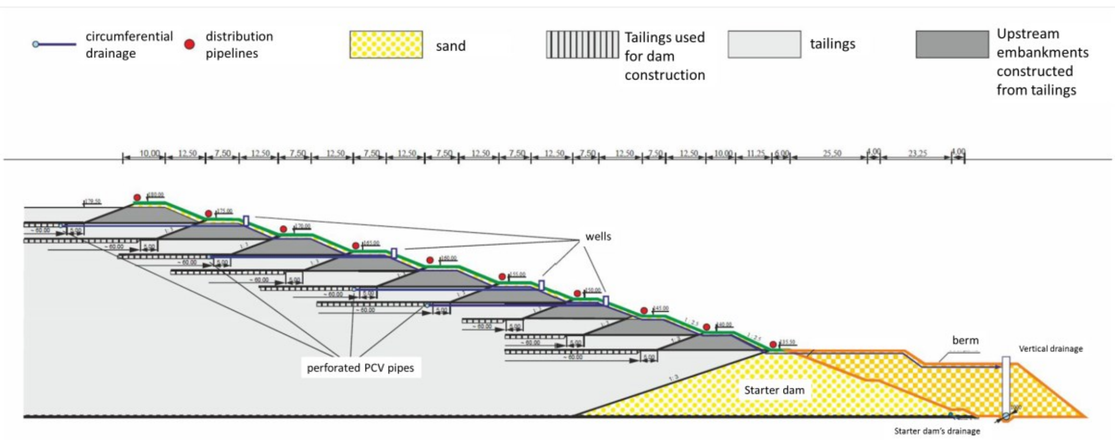
According to the Finnish mine dam requirements, the dam filtering structures and the drainage system are designed to handle 10 times the theoretical quantity of drainage water. Filters and drains are designed to not retain water (Kauppila *et al.* 2013; Niemeläinen *et al.* 2015a). The hydraulic conductivity of the filter in the dam has to be at least 10-100 times that of the dam core material.

Thickness values of the drainage layers are reported in Table 4.14, based on site-specific data reported by operators via the questionnaires or collected from literature.

Table 4.14: Thickness values of the drainage layer and materials employed, based on site-specific data reported by operators via the questionnaires or collected from literature

Site/reference	Drainage layer thickness above the basal structure	Materials
(Kerr and Ulrich 2011)	300 mm (on average)	Granular materials
Cobre Las Cruces (information from questionnaire)	500 mm	Gravel and non-woven filter fabric
Ovacık site (EC-JRC 2009)	200 mm	Gravel
Mastra (information from questionnaire)	500-1 000 mm	Gravel
Erzberg (information from questionnaire)	200 mm	Gravel

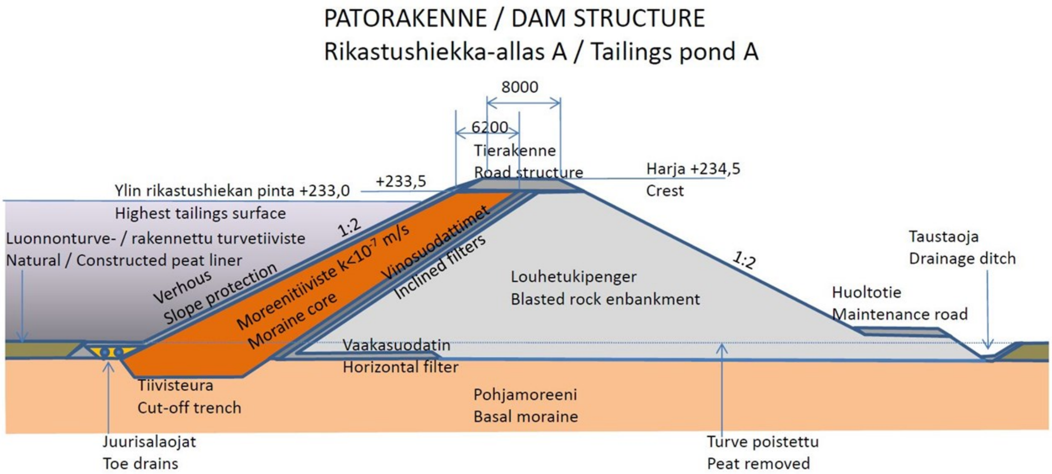
- The drainage system in the Żelazny Most tailings pond is shown in Figure 4.19. It includes:
    - o the starter dam's drainage beneath the embankment and perpendicular PVC pipes for transferring the drainage water to the ditch located at the dam toe;
    - o circumferential drainage that transfers water to the ditch located at the dam toe by means of the tight pipes;
    - o vertical drainage wells located around the extractive waste deposition area (including the EWF) with the aim of creating a barrier; the water from these wells is pumped to the ditches or to retention tanks from where it is pumped back to the flotation process.



Source: KGHM Polska Miedź S.A., Żelazny Most tailings pond questionnaire

Figure 4.19: Example of a drainage system at the Żelazny Most tailings pond

- At the Kevitsa mine, the drainage system consists of a toe drain where the water is usually collected in a sump at the lowest point of the foundation and pumped out via steel pipes. A small submergible pump is placed for that purpose in a steel pipe fixed to the upstream face of the embankment/dam (see Figure 4.20).



Source: Kevitsa Mine questionnaire

Figure 4.20: Schematic drawing of the toe drain pump at the Kevitsa mine

5. Cross-media effects

- None identified apart from material consumption for the drainage system.

6. Technical considerations relevant to applicability

- Dewatering of extractive waste from mineral processing depends on its permeability and fines content.
- Drainage systems for ponds and dams are applicable in combination with water balance analysis (see Section 4.2.1.3.4.1), a water management plan (see Section 4.2.1.3.4.2), geotechnical analysis of ponds and dams (see Section 4.2.1.3.6.1) and diversion of water run-off systems during operation (see Section 4.3.2.1.2).

7. Economics

- The cost of the underlying drainage system is usually high.
- In the case of the Ovacık operation, the cost for installing the HDPE liner was EUR 7.5/m^2 (year 2001) for an area of 16 ha, according to the MTWR BREF (EC-JRC 2009).

- A toe drain system is more expensive than a conventional drainage system due to pumping and maintenance costs.

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements and local legislation.
- Regular sampling and analysis of toe drainage water provides useful information on the emissions to soils.

9. Example sites

- Proyecto Cobre Las Cruces (ES)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Kevitsa Mine (FI)
- Ovacık Gold Mine (TR)

10. Reference literature

(Akcil and Koldas 2006)
(EC-JRC 2009)
(Kerr and Ulrich 2011)
(Kuyucak 1999)

(Niemeläinen *et al.* 2015a)
(Skousen *et al.* 1998)

4.2.1.3.5.2 Drainage systems for heaps

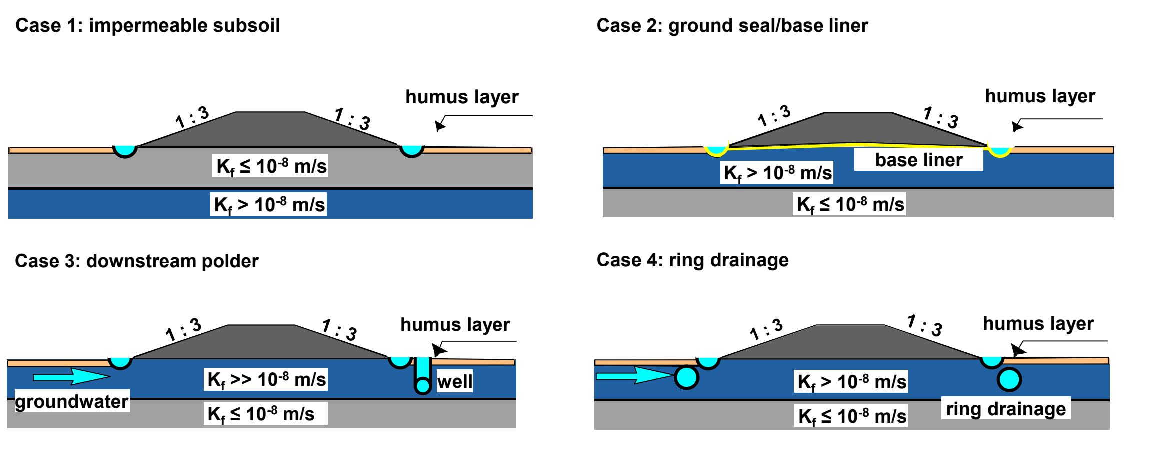
1. Description
This technique consists of designing a proper drainage system to capture and collect the EWIW originating from a heap in order to ensure the physical stability of the deposited extractive waste and to prevent seepage to the ground.

2. Technical description
This BAT candidate is relevant for heaps.

Different systems may be applied and combined to drain an extractive waste heap:

- *Collection ditches* at the perimeter of the heap in combination with lining the toe to collect the EWIW originating from a heap (the so-called *brine* in the management of extractive waste resulting from potash extraction). This water is sent to central retention basins and/or tanks. If the collection ditches' slope is not constant, small pump basins might be necessary. Collection ditches, basins and tanks have to be technically impermeable. A variety of materials are used such as asphalt, PE pipes, concrete, clay lining, HDPE lining.
- *Drainage system or drains below the heap* to capture the EWIW, for example with a fishbone configuration, above the basal structure (see Section 4.2.1.3.3.2.3.1), and send it to the collection ditches.
- *Composite lining system* composed of a basal structure (see Section 4.3.1.1) and an overlying drainage system (see Figure 4.18 case 2 and Section 4.2.1.3.3.2.3.1) for new heaps or new extensions.
- *Rock drain at the heap base*: when extractive wastes from excavation are deposited, the coarsest fraction often ends up at the bottom of the heap, creating a rock drain. Depending on topography, this drain can represent a useful tool for controlling the drainage water, according to the SME Handbook (Orman *et al.* 2011).

According to the MTWR BREF (EC-JRC 2009), negative effects on groundwater and surface water systems from extractive waste heaps can be avoided by means of the presence or the placement of an impermeable natural soil layer below the heap, by the placement of a basal structure, by the inclusion of containment wells or by ring drainage (see Figure 4.21).



Source: (EC-JRC 2009)

Figure 4.21: Extractive waste heap design – options for avoiding negative effects on groundwater and surface water systems

The technique is implemented in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Drainage systems for heaps are designed and planned.
- *Operational (construction, management and maintenance) phase*
  Drainage systems for heaps are put in place. Monitoring and maintenance are carried out.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.
  It is ensured that the EWF continues to meet all design criteria (see Section 4.2.1.1.1, Section 4.2.1.2 and Section 4.2.1.3.6.2).

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the heap by:
  - preventing water erosion, which would negatively affect the structural stability of the heap;
  - preventing an anomalous presence of phreatic surface or infiltrated water within the heap, which would negatively affect the structural stability of the heap.
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate water collection.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the uncontrolled release of EWIW to surface water.

4. Environmental performance and operational data

The design and dimensions of the drainage system are planned and designed on the basis of the hydrological and geotechnical calculations specified in the environmental expert studies and/or in the EIA, considering site conditions, the lining system, climatic conditions and the effects of climate change, and the water balance (see Section 4.2.1.3.4.1). An example value of the drainage layer thickness is reported in Table 4.15.

Table 4.15: Example thickness value of the underlying layer and materials employed, based on site-specific data reported by an operator via the questionnaire

Site	Thickness of the underlying drainage layer	Materials	Drainage flows
Erzberg (AT) (questionnaire)	1 500 mm	Limestone pebbles (400-1 000 mm) + Gravel (< 400 mm)	~ 40-80 l/(s.m^2)

Monitoring of the EWIW originating from the heap is performed.

5. Cross-media effects

- None identified apart from material consumption for the drainage system.

6. Technical considerations relevant to applicability

- Drainage systems for heaps are applicable in combination with water balance analysis (see Section 4.2.1.3.4.1), a water management plan (see Section 4.2.1.3.4.2), geotechnical analysis of heaps (see Section 4.2.1.3.6.2) and diversion of water run-off systems during operation (see Section 4.3.2.1.2).
- In order to avoid the effects of crystallisation in the collection ditches and internal drains, which can occur with temperatures lower than approximately 8 °C, the drainage system at the perimeter of the "potash heaps" is sometimes flushed.

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements.

9. Example sites
- El Cogulló (ES)
- El Fusteret (ES)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)

10. Reference literature
(EC-JRC 2009)
(Orman *et al.* 2011)

4.2.1.3.6 Geotechnical analysis and physical stability monitoring techniques

4.2.1.3.6.1 Geotechnical analysis of ponds and dams

1. Description
The physical stability of a dam and a pond is evaluated in the short and long term by considering all the mechanisms that can negatively affect the partial or total structural stability of dams and ponds.

2. Technical description
This BAT candidate is relevant for ponds and dams.

According to UNECE (UNECE 2014), the geotechnical analysis of ponds and dams usually evaluates the following aspects:
- the overall slope stability of the dam, including the basal structure;
- the bearing capacity and stability of the dam foundations;
- the physical and chemical stability of the extractive waste, including static and dynamic liquefaction, freezing and thawing, following ICOLD guidelines or equivalent international or national guidelines;
- the stability against internal dam erosion (i.e. piping) and surface erosion;
- an estimation of the settlement of the dam associated with a probable earthquake;
- the stability of the free water removal systems, the water drainage systems and the emergency spillways.

According to (ICOLD 1996, 2011b, 2016), the geotechnical analysis of a dam usually takes into account the following:
- The storage capacity and the rate of rise of the embankments.
- The position of the phreatic surface in the dam.
- The loading of the free water pond. In cases where the pool is located in the zone of failure influence, the direct load caused by the maximum water level is included in the geotechnical analysis. In cases where the pool is far from the dam and water is stored for long periods, the potential increase of the phreatic surface level is considered.
- The physical properties of dam construction materials, foundations and basal structure, paying particular attention to the use of geosynthetics.
- The geometry of construction and raising (upstream, downstream or centreline methods). For example, for an upstream method the failure zone usually includes a large mass of

extractive waste and may intersect the phreatic surface, requiring consideration of the effect of the pore pressure on the failure surface.

- The seismic loading, including the selection of the seismic parameters that serve as input for the numerical analysis of the dam (ICOLD 2016; Wieland 2012).
- The physical and chemical properties of extractive waste, including the following:
  - Static liquefaction of loose extractive waste. This can result when loadings due to equipment vibrations or to the groundwater level increase are sufficient to rise the pore pressures to the critical level and to lower the effective stresses to values close to the limit equilibrium condition. This typically occurs when the rate of construction raising is faster than the pore pressure dissipation.
  - Dynamic liquefaction of extractive waste under seismic loading.
  - The freezing- and geochemical-related loadings such as freezing and thawing effects, particularly with permafrost soils, oxidation and chemical reactions and gas air pressure.

Where present, the assessment of internal and external bunds is considered.

The geotechnical analysis takes into consideration the results of the water balance analysis (see Section 4.2.1.3.4.1).

The structural stability of a dam is assessed in the short and long term, following the design for closure approach (see Section 4.2.1.1.1). For long-term analysis (closure and after-closure phase), the same principles that apply in the short term (operational phase) are used, but more emphasis is given to extreme events (such as floods, earthquakes, landslides). Events classified as extreme during operations (typically a period of less than 40 years) could be normal from a long-term perspective (up to 10 000 years) (Chambers and Higman 2011; ICOLD 2006; Martin *et al.* 2002). A range of loading conditions are therefore analysed and the safety factor is increased accordingly. Furthermore, slow deterioration of the dam by material weathering, water and wind erosion, freezing and thawing forces, intrusion by vegetation and animals are considered (ICOLD 2006, 2011b, 2016).

In the long term, damage by erosion, temperature and vegetation can be avoided by using stable materials in the construction of the dam and by constructing slopes of a sufficiently low angle. A repose angle of 3:1 (H:V) for the outer surface of the dam is for example considered stable in the long term as such slopes naturally occur in the landscape, according to the MTWR BREF (EC-JRC 2009).

<u>Seismic design parameters</u>

The selection of seismic parameters in this analysis is based on site-specific analyses of the seismic risk, which is defined at Member State level. The seismic design of a dam evaluates the strength to resist seismic forces without damage, the capability to absorb high seismic forces by inelastic deformations, the overall stability and the slope stability.

According to ICOLD (ICOLD 2016), the seismic loads for the design of new dams or for the safety evaluation of existing structures are derived from the following parameters:

- *Safety Evaluation Earthquake* (SEE). This is the maximum level of ground motion for which the dam is designed. For dams with high failure risk potential, the SEE is normally characterised by a level of motion equal to:
  - that expected from the occurrence of a deterministically evaluated *Maximum Credible Earthquake* (MCE, *the largest reasonably conceivable earthquake magnitude that is considered possible along a recognised fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework*); or
  - the probabilistically evaluated earthquake ground motion with a return period of 10 000 years; shorter return periods can be specified for dams with lower failure risk potential (Wieland 2012).

- *Operating Basis Earthquake* (OBE). This represents the level of ground motion at the dam site for which only minor damage is acceptable. The dam, appurtenant structures and equipment should remain functional and damage should be easily repairable. In many cases, a minimum return period of 145 years (i.e. a 50 % probability of not being exceeded in 100 years) is chosen.

  In detail:
  a) for extreme or high-consequence dams, the SEE ground motion parameter is estimated at the 84th percentile level (deterministic approach) *or* need not have a mean Annual Exceedance Probability (AEP) smaller than 1/10 000 (probabilistic approach);
  b) for moderate-consequence dams, the SEE ground motion parameter is estimated at the 50th to 84th percentile level (deterministic approach) *or* need not have a mean AEP smaller than 1/3 000 (probabilistic approach);
  c) for low-consequence dams, the SEE ground motion parameter is estimated at the 50th percentile level if developed by a deterministic approach *or* need not have a mean AEP smaller than 1/1 000 if developed by a probabilistic approach;
  d) the ground motions for the OBE will usually have a mean AEP of ~ 1/145.
  (ICOLD 2016; Wieland 2012)

Depending on the applicable conditions, a dam may be evaluated for one or both of the aforementioned seismic loads (SEE and OBE).

Safety factors
Standards on geotechnical design, such as Eurocode 7-1 (EN 1997-1:2004 - Part 1) (CEN 2004a) or equivalent national standards, are applied in Europe.

In Eurocode 7-1, the provisions for slope stability, embankments and hydraulic failure (by uplift, heave, internal erosion and piping) are contained in Sections 11, 12 and 10, respectively. Section 12 applies to embankments for small dams. These have a height up to 10 m (EC-JRC 2013b; Frank *et al.* 2005). For large dams, it is recommended to follow the provisions of international standards and guidelines such as the ICOLD ones (ICOLD 2001b, 2006, 2011b, 2016). According to the ICOLD definition (ICOLD 2016), *a large dam is one more than 15 m high or one between 10 and 15 m high satisfying one of the following criteria: a) more than 500 m long; b) reservoir capacity exceeding 1 million* m^3*; c) spillway capacity exceeding 2 000* m^3/s*.*

Eurocode 7-1 requires that, for each geotechnical design situation, it is verified that no relevant limit states are exceeded. The limit states include the ultimate limit states and the serviceability limit states that are verified by one or a combination of calculations (analytical model, semi-empirical model or numerical model), adaption of prescriptive measures, experimental models and load tests and the observational method (EC-JRC 2013b).

By applying Eurocode 7-1, the design values of soil/materials properties, loads and resistances are determined by using appropriate partial factors as defined in Annex A to this standard. The choice of which partial factor to use is governed by the ultimate state limit being considered and by the design approach (1, 2 or 3) being used. The values of the partial factors may be set by the National Annexes to Eurocode 7-1.

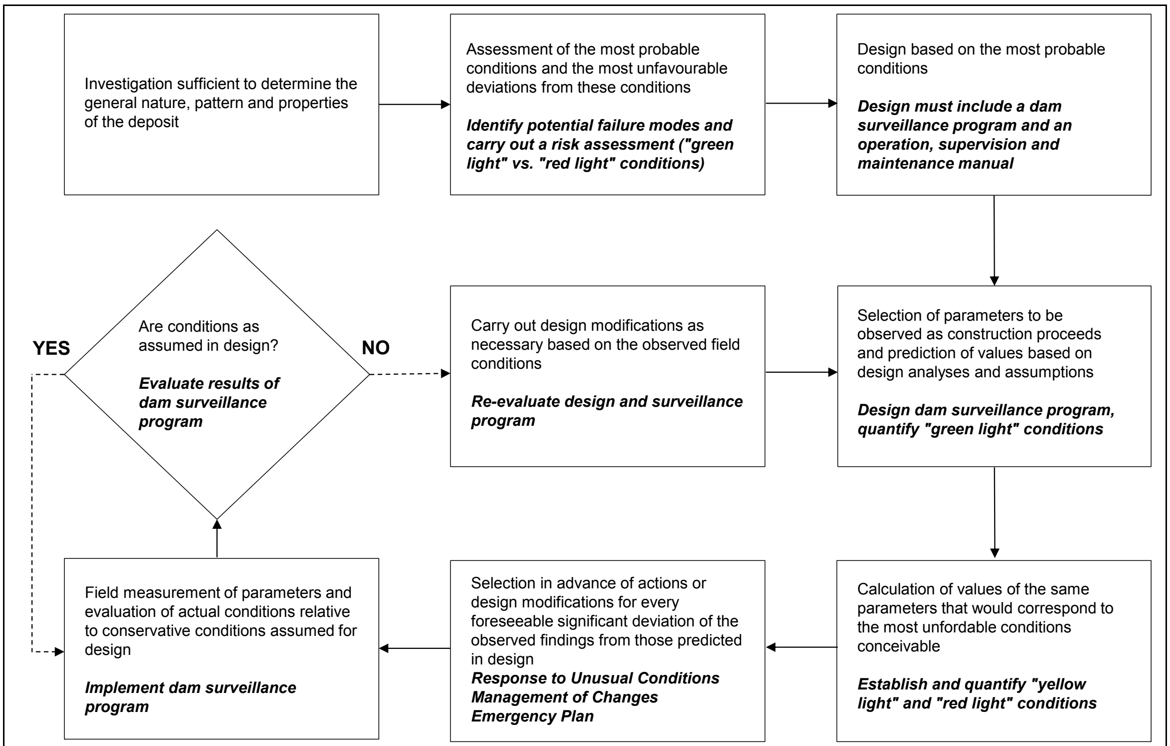
According to Eurocode 7-1, the overall stability of slopes is verified in the ultimate geotechnical (GEO) or structural (STR) limit states by applying an over-design factor (ODF) of at least 1, where the ODF is the ratio between the design resistance (Rd) and the design effect of the loads (Ed).

Assessment of liquefaction potential is extended beyond the recommendations given in EN 1998 Eurocode 8 and in particular Part 5 (CEN 2004b).

Other methods for analysing the overall stability do not apply partial factors to soil/material properties, loads and resistances and evaluate global safety factors. Minimum values for these factors, defined as the ratio between the maximum resisting forces to the driving forces (effect of the loads), are required. For short-term analysis, global safety factors of 1.2-1.3 would be acceptable, while, for long-term stability, factors of safety usually range between 1.4-1.5 (Fleurisson and Cojean 2014). A safety factor of 1.5 is considered to give sufficiently low probability for instabilities underground, in the foundation and within the dam, in the operational phase (short term) and after-closure phase (long term), according to the MTWR BREF (EC-JRC 2009). In Finland, a total safety factor of at least 1.5 is used in a state of constant seepage flow (Isomäki *et al.* 2012). A total safety factor of at least 1.3 is used under exceptional loading conditions (Isomäki *et al.* 2012). Examples of exceptional loading conditions are extreme conditions with flooding associated with dimensioning flow or sudden falls of water level.

When prediction of geotechnical behaviour is difficult during the design phase and when the design is reviewed during construction, the observational method may be applied, according to Eurocode 7-1 or equivalent. The observational method is based on the collection and analysis of data obtained from continuous monitoring by geotechnical instrumentation, field and laboratory tests and numerical modelling to confirm design assumptions. The monitoring programme is properly designed as a support to the observational method, not just by confirming anticipated conditions, but also by detecting unexpected, unfavourable conditions (Davies *et al.* 2002; ICOLD 2011b).

The elements of the observational method are illustrated schematically in Figure 4.22.



Source: adapted from (Davies et al. 2002)

Figure 4.22: Elements of the observational method

Evaluation of the severity of the likely consequences of a failure

Key hydrological parameters associated with the loss of physical integrity of a dam can be estimated by means of simplified correlations between, for example, the geometric parameters of the pond/dam (e.g. dam height, volume of extractive waste) and the hydraulic characteristics of the released outflow of extractive waste.

Following the collapse of a dam retaining extractive waste, only part of the extractive waste and stored water is released and this outflow volume is difficult to estimate prior to the accident.

- According to Azam (Azam and Li 2010), the released amount of extractive waste from mineral processing is about a fifth of the total amount of extractive waste contained in the EWF (the study is based on 198 accidents pre-2000 and 20 accidents post-2000).
- According to Rico and co-authors (Rico *et al.* 2008a) (the study is based on a database of 28 accidents), the volume of the extractive waste stored at the time of failure (V_T) was shown to correlate with the outflow volume (V_F) of the extractive waste, according to the following equation:

  $$V_F = 0.354 \times V_T^{\ 1.01},\ r^2 = 0.86$$

  However, the uncertainty of this correlation is high. Errors result from a large variety of parameters affecting the extractive waste outflow (such as sediment load, fluid behaviour, topography, valley gradient) and from the lack of data related to the water volume existing at the time of failure stored at the decant pond. Notwithstanding the uncertainty, this correlation may provide a first approximation to estimate the outflow volume of extractive waste.

Hydrodynamic models in two or three dimensions may be used to simulate the outflow of the extractive waste released as a consequence of a dam failure. The uncertainty of these models is high, due for example to the difficulties in understanding the interaction of the extractive waste outflow with the topography of the terrain (large-scale topographical features and small-scale roughness). Notwithstanding this, the models can assist in the evaluation of environmental risks and impacts and can allow the mapping of a potentially affected area.

The technique is implemented in all the life cycle phases of the extractive waste management:

- <u>*Planning and design phase*</u>
  The geotechnical analysis is carried out by considering all possible failure modes.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The geotechnical analysis is reviewed. Management systems are applied. When it is difficult to predict the geotechnical behaviour during the design phase, the observational method may be applied.
- <u>*Closure and after-closure phase*</u>
  The geotechnical analysis is reviewed. Management systems are applied.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of dams and ponds.

4. Environmental performance and operational data

Information on geotechnical analysis methods, design and construction standards and safety factors applied in different Member States, based on the data reported by operators via the questionnaires, is provided in Table 4.16.

Table 4.16: Stability analysis methods, design and construction standards and safety factors applied in different Member States, based on the data reported by operators via the questionnaires

MS	Limit equilibrium method	Numerical model - Finite element method (FEM)	Seismic design	Design and construction standards	Safety factors		
					Long term	Short term	Dynamic cond.
AT	Bishop		ONORM B 4040 OENORM B 4433	ICOLD + National guidelines *Eurocode-7* EN DIN 19 700 section 10-15 DIN 4 084		≥ 1.3 ≥ 1.5	≥ 1.1
ES	Spencer Bishop		Local seismic coefficient Pseudostatic (0.1 g)	National *Eurocode-7*	≥ 1.3	≥ 1.3	
DE				National *Eurocode-7* EN DIN 19 700 sections 10, 11 and 15 - DIN 4 084 - DIN 1 054	≥ 1.3-1.4		
FI	Morgenstern-Price Bishop	Yes		National	≥ 1.5	≥ 1.5 ≥ 1.3*	
FR					> 1.5	≥ 1.3	
IE				ICOLD + National + Industrial	≥ 1.5	≥ 1.5	≥ 1.2
PL	Pseudo-statistic (Morgenstern-Price)	Yes Newmark method (simplified)	Local seismic coefficient	ICOLD + National *Eurocode-7*	≥ 1.5	-	≥ 1.15
PT				ICOLD + Industrial			
SE			Yes	National		≥ 1.3	≥ 1.2
SK				National			
UK				National + Industrial			

** In the case of extreme conditions with flooding associated with dimensioning flow or sudden falls of water level.*

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified for the geotechnical analysis of ponds and dams.
- The observational method may be restricted in the case of failure modes that could develop very quickly, e.g. if a potential risk of static liquefaction of loose extractive waste exists. It is only applicable when there are sufficient time and available resources to react, once unfavourable conditions are noted. It does not compensate for an inappropriate site investigation programme (Davies *et al.* 2002). The method is not suitable for projects whose design cannot be changed during operation.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention.
- Safety requirements.
- Legal requirements according to Directive 2006/21/EC and related Commission Decisions, particularly Article 5 of Decision 2009/337/EC, and to national legislation.

- Standards application (for example Eurocode 7-1 or equivalent).
- Application of international and national guidelines.

9. Example sites
Generally applied in Europe according to the questionnaires (24 sites out of 87).

10. Reference literature
(AT BLF 1996)
(CEN 2004a)
(Chambers and Higman 2011)
(Davies *et al.* 2002)
(EC-JRC 2009, 2013b)
(Fleurisson and Cojean 2014)
(Frank *et al.* 2005)
(Frauenstein 2010)
(ICOLD 1996, 2001b, 2006, 2011b, 2016)
(Martin *et al.* 2002)
(Ozcan *et al.* 2013)
(UNECE 2014)
(Wieland 2012)

4.2.1.3.6.2 Geotechnical analysis of heaps

1. Description
The geotechnical stability of a heap is evaluated in the short and long term by considering all the mechanisms that can negatively affect the partial or total structural stability of heaps.

2. Technical description
This BAT candidate is relevant for heaps.

The geotechnical analysis of a heap usually evaluates the following aspects:
- The overall slope stability of the heap, including the basal structure. The typical slope failure modes are surface slumping, shallow flow slides (triggered by rain or snow), rotational circular failures, block translation, wedge failure along the critical interface of the geosynthetic liner system.
- The bearing capacity and stability of the heap foundations. Rotational failure surfaces may also extend into the foundation if the soil is weak.
- The physical and chemical stability of the extractive waste, including static and dynamic liquefaction, freezing and thawing.

(Fleurisson and Cojean 2014; Orman *et al.* 2011)

According to Orman and Fleurisson (Fleurisson and Cojean 2014; Orman *et al.* 2011), <u>the geotechnical analysis of a heap</u> over its life cycle is dependent upon:
- the physical properties of foundations and the basal structures, paying particular attention to the use of geosynthetics;
- the geometry of the heap and the heterogeneities in heap construction, such as segregation of materials at the toe in the case of large heaps, internal stratifications, etc.;
- the relative speed of raising layers compared to the consolidation of extractive waste;
- the position of the phreatic surface in the heap;
- the potential hydraulic and climatic conditions triggering development of pore pressures increase;
- the water drainage in the heap or supporting ground;
- possible external overloads in static (construction on the edge of dump crest, overloads caused by execution equipment) or dynamic (earthquakes, blasting operations) conditions;
- the seismic loading, including the selection of the seismic parameters;

- the physical and chemical properties of extractive waste including the following:
  - static liquefaction of loose extractive waste;
  - dynamic liquefaction of extractive waste under seismic loading;
  - the freezing- and geochemical-related loadings such as freezing and thawing effects, particularly with permafrost soils, oxidation and chemical reactions and gas air pressure.

Loose extractive waste disposed of on heaps can undergo significant settlement due to its own weight and degradation (Williams 2014).

The geotechnical analysis takes into consideration the results of the water balance analysis (see Section 4.2.1.3.4.1).

The physical stability of a heap has to be assessed in the short and long term. In the latter case, more emphasis is given to extreme seismic and climatic events.

The selection of seismic parameters is based on site-specific analyses of the seismic risk, which is defined at Member State level. The seismic design of a heap evaluates the strength to resist seismic forces without damage, the capability to absorb high seismic forces by inelastic deformations, the overall stability and the slope stability.

When a basal structure is included, the strength parameters of the soil-liner interface may become the most critical data for evaluating the slope stability of the heap. This strength depends on several parameters, such as the normal load, rate of applied shear, soil type, density, water content and drainage conditions, as well as liner characteristics, according to the SME Handbook (Orman *et al.* 2011).

In the closure phase, extractive waste heaps are usually reshaped to the angle of natural repose, depending on the extractive waste characteristics, and resulting in a geomorphic shape that either in itself or after the placing of a cover (including a possible vegetative cover), provides long-term stability and adequate protection against wind and water erosion. A repose angle of 3:1 (H:V) is for example considered stable in the long term as such slopes naturally occur in the landscape, according to the MTWR BREF (EC-JRC 2009).

In potash extraction, extractive waste heaps containing more than 80 % sodium chloride may remain stable with a slope angle up to 40 °. However, it may not be possible to cover the heaps that have been designed with a very steep slope.

Standards on geotechnical design, such as Eurocode 7-1 (EN 1997-1:2004 - Part 1) (CEN 2004a) or equivalent national standards, are followed in Europe. In Eurocode 7-1, the provisions for slope stability and embankments are contained in Sections 11 and 12, respectively (see Section 4.2.1.3.6.1)

Assessment of liquefaction potential is extended beyond the recommendations given in EN 1998 Eurocode 8 and in particular Part 5 (CEN 2004b).

The application of the observational method according to Eurocode 7-1 or equivalent is described in Section 4.2.1.3.6.1.

The physical stability of a heap is evaluated in all the life cycle phases of the extractive waste management:

- <u>*Planning and design phase*</u>
  The geotechnical analysis is carried out by considering all possible failure modes.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The geotechnical analysis is reviewed. Management systems are applied. When it is difficult to predict the geotechnical behaviour during the design phase, the observational method may be applied.

- *Closure and after-closure phase*
  The geotechnical analysis is reviewed. Management systems are applied.

3. Achieved environmental benefits
- Helping to ensure the short-term and long-term structural stability of heaps.

4. Environmental performance and operational data
Information on stability methods, design and construction standards and safety factors applied in different Member States, based on the data reported by operators via the questionnaires, is provided in Table 4.17.

Table 4.17: Stability analysis methods, design and construction standards and safety factors applied in different Member States, based on the data reported by operators via the questionnaires

MS	Limit equilibrium method	Numerical model - Finite element method (FEM)	Seismic design	Design and construction standards	Safety factors		
					Long term	Short term	Dynamic cond.
ES	Yes	NI	Local seismic coefficient	National Eurocode 7			
DE		NI	Non-seismic areas	National Eurocode 7			
FI	Yes	NI		National	> 1.3	> 1.3	
TR		NI	Yes	National + industrial	> 1.5	1.5	1.0

By using equivalent national standards that do not apply partial factors and evaluate global safety factors, the overall stability is analysed by applying:
- a safety factor of at least 1.3 in the operational phase (short-term) or equivalent level of safety justified by complex numerical models and taking into account the extractive waste characteristics (see Section 4.1.2.1), the extractive waste site and management options (see Section 4.1.2.2) and the Environmental Risk and Impact Evaluation (see Section 4.1.2.3) and the uncertainty on the information from these techniques;
- a safety factor of at least 1.5 in the after-closure phase (long-term) or at least equivalent level of safety justified by complex numerical models and taking into account the extractive waste characteristics (see Section 4.1.2.1), the extractive waste site and management options (see Section 4.1.2.2) and the Environmental Risk and Impact Evaluation (see Section 4.1.2.3), the uncertainty on the information from these techniques, and provided that appropriate monitoring is in place.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- None identified for the geotechnical analysis of heaps.
- The applicability of the observational method may be restricted in the case of failure modes that could develop very quickly, e.g. if a potential risk of static liquefaction of loose extractive waste exists. It is only applicable when there are sufficient time and available resources to react, once unfavourable conditions are noted. It does not compensate for an inappropriate site investigation programme (Davies *et al.* 2002). The method is not suitable for projects whose design cannot be changed during operation.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention.
- Safety requirements.
- Legal requirements according to Directive 2006/21/EC and related Commission Decisions, particularly Article 5 of Decision 2009/337/EC, and to national legislation.
- Standards application (for example Eurocode 7-1 or equivalent).
- Application of international and national guidelines.

9. Example sites

- Mina Los Santos, Fuenterroble (ES)
- Proyecto Cobre Las Cruces (ES)
- Steirischer Erzberg (AT)
- El Cogulló (ES)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)
- Kisladag Gold Mine (TR)
- Efemçukuru Gold Mine (TR)

10. Reference literature

(CEN 2004a)
(Davies *et al.* 2002)
(EC-JRC 2009, 2013b)
(Fleurisson and Cojean 2014)
(Frauenstein 2010)
(Orman *et al.* 2011)
(Williams 2000)

4.2.1.3.6.3 Monitoring of the physical stability of the extractive waste deposition area (including the EWF)

1. Description

Monitoring the physical stability of the extractive waste deposition area (including the EWF) is aimed at controlling the behaviour of ponds, dams and heaps, the deposited extractive waste, the water infiltration within the dam/heap, the drainage water, the seepage to soil and groundwater and overall water management by means of data collection and engineering models. Instrumentation is installed within and around the extractive waste deposition area (including the EWF). A comprehensive physical stability monitoring plan is developed in the planning and design phase and is implemented and adapted based on the monitoring findings in the operational phase and in the closure and after-closure phase.

2. Technical description

This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back.

Monitoring to confirm the safety of the extractive waste deposition area (including the EWF) involves the following components:

- Planning the monitoring of the extractive waste deposition area (including the EWF), during construction
  - o Typical components of a *construction management system* include:

        - planning and scheduling;
        - survey control (layout, as-built records);
        - grouting monitoring;
        - foundation preparation monitoring;
        - construction material quality control;
        - compaction control;
        - instrumentation monitoring and data synthesis;
        - record-keeping;
        - construction safety;
        - construction environmental criteria.
    - Records of the results of test work (e.g. compaction of supporting strata) carried out for and during construction are properly maintained. As-built drawings and actual procedure records are maintained, highlighting any variances from the original design and if necessary revisiting the design criteria.
    - Construction is supervised by independent qualified engineering/geotechnical specialists.
- <u>Planning the monitoring and conformance checks of the extractive waste deposition area (including the EWF), during operation</u>
    - Typical components of an *operation management system* include:
        - performance monitoring and visual conformance checks;
        - groundwater pressure (pore water pressure) monitoring;
        - monitoring of:
            - water that infiltrates the dam/heap;
            - drainage water;
            - seepage to soil and groundwater;
        - deformation (settlement and stability) monitoring;
        - weather influence monitoring;
        - frost activity in boreal and subarctic climates;
        - seismic events analysis (after the event) and special conformance check programmes after major events (earthquakes, hurricanes, spring break-up, floods) in seismic areas (as defined according to national legislation).
    - *Indicators of instability* and potential deficiencies in the dam/embankment/heap are:
        - distress signals such as longitudinal and transverse cracking;
        - presence of settlements, saturated areas on the downstream dam wall, soft zones and boils along the toe, dirty sediment in seepage;
        - increased rates of drainage water and/or new areas of moisture.
    - *Areas* that require special attention are:
        - spillways;
        - decant structures;
        - drain and pressure relief wells;
        - concrete structures;
        - pipes and channels/trenches through the dam/embankment;
        - siphons;
        - weirs;
        - unusual plant growth and animal dens.

<u>Developing a physical stability monitoring plan</u>
The physical stability monitoring plan may include the following aspects:
- number and location of control stations;
- scheduling (control periods and conformance checks by operators);
- type and purpose of monitoring measures (visual conformance checks by operators, measurements and parameters);
- appropriate instrumentation installed in the structural zone, in the drainage system and in the extractive waste deposit during construction or later in a borehole;
- conformance check methods and evaluation;
- identification of the person/function responsible for the monitoring and reporting;

- data storage and reporting systems;
- criteria to assess the monitoring plan;
- scheduling the monitoring plan review on a regular basis, preferably by the design engineer, to assess whether the design requirements are being met, according to the SME Handbook (Kerr and Ulrich 2011).

Furthermore, this plan may include the following practices:
- A dam surveillance plan (for dams). This will be designed based on the analyses and consequences of an accident. The plan will be a living document and is performance-based. This is linked to the behaviour of the dam, its weaknesses and potential failure modes and their consequences.
- Emergency planning, including an internal emergency plan specifically required for Category A EWFs (see Section 4.2.1.2.4).

Monitoring of the physical stability of the extractive waste deposition area (including the EWF) helps to improve the calibration of the geotechnical models and the slope stability analyses, for example by continuously evaluating the degree of saturation of extractive waste and the phreatic surface position and by understanding the consolidated behaviour of the extractive waste.

Measurements, instrumentation and frequency for monitoring the physical stability of ponds, dams and heaps
Monitoring parameters and frequencies are properly selected according to the site-specific conditions of the extractive waste deposition area (including the EWF), with particular regard to the potential risk of short-term and long-term structural instability, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP.

The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.

Table 4.18 gives examples of reported physical stability monitoring parameters and frequencies for ponds, dams and heaps, based on input received via the information exchange, including data collected from literature or reported by operators via the questionnaires.

Table 4.19 shows examples of reported physical stability monitoring instrumentation for ponds, dams and heaps, based on input received via the information exchange, including data collected from literature or reported by operators via the questionnaires.

Table 4.18: Reported physical stability monitoring parameters and frequencies for ponds, dams and heaps, based on the input received via the information exchange, including questionnaires

Parameters	Reported frequencies
Ponds and dams	
Water level in pond	From weekly to continuously
Drainage water (flow) (EWIW which infiltrates the dam itself, the foundation (if possible) and the abutments and is collected)	From weekly to continuously
Position of the phreatic surface	From monthly to weekly
Pore pressure	From monthly to weekly
Seismicity (in seismic areas)	Continuously
Dynamic pore pressure and liquefaction	From every two weeks to weekly
Horizontal and vertical movements of dam crest, downstream slope and extractive waste	From monthly to weekly
Differential settlement in the embankment	From monthly to continuously
Deformations in the dam and foundations	From monthly to continuously
Geotechnical parameters of extractive waste	From monthly to weekly as well as after the introduction of new ore types or process changes that may have an influence on these parameters
Extractive waste placement	From monthly to weekly
Heaps	
Bench/ slope geometry	Quarterly
Drainage water at the toe	Quarterly
Pore pressure	Quarterly
Seismicity (in seismic areas)	Continuously
Geotechnical parameters of extractive waste	Quarterly as well as after the introduction of new ore types or process changes that may have an influence on these parameters

Literature sources: (EC-JRC 2009; ICOLD 1996, 2011b; Kerr and Ulrich 2011)

Table 4.19: Reported physical stability monitoring instrumentation for ponds, dams and heaps, based on the input received via the information exchange, including questionnaires

Parameters	Instrumentation
Ponds and dams	
Water level in pond	Level scale, Doppler
Drainage water (flow) (EWIW which infiltrates the dam itself, the foundation (if possible) and the abutments and is collected)	• weirs or calibrated containers • pore water pressure gauges, groundwater wells
Position of the phreatic surface	Piezometer (open standpipe or Casagrande standpipe, closed piezometers)
Pore pressure	Piezometer (standpipes), bourdon tube pressure gauge or remote reading piezometers (vibrating wire, pneumatic, hydraulic and electrical resistance)
Seismicity (in seismic areas)	Strong motion accelerographs
Dynamic pore pressure and liquefaction	Vibrating wire piezometers
Horizontal and vertical movements of dam crest, downstream slope and extractive waste	Geodetic points on beach and crest of the dam (markers at the surface preferably in one straight line) aerial photography, GPS. Inclinometers (for horizontal movements)
Differential settlement in the embankment	PVC standpipes with settlement plates or rings
Deformations in the dam and foundations	Borehole inclinometer (cased borehole in which the lining is equipped with two sets of orthogonal longitudinal guiding tracks). Deep inclinometers for ground movements.
Geotechnical parameters of extractive waste (such as grain size distribution and density, shear strength, compressibility, consolidation)	Penetrometers (cone penetrometers). Dynamic penetrometers not recommended for extractive waste from mineral processing)
Extractive waste placement (e.g. discharge from the spigotting outlets, width of the non-submerged beach as an indication of phreatic surface, freeboard)	Aerial or satellite photography. Geodetic points.
Heaps	
Bench/ slope geometry	Geodetic points (markers at the surface), GPS, settlement plates
Drainage water at the toe	Weirs, V-notches
Pore pressure	Piezometers (standpipes)
Seismicity (in seismic areas)	Strong motion accelerographs
Geotechnical parameters of extractive waste (e.g. grain size distribution and density)	Penetrometers

Literature sources: (EC-JRC 2009; IRMA 2016; Kerr and Ulrich 2011)

The scope and frequency of monitoring will change over the life of the extractive waste deposition area (including the EWF), depending on the phase and on the results' consistency (Davies *et al.* 2002). The combination of these results with properly maintained operational tools (e.g. recording dates, locations and meteorological conditions at the time of disposal) allows for a reliable quantification of risk, thereby enabling effective preventive responses (Kossoff *et al.* 2014).

Conformance checks and audits/reviews

The overall physical stability monitoring plan typically also includes plans for routines to assess the stability that may include the following:

- *Visual conformance checks by operators and supervision* are carried out by an experienced operator/supervisor, following a predetermined checklist.
- *Annual reviews* include a full topographical survey of the structure.

- *Independent external audits* is a system for evaluating the performance and safety of a facility on a regular basis by a qualified and experienced expert, who was/is not involved with the design or operation of the facility.
- Dam safety review audits are carried out every 8-15 years by a team of independent experts. These audits include going through all documentation related to the dam, questioning all basic assumptions made leading up to the design and construction of the dam and assessing the coherence between the design and the as-built dam.

The use of systems that provide real-time monitoring coupled to automatic warnings is encouraged. Automation of measurements is particularly relevant where measurements are carried out continuously (e.g. for pH and flows). Another good example is the continuous surveillance of spillways by cameras.

Table 4.20 presents a monitoring programme during operation and in the after-closure phase for ponds, dams and heaps.

Table 4.20: Reported frequencies for conformance checks, reviews, audits and safety evaluations for ponds, dams and heaps during operation and after-closure, based on the input received via the information exchange, including questionnaires

Assessment type	Reported frequencies	
	Operational phase	After-closure phase
Ponds and dams		
Visual conformance checks by operators	Daily	Every 6 months
Supervision	Quarterly	Every 6 months
Annual review	Yearly	Yearly
Independent external audit	Every 3 years	Every 10 years
Dam safety review	Every 8-15 years	Every 8-15 years
Heaps		
Visual conformance checks by operators	Daily	Every 6 months
Geotechnical review	Yearly	Every 2 years
Independent external geotechnical audit	Every 3 years	Every 10 years

Source: (EC-JRC 2009) and questionnaires and expert statements at the Final TWG Meeting

Table 4.21 presents examples of personnel employed for conformance checks, reviews, audits and safety evaluations for ponds, dams and heaps during operation and in the after-closure phase.

Table 4.21: Reported examples of personnel for conformance checks, reviews, audits and safety evaluations for ponds, dams and heaps during operation and after-closure, based on the input received via the information exchange, including questionnaires

Assessment type	Personnel
Ponds and dams	
Visual conformance checks by operators	Dam operators; after the closure possibly follow-up staff
Supervision	Manager or an appointed person
Annual review	Engineer (coordinator or external specialist)
Independent external audit	Independent expert
Dam safety review	Team of independent experts
Heaps	
Visual conformance checks by operators	Heap operators; after-closure possibly follow-up staff
Geotechnical review	Engineer
Independent external geotechnical audit	Independent expert

Source: (EC-JRC 2009) and questionnaires

The frequencies given for the after-closure phase are relevant for the initial period after closure. Based on the monitoring results, the frequency may be decreased with time to an extent that conformance checks by operators and audits/reviews are no longer necessary if restoration is properly completed. Furthermore, the monitoring programme in the after-closure phase allows verification that the overall closure objectives and long-term functioning are achieved. If the closure objectives are not met, corrective measures are taken during the verification period.

The monitoring of the physical stability of the extractive waste deposition area is implemented during all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  A physical stability monitoring plan is developed.
- *Operational (construction, management and maintenance) phase*
  The physical stability monitoring plan is implemented, by monitoring of the parameters as defined in the planning and design phase, and adapted based on the monitoring findings over time.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing the inappropriate monitoring of the extractive waste deposition area (including the EWF).
- Prevention and reduction of negative environmental impacts from the management of extractive waste.
- Mitigation of accidents during the operational (construction, management and maintenance) phase.
- Ensuring a high level of protection of the environment as a whole.
- Maintaining the appropriate operation, closure and after-closure of the extractive waste deposition area (including the EWF).

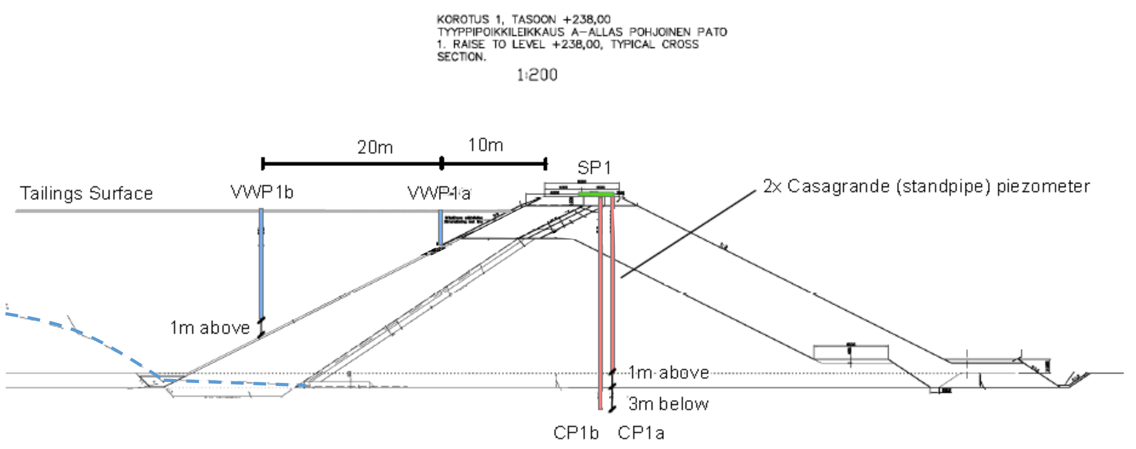
4. Environmental performance and operational data

At the KGHM Polska Miedź S.A Żelazny Most tailings pond, the following continuous monitoring system is applied:

- *Meteorological measurement*: station situated on the dam measuring rainfall, temperature, wind velocity and direction, and humidity.

- *Observation of the state of all elements of the EWF and its infrastructure:*
    - routine visual conformance checks by operators;
    - exceptional conformance checks after any tremors and during heavy rain;
    - periodic conformance checks by a committee in charge of the technical state of the structure (monthly, twice a year);
    - inspection by a competent authority.
- *Minimum distance between the coastline and the dam crest:* keeping 200 m between the coastline and the dam crest.
- *Control of phreatic line location in the extractive waste and in the dam body:*
    - measurements of the levels of water and sediments in the pond (1-12 times a year);
    - measurements of the water table within the body of the starter dam (1-12 times a year);
    - measurements of the water table and dissolved solids composition in piezometers and wells, situated in the vicinity of the pond (twice a week to twice a year);
    - measurements of the water level in some piezometers for warning purposes;
    - measurements of the water flow rate:
        - through the dam (twice a year);
        - through its toe (monthly);
        - in the ditches located at its toe;
        - in the horizontal drainage in chosen wells (twice a year);
        - in piezometers in the vicinity of the pond (once or twice a week).
- *Measurement of horizontal displacements in the dam and its foundation:* inclinometer measurements of horizontal displacements (1-12 times a year).
- *Measurements by the net of landmarks situated on the crest, slopes and the toe of the dam:* geodetic displacement measurements.
- *Seismic measurements of the foundation acceleration caused by mining tremors:* by seismic stations equipped with accelerometers. The measured signals are continuously transmitted to the mine.
- *Prediction of the water table related to the vicinity of the beach:* automatic measurements in a group of piezometers situated at different depths and at different distances from the dam, as well as measurements carried out with a cone penetrometer (CPTU).
- *The system of linear transducers in the body of the starter dam, at the perimeter of the pond on two levels with signal transfer to the main station.*
- *Warning system equipped with land deformation and water level sensors.*

At the Kevitsa mine, data are collected electronically and transmitted to a web-based database:
- the pore pressure is monitored by means of 12 vibrating wire piezometers (VWP) installed in the extractive waste at 500-metre intervals along the embankment;
- potential movements of the dam are monitored by 6 settlement plates (SP) placed at regular intervals along the crest;
- the filters and core performance, phreatic surface and pore pressure in the foundation are monitored by 12 Casagrande standpipe piezometers (CP) (see Figure 4.23) placed in the downstream shoulder of the dam, one above the foundation and one in the foundation ground.



Source: *Kevitsa Mine questionnaire*

Figure 4.23: Cross-section of the EWF embankment at the Kevitsa Mine and typical location of the instruments in the embankment (reported by an operator via a questionnaire)

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- Settlement plates have to be placed below the freezing depth.
- Vibrating wire piezometers are placed at a sufficient extractive waste depth.
- Piezometers to measure pore pressure are not used if extractive waste has a high salt content which crystallises after compaction, forming a monolithic block.

7. Economics

- Economic savings arising from the avoidance of clean-up and remediation costs due to EWF failures are reported in Section 4.2.1.1.1 (heading 7).

8. Driving force for implementation

- Risk prevention and management.
- Safety requirements.
- National legal requirements. Local environmental quality standards.
- Increased confidence of local communities.
- Surveillance and early warning.

9. Example sites

- Generally applied at sites with ponds, dams and/or heaps.

10. Reference literature

(Davies *et al.* 2002)
(Brinkmann *et al.* 2018; EC-JRC 2009)
(ICOLD 1996, 2011b)
(IRMA 2016)
(Kerr and Ulrich 2011)
(Pöyry 2011a)
(Rodriguez *et al.* 2015)
(Stefanek *et al.* 2010)

4.2.1.3.6.4 Conformance checks and internal and external auditing

1. Description

Conformance checks and internal and external audits are a system for evaluation of the performance and safety of an extractive waste deposition area (including the EWF) on a regular basis, by a qualified and experienced expert.

2. Technical description

This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back.

The evaluation of the performance and safety of an extractive waste deposition area (including the EWF) is carried out on a regular basis by a qualified and experienced expert by means of one or a combination of the following techniques:

- conformance checks (with or without a third party);
- internal audits;
- external audits.

According to the MTWR BREF (EC-JRC 2009), an <u>independent external audit</u> covers all aspects that can affect the overall extractive waste deposition area (including the EWF) safety, e.g.:

- current design, design according to permits and applicable standards, as-built and design changes documentation;
- previous construction/deposition phases in accordance with design;
- past problems and incidents;
- future/planned design in accordance with applicable standards;
- ongoing construction and deposition in accordance with applicable standards;
- data about the properties of construction materials and comparisons with the design criteria;
- monitoring of:
  - drainage water, seepage, surface and groundwater (frequency, location and analysed parameters);
  - pore pressure;
  - calibration of equipment;
  - evaluation and records of readings;
  - action plan when readings fall outside expected results;
- safety organisation of the extractive waste deposition area (including the EWF), i.e. check that one person is appointed responsible, roles and responsibilities for individuals, training programme and incident reporting system;
- adequacy of the operating manual, i.e. the Operation, Maintenance and Surveillance manual (OMS manual);
- overall water balance of the extractive waste deposition area (including the EWF);
- surveillance performed according to applicable standards;
- Environmental Risk and Impact Evaluation:
  - review of the safety and stability monitoring results;
  - information on the location and depth of boreholes and their proposed monitoring;
- emergency planning;
- closure plan.

Qualifications to perform an audit might vary depending on the hazard rating / class of the EWF. If the audit incorporates several technical fields, a team of specialists is usually assembled. For dams, geotechnical science is generally of particular interest. Other sciences, depending on local site conditions, may be hydrology and hydrogeology. The person or persons performing an audit are specialists with documented experience in the particular sciences. It may be useful to work with specialists from abroad to bring in new knowledge and views, according to the MTWR BREF (EC-JRC 2009).

Independent external audits are performed by an expert that has not previously been involved with the specific site undergoing the audit.

Conformance checks and internal and external audits are implemented during all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Conformance checks and internal and external audits are planned.
- *Operational (construction, management and maintenance) phase*
  Conformance checks and internal and external audits are carried out. Management systems are applied.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - supporting the monitoring of the physical stability of the extractive waste deposition area (including the EWF).
- Prevention and reduction of negative environmental impacts.
- Mitigation of accidents.
- Improvement of risk management.

4. Environmental performance and operational data

Reported frequencies of the conformance checks and the internal and external audits for the assessment of ponds and dams and of heaps during operation and after-closure and examples of personnel employed for conformance checks, reviews and audits are indicated in Section 4.2.1.3.6.3.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- Risk prevention.
- Avoidance of potential human errors and construction defects by having an independent expert opinion.

9. Example sites

- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature

(EC-JRC 2009)

4.2.1.4 Extractive waste containment in underground extractive waste deposition areas

4.2.1.4.1 Closure of the access to the underground extractive waste deposition area

This BAT candidate is relevant for underground extractive waste deposition areas accessed via a wellbore.

The confinement of extractive waste from oil and gas exploration and production in the underground deposition area is usually related to the geological characteristics of the site, i.e. a low-permeability confining geological layer and no pathway to aquifers.

No specific techniques were provided by operators for evaluating the confinement of extractive waste in the underground deposition areas. Nonetheless, it is considered good practice:
- to provide information on the confining formation, also taking into consideration the information from fracture propagation during well completion, where relevant;
- to provide information on faults, e.g. mapping the faults near the well and the underground deposition area;
- to provide information on the planned well construction and on the plugging and closure of any well used for the deposition of extractive waste;
- to demonstrate that the groundwater is protected from extractive waste contamination.

No specific techniques were provided by operators for well closure; nonetheless, it is considered good practice to close the access by applying the closure practices identified in (UKOOG 2015).

In the UK, as in other countries, the well closure is regulated with a specific regulation and it is included in the waste management closure plan (UK EA 2016).

The technique is implemented in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Containment of extractive waste in the underground extractive waste deposition areas and the closure of any wellbore are evaluated.
- *Closure and after-closure phase*
  The access to the underground extractive waste deposition area is closed by applying the following closure practices (UKOOG 2015):
    - designing the closure of the wellbore that connects the surface with the underground area in order to contain the extractive waste underground and prevent any migration of extractive waste and/or pollutants which could have negative effects on the environment and human health;
    - cementing any identified pathway to groundwater inside or outside the casing;
    - avoiding, by appropriate cementation inside or outside the casing, any contact between different geological structures in order to isolate the producing formation and the aquifers, in particular in the case of freshwater aquifers;
    - plugging the well in order to avoid any leaks to the surface; plugs need to cover the full diameter of the hole, with only casing (no cables) within the cement in order to achieve full lateral coverage;
    - assuring the well casing is appropriately covered;
    - cleaning up the site after production and rehabilitating it as far as possible to its original state or agreed re-use.

4.2.1.4.2 Monitoring of fracture propagation and induced seismicity resulting from pressure injection operations in oil and gas exploration and production

1. Description

The technique consists of the development of a monitoring plan for fracture propagation and induced seismicity resulting from pressure injection operations of extractive waste, purposely placed or unavoidably remaining in the underground deposition area..

2. Technical description

This BAT candidate is relevant for underground extractive waste deposition areas.

Fracture propagation and induced seismicity resulting from pressure injection operations of extractive waste, purposely placed or unavoidably remaining in the underground deposition area, are monitored by means of appropriate monitoring techniques, e.g. seismometers, tiltmeters and microseismic monitoring during the production/operational phase, in order to facilitate the identification of the extent of any extractive waste dispersion/migration.

A fracture propagation and seismicity monitoring plan is developed and implemented.

The monitoring of fracture propagation and induced seismicity is carried out when extractive waste is purposely placed or unavoidably remains in the underground deposition area as the result of underground pressure injection operations. The monitoring of fracture propagation and induced seismicity is implemented during different life cycle phases:

- *Planning and design phase*
  A fracture propagation and induced seismicity monitoring plan is developed.
- *Operational (construction, management and maintenance) phase*
  Fracture propagation and induced seismicity in the underground extractive waste deposition area, resulting from pressure injection operations of extractive waste, is monitored by means of appropriate monitoring techniques, e.g. seismometers, tiltmeters and microseismic monitoring.

3. Achieved environmental benefits

- Helping to ensure the short-term and long-term stability of the underground extractive waste deposition area by:
  - helping to ensure the appropriate containment of extractive waste underground.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- Safety requirements.
- National legal and environmental requirements.

9. Example sites

- In 2015, the British Columbia Oil and Gas Commission confirmed that a 4.6-magnitude earthquake that occurred in August 2015 was caused by fracking (Canadian Press 2015).

10. Reference literature
(Canadian Press 2015)
(Verdon and Wüstefeld 2013)

4.2.2 Physical and chemical stability of extractive waste

4.2.2.1 Physical stability of extractive waste

4.2.2.1.1 Techniques for the solid/liquid control of extractive waste

4.2.2.1.1.1 Mechanical screening

1. Description
This technique consists of passing a solid/liquid flow through a screening device to separate the coarse fraction of the solid phase from the liquid phase.

2. Technical description
This BAT candidate is relevant for extractive waste from excavation and extractive waste from mineral processing. It is particularly relevant for extractive waste from mineral processing to be deposited into ponds. It is also relevant for drilling muds and other extractive wastes from oil and gas exploration and production.

A liquid-solid flow passes through a screening device to separate the coarse fractions of the solid phase from the liquid phase. This includes the use of for example rotating or vibrating screens and shale shakers.

More specifically for the case of drilling muds and other extractive waste from oil and gas exploration and production, the drilling mud circulates between the bottom of the well and its surface, picking up drilled solids during the ascent. Both Water-Based Muds (WBM) and Oil-Based Muds (OBM) containing drill cuttings returning to the surface are passed through surface processing equipment to remove solids (cuttings and fines) from the liquid stream. This separation technique is a standard practice. Drilling muds are then re-used in drilling activities. The separation equipment consists of a vibrating screen or shale shaker, which oscillates to remove large particles (≥ 75 µm).

The technique is designed to achieve maximum density and efficient deposition.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- _Planning and design phase_
  The performance and characteristics of the mechanical screening are designed in the planning and design phase in order to meet the site-specific extractive waste management objectives.
- _Operational (construction, management and maintenance) phase_
  Mechanical screening systems are implemented to separate the coarse fraction of solids from the EWIW.

3. Achieved environmental benefits

- Helping to ensure the physical stability of extractive waste by:
  - preventing or reducing the presence of residual water that could negatively affect the stability of extractive waste following deposition;
  - control and improvement of the extractive waste characteristics;
  - in the case of drilling muds and other extractive wastes from oil and gas exploration and production:
    - reducing the drilling muds treatment, chemical consumption and raw materials needed for subsequent mud preparation;

  - improving the properties and performance of the drilling fluids;
  - reducing extractive waste generation by enabling more drilling fluids to remain in the circulating system;
  - preventing the wells from clogging up;
  - reducing the amount of spent drilling muds and other extractive wastes from oil and gas exploration and production to be disposed of at the end of the drilling activities.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.

4. Environmental performance and operational data

The separation of drill cuttings from drilling muds will create a solid extractive waste with residual drilling mud. In the management of drilling muds and other extractive wastes from oil and gas exploration and production, a well of 5 500 m with a standard configuration generates approximately 1 600 t of solid extractive waste. The use of secondary solids control equipment to remove drill cuttings from drilling muds can be expected to reduce drilling fluid waste volumes by ~ 50 %.

No operational data were provided in the questionnaires.

Data collected from literature indicate a level of drilling fluids' Retention On Cuttings (ROC) ranging from 5 % to 15 % in general (IOGP 2016).

In vacuum-assisted shale shakers, the ROC ranges from 3 % to 6.9 % (AECOM 2016) which is comparable with the best performing shale shakers for which the ROC ranges from 3 % to 8 % (IOGP 2016).

5. Cross-media effects

- Energy consumption (diesel and electricity) for mechanical screening.

6. Technical considerations relevant to applicability

- The technique is applicable when meeting design criteria for dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2), and in combination with extractive waste characterisation (see Section 4.1.2.1.1), where the recovered solid materials are used for dam construction.
- Mechanical screening is not applicable to remove fine particles from EWIW.
- The ability to carry out the operation will be dependent upon several factors, such as the site footprint, the extractive waste characteristics and the capacity of the extractive waste deposition area. In the extraction of oil and gas, with a limited deposition capacity, the site is reliant upon transporting extractive waste off site to third-party treatment and permanent disposal.

7. Economics

- By removing drill cuttings from the drilling muds, the reduction of the treatment costs can be expected to be in the order of 50 %, based on the data reported by operators via the questionnaires.

8. Driving force for implementation

- Legal and environmental requirements.
- Reduction of costs for the extractive waste management.

9. Example sites

- ENI upstream - DIME - Distretto Meridionale (Southern District) (IT)
- Armatella 2 Or (IT)
- Preston New Road (UK)

10. Reference literature
(Cuadrilla 2014a, b)
(IOGP 2009)

4.2.2.1.1.2 Hydro-cycloning

1. Description
This technique consists of separating the fine particles from the liquid phase using hydro-cyclones.

2. Technical description
This BAT candidate is relevant for extractive waste from mineral processing. It is particularly relevant for extractive waste from mineral processing to be deposited into ponds. It is also relevant for drilling muds and other extractive wastes from oil and gas exploration and production.

Fine particles are separated from the liquid phase by hydro-cyclones for the following purposes:

- To obtain slurried extractive waste from mineral processing that is transported by centrifugal pumps to a pond. Slurried extractive waste from mineral processing typically consists of 30-40 % solids by weight, but levels of 15-50 % solids have been known. Typical slurry characteristics, including solids concentration, and equipment to dewater different slurried extractive waste are reported in Table 4.22. Slurried extractive waste is typically managed in a pond where a decant system is included.
- To separate solids from the drilling fluids in order to maximise the recycling of drilling fluids and minimise the final volume of extractive waste. Usually, particles in the range of 15 µm to 80 µm can be removed (IOGP 2016). The removal of particles up to 35 µm was also reported by operators via the questionnaire. The waste generated from a hydro-cyclone is a slurry of concentrated solids that requires disposal. A hydro-cyclone can reduce oil and grease concentrations in the water stream to 10 ppm (CSM 2009).

Table 4.22: Characteristics of the dewatering of slurried extractive waste from mineral processing

Dewatering characteristics	Description		
Dewatering technique	Hydro-cyclones		
Typical extractive waste concentration	Typically 30-40 % solids	Extractive waste from mineral processing of base metal	40 %
		Extractive waste from mineral processing of coal	25-30 %
		Extractive waste from mineral processing of gold	45 %
		Mineral sands slimes	15 %
		Extractive waste from mineral processing of nickel	35 %
Typical transportation method	Centrifugal pumps		
Bleed water	Fines to pond with significant water amount to manage		
Deposit character	Segregating		
Physical strength model	Fluid rheology		
Beach slopes	Flat with concavity		
Post-depositional settlement (consolidation)	Creep may still affect the non-linear finite strain predictions		
Containment of extractive waste	Retention structures (dam/embankment) for subaerial deposition		

Source: adapted from (AU DITR 2007; Davies et al. 2010)

The technique is designed to achieve maximum density and efficient deposition.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The performance and characteristics of the hydro-cyclones are designed in the planning and design phase in order to meet the site-specific extractive waste management objectives.
- *Operational (construction, management and maintenance) phase*
  Hydro-cycloning systems are implemented to separate the finer fraction of solids from the EWIW.
  In the management of extractive waste from mineral processing, hydro-cyclones are used to separate the coarser fractions of extractive waste in order to use them as construction material.

3. Achieved environmental benefits

- Helping to ensure the physical stability of extractive waste by:
  - preventing or reducing the presence of residual water that could negatively affect the stability of extractive waste following deposition;
  - control and improvement of the extractive waste characteristics.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.

4. Environmental performance and operational data

Potential total water recovery is typically ~ 50 % to 60 % (AU DITR 2007) from the slurry of mineral processing extractive wastes.

5. Cross-media effects

- High mobility of the slurried extractive waste due to its chemical and physical characteristics.
- Low consolidation rate and susceptibility to liquefaction.
- The resulting slurry contains much more water, in comparison with thickened extractive waste from mineral processing, which will need to be managed/treated.

6. Technical considerations relevant to applicability

- The technique is applicable when meeting design criteria for dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2), and in combination with extractive waste characterisation (see Section 4.1.2.1.1), where the recovered solid materials are used for dam construction.

7. Economics

- Management total costs for slurried extractive waste from mineral processing vary between EUR 0.3 and EUR 1.6 per tonne of dry extractive waste, according to the MTWR BREF (EC-JRC 2009).

- Furthermore, the cost of pumping to the pond varies from EUR 0.1 EUR to EUR 0.5 EUR per tonne of extractive waste, the cost of the pipe wear is ~ EUR 0.16 EUR per tonne of extractive waste and the cost of the piers is ~ EUR 0.07 per tonne of extractive waste in the case of extractive waste resulting from metal ores extraction, according to the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation

- No information provided.

9. Example sites

- Commonly applied at many sites.

10. Reference literature

(CSM 2009)
(Davies *et al.* 2010)
(EC-JRC 2009)
(IOGP 2009)

4.2.2.1.1.3 Thickening and clarifying

1. Description

This technique consists of using mechanical equipment to dewater extractive waste from mineral processing to ~ 50-75 % solids.

2. Technical description

This BAT candidate is relevant for extractive waste from mineral processing. It is particularly relevant for extractive waste from mineral processing to be deposited into ponds. It is also particularly relevant for extractive waste from alumina refining (red muds).

Essentially, the management of thickened/paste extractive waste from mineral processing requires the use of mechanical equipment to dewater extractive waste to ~ 50-75 % solids content. The yield stress is typically higher than 20 Pa but no higher than 100 Pa (Engels 2016a).

The basics of these techniques are introduced in Annex 9.2.1.2.7.

Typical thickened/paste extractive waste characteristics, including solids concentration, and equipment to dewater them, are reported in Table 4.23.

Table 4.23: Characteristics of the dewatering of thickened/paste extractive waste from mineral processing

Dewatering characteristics	Thickened extractive waste	Paste extractive waste
Dewatering technique	Coagulants/flocculants Hydro-cyclones Thickeners Lamella clarifiers On-line chemical modification	Deep Cone Thickeners (DCT) Additional flocculants and coagulants
Typical extractive waste concentration	~ 50-65 % solids	65-70 % solids
	Bauxite red mud ~ 50 %	
	Extractive waste from mineral processing of base metal ~ 75 %	
	Extractive waste from mineral processing of gold ~ 70 %	
	Mineral sands slimes ~ 25 %	
	Extractive waste from mineral processing of nickel ~ 50 %	
Typical transportation method	Centrifugal pumps	Positive displacement pumps and high-pressure piping. Viscosity reducers needed.
Bleed water	Considerable water to manage	Little to no bleed water to manage
Deposit character	Possibly segregating	Non-segregating
Physical strength model	Fluid rheology	Transition to soil mechanics
Beach slopes	Less concavity and slightly steeper than conventional slurry. Beaches form through channelised flow.	Beaches can be inhibited by strength. Angle of repose between 3-10 ° is reached if the underlying paste material is stabilised.
Post-depositional settlement (consolidation)	Creep may still affect non-linear finite strain predictions	Approaching traditional soil mechanics models
Containment of extractive waste	Self-supporting on very low angle slope. Modest retention structures still required.	Self-supporting on modest slopes. Minimal retention structures required.

Source: adapted from (AU DITR 2007; Davies et al. 2010)

The technique is designed to achieve maximum density and efficient deposition.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The performance and characteristics of the clarifiers and/or thickeners are designed in the planning and design phase in order to meet the site-specific extractive waste management objectives.
- *Operational (construction, management and maintenance) phase*
  Thickening and/or clarifying systems are implemented to separate the liquid phase from the solid phase.
  Clarifiers can also be used as water treatment techniques to remove suspended solids.

3. Achieved environmental benefits

- Helping to ensure the physical stability of extractive waste by:
  - o preventing or reducing the presence of residual water that could negatively affect the stability of extractive waste following deposition;
  - o control and improvement of the extractive waste geochemical and geotechnical characteristics;
  - o producing thickened extractive waste that is less mobile than slurried extractive waste, which is beneficial in the event of a dam burst.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.

4. Environmental performance and operational data

- At the Neves Corvo site, extractive waste from mineral processing with a high sulphide content is submitted to a process of thickening through a Deep Cone Thickener (DCT) technology, usually with addition of flocculants to produce a non-segregating paste / thickened extractive waste. The input slurry with a solid content of ~ 20 % is thickened to 62-63 % solids, with a density of 1.85 t/m^3. The overflow from the DCT is recycled to the mineral processing. The non-segregating thickened extractive waste is deposited in subaerial facilities. Co-disposal of extractive waste from mineral processing and extractive waste from excavation is carried out.
- At the Yerakini Mine, anionic flocculants are added in a cone thickener for dewatering extractive waste from mineral processing. As shown in Table 4.23, industrial minerals might show a moisture content higher than that of metal ores. In this case, extractive waste contains almost 30-35 % solids and has a density of around 1.3 t/m^3. And 90 % of water collected in the thickener is re-used in the closed loop in the processing plant.
- At Efemçukuru Mine, the dewatering is carried out using a two-step process, dewatering up to 60 % of the solids content with thickeners, followed by dewatering with large-capacity vacuum and pressure belt filter technology in order to obtain dry extractive waste from mineral processing with a final solids content of 80-84 %.

In general, water recovery is typically 60-70 % (AU DITR 2007).

Water and energy consumption is reduced with continuous operation and there is zero, or negligible, use of reagents.

5. Cross-media effects

- More energy consumption is required for producing thickened/paste extractive waste than for slurried extractive waste from mineral processing.
- In the case of PAG extractive waste, dewatering methods may lead to oxidation, which counteracts ARD prevention.

6. Technical considerations relevant to applicability

- The technique is applicable when meeting design criteria for dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2), and in combination with extractive waste characterisation (see Section 4.1.2.1.1), where the recovered solid materials are used for dam construction.
- According to the MTWR BREF (EC-JRC 2009), the thickened extractive waste method is particularly advantageous in flat topography, allowing development of a wide conical deposit with flat slopes.
- This method is not applicable with a content of less than 15 % of particles < 20 μm (dry basis) in the extractive waste from mineral processing, according to the MTWR BREF (EC-JRC 2009) and (Edraki *et al.* 2014).
- Production of thickened/paste extractive waste from mineral processing is increasingly used in small/medium-size facilities (< 30 000 t/day). Slow adoption due to economic/technical challenges at larger scales has been observed (Davies *et al.* 2010).

7. Economics

- The operating costs for thickened extractive waste from mineral processing are ~ 25 % higher compared to slurried extractive waste management if deep thickeners are used and 40 % higher if filters are used. For example, the CAPEX for a thickener (14 m height) is reported to be EUR 170 000 in the MTWR BREF (EC-JRC 2009).

- Even though the CAPEX of positive displacement pumps is higher than that of an equivalent capacity centrifugal system, the paste system may provide cost benefits during the whole life cycle (AU DITR 2007).

8. Driving force for implementation
- Safety requirements.
- Legal (local) and environmental requirements.
- Reduction of costs during the operational and closure phases.

9. Example sites
- Minas de Aguas Teñidas (ES)
- Yerakini Mine (EL)
- Somincor Neves Corvo Mine (PT)
- Efemçukuru Mine (TR)
- Kidd Creek, Myra Fall and Falconbridge Strathcona Mill (Canada); Bulyanhulu (Tanzania) (Davies *et al.* 2010)

10. Reference literature
(AU DITR 2007)
(Davies *et al.* 2010)
(EC-JRC 2009)
(Edraki *et al.* 2014)
(Engels 2016a)
(Junqueira *et al.* 2009)
(Lopes *et al.* 2013, 2015)
(Oliveira *et al.* 2011; Oliveira 2012)
(Raposo *et al.* 2014)
(Verburg *et al.* 2006; Verburg *et al.* 2009; Verburg and Oliveira 2011)

4.2.2.1.1.4 Dewatering by means of a pressure gradient or a centrifugal force

1. Description
This technique consists of using filter presses, vacuum filters and centrifuges to produce wet filter cakes (nearly saturated) or dry filter cakes (70-85 % saturated) with a 70-85 % solids content.

2. Technical description
This BAT candidate is relevant for extractive waste from mineral processing. It is particularly relevant for extractive waste from mineral processing to be deposited into ponds. It is also particularly relevant for extractive waste from alumina refining (red muds). It is relevant for drilling muds and other extractive wastes from oil and gas exploration and production too.

Extractive waste dewatered to wet or dry filter cakes has the following characteristics: wet filter cake is near-saturated while dry filter cake is 70-85 % saturated. Extractive waste has a solids content of 75-85 % (AU DITR 2007; Davies *et al.* 2010).

The basics of these techniques are introduced in Annex 2, Section 9.2.1.2.7.

Typical wet or dry filter cake characteristics, including solids concentration, and equipment to dewater them are reported in Table 4.24.

Table 4.24: Characteristics of dewatering dry or wet filter cakes

Dewatering characteristics	Description
Dewatering equipment used	Filter presses (the plate-and-frame filter press and the chamber press) Vacuum filters (continuous drum filters, continuous disk filters and horizontal belt filters) Centrifuges
Typical extractive waste concentration	75-85 % solids
Typical conveyance	Trucks or conveyors
Bleed water	Negligible. Only consolidation
Deposit character	Non-segregating
Physical strength model	Soil mechanics
Post-depositional settlement (consolidation)	Traditional soil mechanics models
Containment of extractive waste	Self-supporting at high angle slopes without the need for retention structures

Source: adapted from (Davies et al. 2010)

The technique is designed to achieve maximum density and efficient deposition.

The MTWR BREF (EC-JRC 2009) reports the following:
- In hydrometallurgical operations (i.e. leaching), this method is part of the process. In combination with an appropriate basal structure this method may be applicable to extractive waste deposition.
- In potash extraction, extractive waste from mineral processing is managed as dry filter cakes on heaps (see Section 4.2.1.3.3.2.2).

In the management of drilling muds and other extractive wastes from oil and gas exploration and production, centrifuges are used to control the fine solids content in the drilling fluids in order to maximise the recycling of these fluids. Centrifuges enable the recovery of fine baryte solids that can then be re-used for drilling.

The technique is applied in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  The performance and characteristics of the filters and/or centrifuges are designed in the planning and design phase in order to meet the site-specific extractive waste management objectives.
- *Operational (construction, management and maintenance) phase*
  Filter and/or centrifuge systems are implemented to separate the liquid phase from the solid phase.

3. Achieved environmental benefits
- Helping to ensure the physical stability of extractive waste by:
  - preventing or reducing the presence of residual water that could negatively affect the stability of extractive waste following deposition;
  - control and improvement of the extractive waste characteristics.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.
- Implementation of the waste hierarchy principles:
  - reduction of extractive waste to be transported and disposed of;
  - recovery of process water to be re-used in the mineral processing;
  - further mineral recuperation after filtration;
  - facilitating the re-use/recycling of extractive waste (see Section 4.1.3.3.3);
  - reduction of drilling fluids consumption in oil and gas drilling.

4. Environmental performance and operational data

The storage volume of extractive waste from mineral processing can be reduced by up to 50 % in some cases (AU DITR 2007).

- At the Cobre Las Cruces site, 172.5 m^3/h of leached extractive waste is pumped to a belt vacuum filter where it is washed to remove soluble copper. Process water consumption is 0.6 m^3/t of dry solids. Primary filtrate from the filter is returned to the leaching process and the wash filtrates rich in copper are treated to recover this metal.
- At the Alteo Gardanne site, three filter presses handle a total volume of 300 000 t/year of extractive wastes from alumina refining (red muds) (dry solids equivalent). The two biggest presses have 177 filter plates for a total surface area of 850 m^2. They are fed with red muds with 350 g/l of solids and they produce 31 t/hour of filter cake with a 70 % solids content. The filtrate contains 250 mg/l of solid matter. Furthermore, a pressure filter is used. Trials on a pilot line demonstrated that without adding flocculants a filtrate with 35 mg/l of solid matter can be obtained, but the maximum possible flow of 0.45 m^3 per square metre of filter surface and per hour is not workable industrially. By adding slaked lime, an acceptable maximum flow of 5 $m^3/m^2/h$ has been achieved.

5. Cross-media effects

- Energy consumption for filtration and centrifugation.
- In the case of PAG extractive waste, dewatering methods may lead to oxidation, which counteracts ARD prevention.

6. Technical considerations relevant to applicability

- The technique is applicable when meeting design criteria for dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2), and in combination with extractive waste characterisation (see Section 4.1.2.1.1), where the recovered solid materials are used for dam construction..
- Filtration is particularly advantageous in cases where the available space for extractive waste deposition is very limited.
- Pressure filtration is carried out on a wider spectrum of materials than vacuum belt filtration, especially in larger scale operations.
- Filtration effectiveness decreases with high percentages of clay minerals (particle size < 63 µm). Furthermore, extractive waste containing residual bitumen (e.g. from mineral processing of oil sands) is difficult to filter.
- The slurried feed to the filtering equipment must have a suitable density and a stable flow.
- The filtration is not proven for high production rates (Watson 2010) and, due to its high costs and operational management requirements, it is only really applicable to small/medium-size facilities (≤ 20 000 t/day) based on information collected from literature (Davies *et al.* 2010; Engels 2012; Punkkinen *et al.* 2015c). However, slow adoption in large facilities has also been observed (Davies *et al.* 2010).

7. Economics

- Dewatering of extractive waste by centrifuges and filters and dry stacking is usually a costly method (AU DITR 2007; Watson 2010). In the past 10-15 years, advances in filter technology has seen a wide range of extractive wastes being stacked and decreased CAPEX/OPEX on a per tonne basis (Davies *et al.* 2010). The cost of this technique increases exponentially with the decrease of the grain size. For many low-grade operations, the cost of this method is prohibitive to the extent that the extractive waste management cost may exceed the ore value, according to the MTWR BREF (EC-JRC 2009).
- At the Asturiana de Zinc site, the cost for dewatering in belt filters was EUR 0.95 per tonne of ore. The CAPEX of the filtration plant was EUR 3.5 million, according to the MTWR BREF (EC-JRC 2009).
- At the Neves Corvo site, the cost for dewatering with pressure filters was expected to be EUR 2.5 per tonne of ore, according to the MTWR BREF (EC-JRC 2009).

- At the Los Santos Tungsten Mine, the cost of filtering 500 000 t/year of extractive waste exceeds the costs of pumping slurried extractive waste into a pond. However, the costs of maintenance will be lower and 9 years of additional operation lifetime will be ensured to the site.
- In Alteo Gardanne, the CAPEX for three filter presses and the pressure filter treating a total volume of 300 000 t/year of extractive wastes from alumina refining is EUR 30 million.
- The total operating cost of dry deposition of extractive waste from mineral processing at Greens Creek site was ~ EUR 4.3-6.4 (USD 4-6, year 2002) per tonne for a treatment capacity of 1 000 tonnes of extractive waste per day. The cost was associated with thickening reagents, compressed air (mainly electric power) for the pressure filters, operating and maintenance labour and trucking of the extractive waste 15 km to the surface pond. This is much more expensive than a typical slurry disposal system, where the extractive waste is piped to a pond (often by gravity), according to the MTWR BREF (EC-JRC 2009).
- The OPEX at La Coipa site are much lower than at the Greens Creek site, because the extractive waste is coarser and can be filtered by vacuum filters, the treatment capacity is higher (15 000 t/day versus 1 000 t/day) and the site conditions are better (flat dry desert rather than mountainous wet climate).

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements.
- Lack of available surface in densely populated areas.
- Reduction of costs for the extractive waste management.

9. Example sites
- Mina Los Santos, Fuenterroble (ES)
- Enara Investigation Permit (ES)
- Proyecto Cobre Las Cruces (ES). Vacuum filtration or vacuum belt filtration
- Aughinish Alumina Ltd (IE)
- Mange Garri (FR) Alteo Gardanne: three filter presses handle a total volume of 300 000 t/year of extractive waste from alumina refining (dry basis). A pressure filter pilot project was commissioned in October 2015
- Aluminium of Greece: dry red muds by filter presses
- La Coipa (gold and silver) and Mantos Blanco (copper) (Chile); Greens Creek (gold, silver and zinc) and Pogo (gold), Alaska (US); Raglan (lead and zinc), Quebec (Canada) (AMEC 2008) and questionnaires. Many small-scale precious and base metal mines in Canada and Alaska (US) (paste extractive waste) (Davies 2011; Punkkinen *et al.* 2015c)

10. Reference literature
(AMEC 2008)
(AU DITR 2007)
(Davies *et al.* 2010; Davies 2011)
(EC-JRC 2009)
(Engels 2012)
(Punkkinen *et al.* 2015c)
(Watson 2010)

4.2.2.1.2 Techniques to stabilise extractive waste for placing back into excavation voids

1. Description
Stabilisation of extractive waste consists of preparing extractive waste that will act as a support when placed back into excavation voids for structural purposes and rehabilitation purposes. It includes preparing cemented coarse extractive waste, slurried extractive waste (uncemented and cemented) and paste extractive waste to be placed back into excavation voids.

2. Technical description
This BAT candidate is relevant for extractive waste to be placed back into excavation voids.

Where extractive waste has to act as a support when placed back into excavation voids for structural purposes (such as preventing roof or wall rock collapse or subsidence underground) and rehabilitation purposes, the extractive waste is usually stabilised in mixing plants on the surface and transported:

- by gravity or pumped through a network of pipes and boreholes into the underground excavation voids;
- by trucks or conveyors or pumped through a network of pipes into surface excavation voids.

Prior to placing extractive waste back into excavation voids, operators usually carry out:

- a characterisation of the site where the placing back takes place which includes collecting information on hydrogeology and bedrock fractures;
- preparation of the site if necessary (e.g. sealing of bedrock fractures);
- a characterisation of the extractive waste that will be used to prepare the extractive waste slurry or the paste extractive waste to be placed back;
- a characterisation of the produced extractive waste slurry or paste extractive waste.

After placing extractive waste back into excavation voids, operators usually put in place a monitoring programme.

The following techniques for preparing stabilised extractive waste can be distinguished:

- <u>Preparing cemented coarse extractive waste to be placed back into excavation voids</u>
  This generally consists of mixing coarse fractions of extractive waste from mineral processing, sometimes including extractive waste from excavation (coarse and fine fraction), with cementitious binders (such as cement, fly ash). Extractive waste is appropriately graded with respect to particle size to obtain high compressive strengths. The following methods are applied:
    - *mixing* the extractive waste and the cement slurry in a hopper before placing the mixture into the voids (e.g. stopes or mined out longwall); or
    - *percolating* a cement slurry over the extractive waste that is placed back.

- <u>Preparing extractive waste slurry (uncemented and cemented) to be hydraulically placed back into excavation voids</u>
  This consists of classifying extractive waste from mineral processing into a coarse fraction (a slurry with a solids content of approximately 65-70 %) and a fine fraction (slimes, with a typical D10 size of 74 µm, which are then discarded), for example through hydro-cyclones. Fines are removed to improve the drainage capacity of the stabilised extractive waste, leading to an improved stability, and to avoid liquefaction.

  The slurry with the coarse fraction may be mixed with cementitious binders, if needed. Often, a larger amount of these cementitious binders may be required to match the final strength achieved when using cement, according to the MTWR BREF (EC-JRC 2009).

  The slurried extractive waste is transported by gravity or hydraulically pumped from the surface through a network of pipes and boreholes into the underground excavation voids. In the latter case, a centrifugal slurry pump is usually used. Note that the strength of the stabilised extractive waste decreases with water content and the water content needed for the hydraulic transport is far in excess of what is required for cement hydration. Hence, extractive operators are moving towards using less water in the mixture in order to decrease the cement and binder consumption. Flow velocities in excess of 2 m/s are required to maintain a homogeneous dispersion of the solid particles in the slurry.

- Preparing paste extractive waste to be placed back into excavation voids
  According to the MTWR BREF (EC-JRC 2009), the entire extractive waste from mineral processing (fine and coarse fractions) is mixed with cementitious binders to create a paste with a solids content of 75-80 %. As a general rule, the content of fines is at least 15 % by weight. It is similar to thickening/pasting techniques (see Sections 4.2.2.1.1.3). The facility producing stabilised extractive waste typically includes storage tanks, paste thickeners, mixers and positive displacement pumps. The density of the mixture is higher compared to other stabilisation methods and more extractive waste can be stored in the excavation voids. Several underground extractive sites are moving towards placing paste extractive waste back into excavation voids as a lower cement content is necessary to gain the equivalent strength needed to act as a support as compared to conventional hydraulic placing back.

  Thickening fine fractions of extractive waste from mineral processing in concrete pools and placing the cake back into surface excavation voids is applicable in small-scale operations and under climatic conditions where the extractive waste dewaters rapidly. Extractive waste is transported by trucks in this case. It is applied, for example, in one small baryte excavation void in Spain (EC-JRC 2009).

The technique is applied in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Stabilisation of extractive waste to be placed back into excavation voids is planned and designed.
- *Operational (construction, management and maintenance) phase*
  During the operational phase of the extractive waste management, extractive waste is prepared prior to placing back into excavation voids for rehabilitation and construction purposes in order to meet the site-specific stability objectives/specifications. Such an operation is usually carried out in a dedicated facility.
- *Closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

3. Achieved environmental benefits
- Helping to ensure the physical stability of extractive waste by:
  - ensuring that extractive waste acts as a proper support when placed back into excavation voids for structural and/or rehabilitation purposes.

4. Environmental performance and operational data
The amount of cement required, if needed, depends on the strength requirements of the extractive waste to be placed back.

The data collected from the questionnaires suggest that the cement content varies from 3 % to 7 % in the stabilised extractive waste to be placed back. Some indicative examples of cement to extractive waste ratios are given in Table 4.25.

Table 4.25: Examples of cement to extractive waste ratio collected from literature

Application	Cement to extractive waste ratio
Bulk placing back	1:30
Barriers against adjacent pillar, adjacent stope or related structures	1:10
Mucking floors	1:6 to 1:12
Water-retaining bulkheads (no restriction of stope)	1:2

Source: (Hambley 2011)

For PAG extractive waste, the cement will reduce the oxidation and ARD potential of the extractive waste placed back, thus resulting in reduced mobilisation of pollutants (e.g. metals). This is particularly useful if underground excavation voids are below the water table, as, when pumping ceases, the cemented extractive waste will be in direct contact with groundwater. Problems with extractive waste migration, liquefaction and slump are prevented.

However, according to Alakangas and co-authors, there is a high level of uncertainty in the attainable compressive strength and the decrease in pollutants release in the case of cemented PAG extractive waste (Alakangas *et al.* 2013). Gypsum might be formed due to addition of sulphate from the sulphide oxidation that has been seen to occur in cemented extractive waste. This is referred to as sulphate attack and could reduce the stabilised extractive waste strength and potentially make the stabilised extractive waste collapse (Benzaazoua *et al.* 2004; Ercikdi *et al.* 2009).

5. Cross-media effects

- Consumption of energy for hydro-cycloning, thickening or pasting and for pumping the stabilised extractive waste.
- Consumption of additional auxiliary materials (cementitious binders).

6. Technical considerations relevant to applicability

- The technique is applicable in combination with extractive waste characterisation (see Section 4.1.2.1.1).
- Preparing extractive waste slurry (uncemented and cemented) to be hydraulically placed back into excavation voids:
  - The technique is not applicable when, e.g.:
    - the extractive waste slurry has a high fines content (it is better to have a steep granulometric curve);
    - the particle shape of the extractive waste slurry is very flat (for example, flat silicates are not favoured).
  - The technique is not applicable if the local hydrogeology (e.g. oxygen-rich groundwater) can oxidise the extractive waste that is placed back (e.g. ARD).
  - The technique is not applicable to drilling muds and other extractive wastes from oil and gas exploration and production.

- Preparing paste extractive waste to be placed back into excavation voids is generally applicable, according to the MTWR BREF (EC-JRC 2009),when:
  - there is more than 15 % fine particles < 20 µm (dry basis) in the extractive waste from mineral processing; or
  - the extractive waste has a high fines content; or
  - it is desirable to keep water out of the extraction site; or
  - it is costly to pump back the water recovered from the extractive waste from mineral processing (i.e. over a large distance).

  It is not applicable to drilling muds and other extractive wastes from oil and gas exploration and production.

7. Economics

Large investments are needed for facilities producing stabilised extractive waste to be placed back into excavation voids for structural and/or rehabilitation purposes.

- The cost of adding cement or other cementitious binders can represent up to 75 % of the costs of placing extractive waste back.
  Adding cement might make placing extractive waste back very expensive. Therefore, in several operations, alternative cementitious binders are used. Depending on the local situation, these materials are available at lower costs. According to the MTWR BREF (EC-JRC 2009), at one site the cost per tonne of fly ash delivered to the extractive site amounted to EUR 17-18 (year 2003).
- According to the MTWR BREF (EC-JRC 2009), assuming the cost of cement delivered to the extraction site to be EUR 85.7/t (USD 80/t, year 2002), and assuming the produced dewatered extractive waste in the filter plant to have on average ~ 15-20 % moisture content, in this case the cost of placing back extractive waste into excavation voids with a cement addition of 3-5 % by weight would therefore be ~ EUR 2.6 to EUR 4.3 (USD 2.40 to USD 4.00, year 2002) per tonne of extractive waste placed back (3/100x85.7 = EUR 2.6/t; 3/100x80 = USD 2.40/t).
- The OPEX of a facility producing stabilised paste extractive waste is lower than that of one for stabilised slurried extractive waste as the mixing is done on the ground and pumped by pipelines. According to the Closedure project (Tornivaara 2015c), the CAPEX is approximately twice that of a slurried EWF of the same capacity.
- According to the MTWR BREF (EC-JRC 2009), the investment costs for an appropriate facility to produce stabilised extractive waste in the Ruhr, Saar and Ibbenbüren collieries have been calculated at up to EUR 40 million. Additional investigations showed that operational costs implied by placing back operations amount to EUR 20 per tonne of coal produced, split equally between staff and material costs.
- For paste extractive waste to be placed back, the majority of the costs are due to construction of pipelines, including material and labour costs.
- For cemented coarse extractive waste to be placed back, loading and transport costs have to be added.
- Costs of maintenance should also be considered.

8. Driving force for implementation
- Compliance with the waste hierarchy principles: to prevent waste production or reduce the amount of waste produced.
- Helping to enable continued extraction of the deposits by ensuring stability underground.
- Efficient use of materials.
- Use of extractive waste for land rehabilitation.
- Legal and environmental requirements, particularly Article 5 of Directive 2006/21/EC, and national legislations (such as the Finnish Government Decree 190/2013 and Spanish legislation).
- Economic benefits: minimisation of operational, closure and after-closure costs.

9. Example sites
- Minas de Aguas Teñidas (ES)

10. Reference literature
(Alakangas *et al.* 2013)
(Benzaazoua *et al.* 2004)
(EC-JRC 2009)
(Ercikdi *et al.* 2009)
(Hambley 2011)
(Tornivaara 2015c)

4.2.2.1.3 Techniques to stabilise and solidify drilling muds

This BAT candidate is relevant for drilling muds and other drilling extractive wastes from oil and gas exploration and production.

During the information exchange process, some operators stressed the importance of stabilising the extractive waste prior to deposition. Solidification of slurries by mixing with bentonite (5 %) was mentioned, but no further details were provided that would have allowed to develop a 10-headings description.

Based on the information provided by an industry association (IOGP 2016), typical materials used to solidify the drilling muds are cement and lime for oily drilling wastes. Other materials such as fly ash can also be used.

A typical water to binder ratio in the range of 0.4:1 to 0.6:1 was reported.

Stabilisation refers usually to the addition and mixing of drilling wastes and water with reagents to promote sorption, precipitation or incorporation into crystal lattices. An example of such materials is the use of charcoal based products which can adsorb the organic contaminants, metals and metalloids.

Automated processes are commercially available.

4.2.2.1.4 Techniques to compact, consolidate and deposit extractive waste

4.2.2.1.4.1 Thickened/paste extractive waste subaerial deposition

1. Description
This technique consists of spreading thickened/paste extractive waste from mineral processing in layers over the deposition area.

2. Technical description
This BAT candidate is relevant for extractive waste from mineral processing.

- Thickened or paste extractive waste from mineral processing is spread in layers over the deposition area to allow further dewatering through a combination of drainage and evaporation, according to the MTWR BREF (EC-JRC 2009). Retention structures (embankments/dams) are built along the perimeter to contain the deposited extractive waste.
- A composite basal structure system (see Section 4.2.1.3.3.1.3.1) is usually included, particularly for non-inert extractive waste. Sequential construction of small deposition areas (cells) within the extractive waste deposition area is a good management practice that allows progressive rehabilitation and concurrent closure by means of dry covers (see Section 4.3.1.3.1). Extractive waste from excavation can be used for building berms or dykes to divide the cells.
- Special systems for collecting surface water run-off and drainage water are usually constructed. The collected drainage water requires proper management, according to the MTWR BREF (EC-JRC 2009).
- In alumina refining, red muds are usually treated using the thickened extractive waste method and deposited on a "stack". It includes pervious perimeter rock fill dams, a composite basal structure system for sealing the underlying surface and a surrounding system for the collection of surface water run-off.
  Thickened/paste extractive waste management is associated with a good recovery of the caustic mother liquor, as the management at the pond will not involve further neutralisation. The density and viscosity of the thickened extractive waste is so high that the dewatering is carried out preferably at the EWF, unless the stack is located adjacent to the refinery. If the two sites are some distance from each other, pumping is done at low density prior to dewatering at the pond site, to produce the thickened/paste extractive waste right at the pond feed, in which case the surplus water has to be pumped all the way back to the mineral processing plant. Therefore, this technique involves an additional investment for a high

pressure pumping station, e.g. with membrane pumps, or installation and operation of a deep thickener at the pond.

- In some operations for extractive waste from mineral processing of coal, fine extractive waste < 0.5 mm from flotation is first thickened to 40-50 % solids content. Provided sufficient area for final deposition in engineered ponds is available, processed fine extractive waste is transported via pipelines or trucks – depending on the distance and volumes - to these facilities. When deposition of the fine extractive waste on heaps is selected, further dewatering operations are carried out in order achieve a sufficient structural stability, according to the MTWR BREF (EC-JRC 2009).

The deposition method of thickened/paste extractive waste from mineral processing is closely linked to the extraction process. When selected, the technique is planned in the design phase and implemented in the operational phase. The design of the EWF is linked to the deposition method.

- *Planning and design phase*
  The EWF and the extractive waste management are designed based on the selected deposition method.
- *Operational (construction, management and maintenance) phase*
  The extractive waste from mineral processing is deposited using the selected method and monitoring of physical and chemical stability is carried out.

3. Achieved environmental benefits

- Helping to ensure the physical stability of extractive waste due to the physical (low susceptibility to liquefaction) and chemical characteristics of thickened/paste extractive waste by:
  - preventing or reducing negative effects on the stability of the deposited extractive waste that are linked to the presence of any residual water;
  - preventing or minimising failure risks (no large ponds are needed).
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the leaching of pollutants.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - footprint reduction, both for the dam and the extractive waste deposition area, compared to slurried extractive waste deposition;
  - progressive rehabilitation and closure of small individual cells during operation.

4. Environmental performance and operational data

Data provided in the questionnaire have been used to plot the total amount of deposition of extractive waste from mineral processing per hectare. A qualitative analysis shows that 2 to 8 times more extractive waste is stored per surface unit when reducing the water content in the extractive waste from 80 % to 5 % (see Figure 4.24).

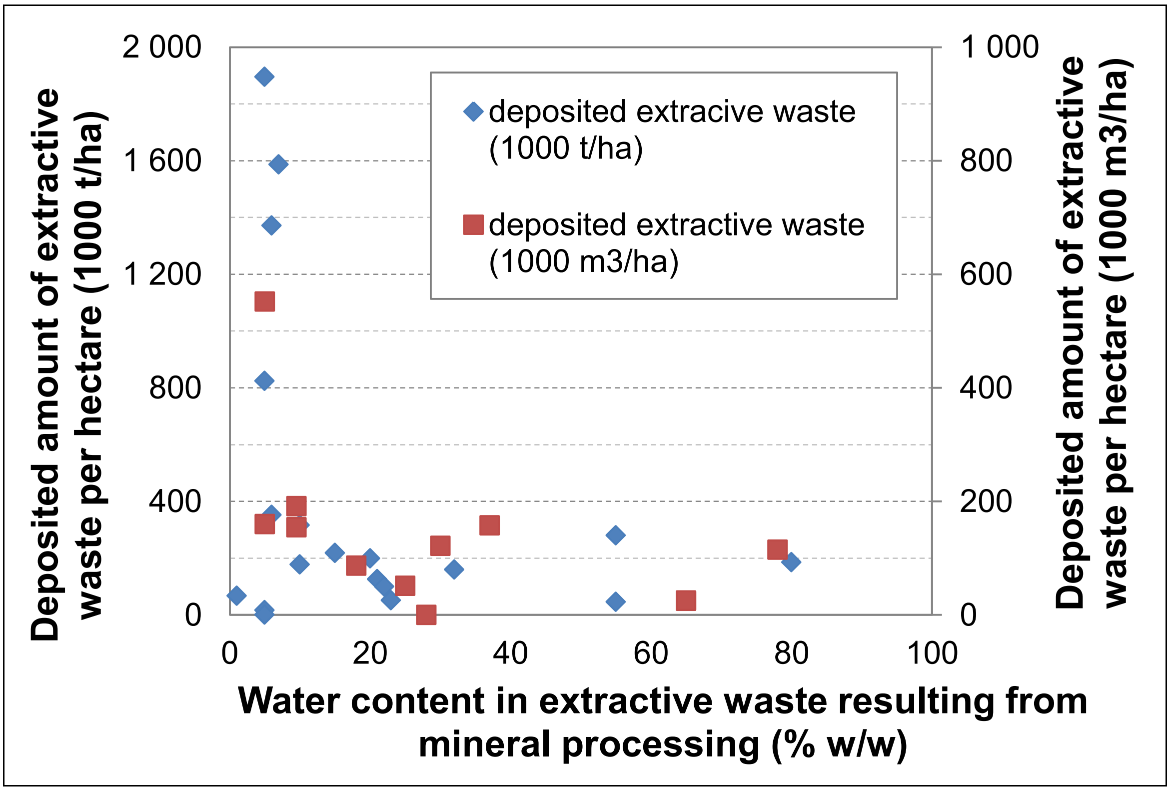


Figure 4.24: Deposited extractive waste from mineral processing per surface unit depending on its water content.

5. Cross-media effects

- Dusting may occur from the dried out extractive waste surfaces, both during operation and after closure, particularly in semi-arid climate. Therefore an spraying system may be necessary.
- Fuel consumption for transportation of materials, particularly by trucks.
- Potential aeration and oxidation of extractive waste from mineral processing, if not properly covered.

6. Technical considerations relevant to applicability

- The ability of achieving consistent compaction of the filtered extractive waste is influenced by climatic conditions. In regions with heavy rainfall or a wet climate, the deposited extractive waste may become chemically and/or physically unstable during extreme rainfall. In such regions, deposition of thickened extractive waste from mineral processing may require additional dam structures or retaining dykes to prevent spreading of extractive waste as a result of heavy rains.
- This technique is also applicable within existing ponds.

7. Economics

- No information provided.

8. Driving force for implementation

- Safety requirements.
- Legal (local) and environmental requirements.
- Reduction of costs during the operational and closure phases.

9. Example sites

- Proyecto Cobre Las Cruces (ES)
- Efemçukuru Mine (TR)

10. Reference literature
(EC-JRC 2009)
(Hudson *et al.* 2015)
(Lupo and Mussé 2014)
(Umedera 2014)
(Ulrich and Coffin 2013)
(SRK 2012)
(Davies and Rice 2004; Davies *et al.* 2010)
(Newman *et al.* 2010)
(AU DITR 2007)

4.2.2.1.4.2 Wet or dry filter cake deposition (or dry stacking)

1. Description
This technique consists of transporting wet or dry filter cakes by conveyors or trucks, followed by placing and compacting them to form a dense and stable "dry stack" without the need for a retention dam.

2. Technical description
This BAT candidate is relevant for extractive waste from mineral processing. It is particularly relevant for extractive waste from alumina refining (red muds).

Wet or dry filter cakes are transported by conveyors or trucks, placed and compacted to form a dense and stable deposition area usually named "dry stack". It does not require the construction of retention dams (AU DITR 2007).

For the surface water run-off within the dry stack, perimeter ditches and a drainage system are designed, considering appropriate hydrological event(s) and climate change or variations in climatic conditions.

A more stable solution for addressing climate change or variations in climatic conditions is to design and operate the dry stack with small cells that can be progressively covered and rehabilitated. Filter cakes meeting all technical specifications can be used in the construction of the external part of the cells (the "shell").

Wet or dry filter cakes deposition is applied in the life cycle phases of the extractive waste management listed below.

- *Planning and design phase*
  The EWF and the extractive waste management are designed based on the selected deposition method.
- *Operational (construction, management and maintenance) phase*
  The extractive waste from mineral processing is deposited using the selected method and monitoring of physical and chemical stability is carried out.

3. Achieved environmental benefits
- Helping to ensure the physical stability of extractive waste due to the physical (low susceptibility to liquefaction) and chemical characteristics of wet/dry filter cakes by:
  - preventing or reducing negative effects on the stability of the deposited extractive waste that are linked to the presence of any residual water;
  - preventing or minimising failure risks (no large ponds are needed).
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the leaching of pollutants.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - footprint reduction, both for the dam and the extractive waste deposition area, compared to slurried extractive waste deposition;

  - progressive rehabilitation and closure of small individual cells during operation.

4. Environmental performance and operational data
- See Figure 4.24 in Section 4.2.2.1.4.1.

5. Cross-media effects
- Dusting may occur from the dried out extractive waste surfaces, both during operation and after closure, particularly in semi-arid climate. Therefore an spraying system may be necessary.
- Fuel consumption for transportation of materials, particularly by trucks.
- Potential aeration and oxidation of extractive waste from mineral processing, if not properly covered.

6. Technical considerations relevant to applicability
- In regions with heavy rainfall or a wet climate, the deposited extractive waste may become chemically and/or physically unstable during extreme rainfall. In such regions, dry stacking may require additional dam structures or retaining dykes and composite basal structure (see Section 4.2.1.3.3.1.3.1 and Section 4.2.1.3.3.1.3.3) to prevent spreading of extractive waste as a result of heavy rains.

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal (local) and environmental requirements.
- Reduction of costs during the operational and closure phases.

9. Example sites
- Efemçukuru Mine (TR)

10. Reference literature
(AU DITR 2007)
(Davies and Rice 2004; Davies *et al.* 2010)
(EC-JRC 2009)
(Hudson *et al.* 2015)
(Lupo and Mussé 2014)
(WA DMP 2013)
(Newman *et al.* 2010)
(SRK 2012)
(Ulrich and Coffin 2013)
(Umedera 2014)

4.2.2.1.4.3 Deposition by placing extractive waste back into excavation voids

1. Description
This technique consists of safely placing extractive waste, including stabilised extractive waste, back into excavation voids for structural and/or rehabilitation purposes.

2. Technical description
This BAT candidate is relevant for non-hazardous extractive waste.

Extractive waste can be placed back into excavation voids for rehabilitation and/or construction purposes. The placing back of extractive waste might be carried out concurrently with the extraction operation. Both surface excavation voids and underground excavation voids from mineral resources extraction are included.

Extractive waste can be placed back progressively during operation, if possible, including at closure.

The following type of activities may be considered:
- placing dry extractive waste back into excavation voids followed by compaction if necessary for site rehabilitation purposes;
- placing extractive waste back into surface excavation voids permanently covered by water if parts of the extractive waste (e.g. waste-rock) have a net ARD potential (see Section 4.3.1.3.4.2.1) according to the MTWR BREF (EC-JRC 2009) and the Closedure project (Punkkinen *et al.* 2015a).
- where extractive waste has to act as a support when placed back into excavation voids for structural purposes (such as preventing roof or wall rock collapse or subsidence underground) and rehabilitation purposes, it has to be converted into a stabilised material after being placed back into excavation voids and after curing. The techniques for stabilising extractive waste are described in Section 4.2.2.1.2. Similar techniques are applied in the case of extractive materials that in principle qualify as by-products/products.

Fracture zones in the bedrock are potential flowpaths for possible contaminants leaching from the extractive waste placed back into excavation voids, and may in the worst case result in the transport of pollutants to groundwater and even further down to surface water bodies. Therefore, the technique may require:
- sealing of bedrock fractures to prevent groundwater, soil and surface water pollution;
- further detailed environmental characterisation of extractive waste to ensure the safe placing back;
- a proper monitoring to verify ensure environmental performance of the extractive waste that has been placed back.

The technique is applied in all the life cycle phases of the extractive waste management.
- *Planning and design phase*
  Deposition of extractive wastes back into excavation voids is planned and designed.
- *Operational (construction, management and maintenance) phase*
  During the operational phase of the extractive waste management, extractive waste are deposited into excavation voids for rehabilitation and construction purposes. An extractive waste preparation plant is then usually required.
- *Closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

3. Achieved environmental benefits
- Helping to ensure the physical stability of the extractive waste by:
  - preventing or reducing negative effects on the stability of the deposited extractive waste that are linked to the presence of any residual water.
- Helping to ensure the short-term and long-term structural stability of the excavation voids by allowing the wall rock to retain load bearing capacities.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the leaching of pollutants.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - rehabilitating extractive and disposal sites, allowing to recreate pieces of land with new uses;
  - avoiding temporary storage, preventing erosion and dusting by means of progressive site rehabilitation during operation.
- Implementation of waste hierarchy principles by:
  - maximising the ore reserves and facilitating mineral extraction;
  - reducing extractive waste transport, when it is placed back directly into underground or surface excavation voids;

- eliminating the need of importing materials.

4. Environmental performance and operational data

Operators reported the placing back of extractive waste from mineral processing of metalliferous ores in a range of 10-15 % of the total amount of produced extractive waste from mineral processing and the placing back of extractive waste from mineral processing of industrial minerals > 90 % of the total amount of produced extractive waste from mineral processing.

When extractive waste is placed back into excavation voids, operators take all the necessary measures to avoid physical and chemical instability of the extractive waste, such as ARD linked to oxidation of sulphur or dissolution of extractive waste e.g. extractive waste resulting from the mineral processing of gypsum.

5. Cross-media effects

- Consumption of energy for dewatering and pumping of extractive waste to be placed back.

6. Technical considerations relevant to applicability

- The applicability depends on site-specific conditions (such as location, mineral deposit, extractive waste characteristics) and is assessed individually for each type of excavation void.
- Placing extractive waste back into excavation voids is not applicable:
  - to PAG extractive waste, unless deposited under water cover;
  - to partially oxidised extractive waste with residual ARD potential;
  - during operation if it inhibits the extraction activities;
  - at closure if it would cause instability or a negative environmental impact.

7. Economics

- In some cases, environmental or economic considerations may narrow the range of extractive waste deposition options. For example:
  - if the ore is transported at great distance from an underground extraction site to the processing plant, it might be very expensive to return the extractive waste back to the underground voids;
  - transferring extractive waste from mineral processing to mined-out surface excavation voids will usually have a low cost only if the voids are nearby (a few kilometres distance).
- In the MTWR BREF (EC-JRC 2009) the following indicative range of costs for placing back extractive waste is reported: from 0.3 EUR/t to 0.8 EUR/t depending on the transport distance (15 or 100 km respectively). With the same transportation distances, it is cheaper to place back extractive waste into a surface excavation void than to prepare a new surface extractive waste deposition area (including a EWF).
- Placing extractive waste with high levels of salts back into excavation voids with flat-lying layers ("flat storage") may not always be possible under economically viable conditions, due to the cost of transport, distribution and deposition of extractive waste.

8. Driving force for implementation

- Safety and stability purposes.
- Efficient use of materials.
- Use of extractive waste for land rehabilitation.
- Legal and environmental requirements, particularly Article 10 of Directive 2006/21/EC, but also according to national legislations (such as the Finnish Government Decree 190/2013 and Spanish legislation).
- Economic benefits: minimisation of operational, closure and after-closure costs and maximisation of the ore recovery.

9. Example sites
- Mina Los Santos, Fuenterroble (ES)
- Minerali industriali, Sondalo and Lozzolo (IT)
- Boliden Tara Mines (IE)
- Kemi Mine (FI)

10. Reference literature
(EC-JRC 2009)
(Hambley 2011)
(INAP 2014h)
(ITRC 2010g)
(MEND 1995)
(Tornivaara 2015c)

4.2.2.1.4.4 Mud farming

1. Description
This technique consists of compacting and dewatering red mud layers with special equipment and enhancing the exposure of the layers to atmospheric carbonation to reduce their alkalinity.

2. Technical description
This BAT candidate is relevant for extractive waste from alumina refining (red muds).

Mud farming is an additional dewatering technique to thickening and clarifying (see Section 4.2.2.1.1.3) or dewatering by means of a pressure gradient or a centrifugal force (see Section 4.2.2.1.1.4).

Mud farming is a mechanical technique for the management of extractive waste from mineral processing, especially from alumina refining, which requires the placement of extractive waste (especially red muds but also other soft residues, such as oil sands) in discrete layers. Extractive waste is dewatered through repeated ploughing or mud scrolling to achieve a high final density and strength. By increasing the exposed surface area (resulting from the ploughed furrows and ridges), this process facilitates the extractive waste atmospheric carbonation, enhances evaporation from the residue and reduces alkalinity and pH.

Archimedes Screw Tractors, also called amphirols (Figure 4.25a), are commonly used. The weight and the dynamic movement of the scrolls squeeze out residual fluid, increasing the solids content of the deposited red mud. Low-ground-pressure bulldozers (Figure 4.25b) are then used to flatten the furrowed surfaces prior to the placement of the fresh red mud layer.

Although mud farming can be achieved using conventional earth-moving equipment, it is most efficiently carried out using Archimedes screw tractors.

Source: Aughinish Alumina Ltd questionnaire

Figure 4.25: Amphirol screw tractor (left) and pressure bulldozer (right)

The deposition method, when selected, is planned in the design phase and implemented in the operational phase. The design of the EWF is linked to the deposition method.

- <u>Planning and design phase</u>
  The EWF and the extractive waste management are designed based on the selected deposition method.
- <u>Operational (construction, management and maintenance) phase</u>
  The extractive waste from mineral processing is deposited using the selected method and monitoring of physical and chemical stability is carried out.

3. Achieved environmental benefits

- Helping to ensure the physical stability of the extractive waste by:
  - preventing or reducing negative effects on the stability of the deposited extractive waste that are linked to the presence of any residual water.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the leaching of pollutants;
  - reducing the alkalinity and pH of red muds by means of atmospheric carbonation.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste. Enhancement of the storage capacity.

4. Environmental performance and operational data

The red mud characteristics and the potential improvements achieved by mud farming are shown in Table 4.26.

Table 4.26: Characteristics of red muds before and after mud farming, based on the site-specific data reported by one sole operator via the questionnaire

Red mud characteristic	Unfarmed layers	Farmed layers	Improvement
Moisture rate (%)	31-49	26-38	Decrease of 16-22 %
Dry density (kN/m^3)	15.5	16.8	Increase of 8 %
Undrained shear strength (2 % strain) (kPa)	3-68	3-129	Increase from 0 % to 89 %
pH		< 11.5	

When applied correctly, this form of extractive waste management can provide layers of high-strength dewatered extractive waste (> 25 kPa) in less than 6 weeks (Residue Solutions 2016).

5. Cross-media effects

- Fuel consumption for the equipment.

6. Technical considerations relevant to applicability

- This technique is applicable in combination with the techniques to reduce extractive waste alkalinity (see Section 4.2.2.2.1.1).
- This technique is applicable where it can be carried out safely.
- Climatic conditions may limit the applicability of the technique.

7. Economics

- Costs include the CAPEX for the equipment (such as the Archimedes screw tractor).

- The increase in the CAPEX and OPEX compared to deposition techniques where this additional dewatering technique is not used may be balanced by the benefits in terms of extractive waste management, storage capacity and environmental management performance.

8. Driving force for implementation

- Legal and environmental (local) requirements.
- Increase of the storage capacity of the EWF.

9. Example sites

- Aughinish Alumina Ltd (IE)
- Rusal Nikolaev (Ukraine); Alcoa Kwinana and Waggerup plants (Western Australia)
- Oil sands industry extractive waste in Alberta (Canada)

10. Reference literature

(Munro and Smirk 2012)
(Residue Solutions 2016)

4.2.2.1.4.5 Co-disposal

1. Description

Co-disposal consists of mixing extractive waste from mineral processing and extractive waste from excavation in order to improve the extractive waste characteristics.

2. Technical description

This BAT candidate is relevant for extractive waste from excavation and for extractive waste from mineral processing.

Extractive waste is usually co-disposed of according to the following techniques:

- *By co-mixing*, where extractive waste from mineral processing and extractive waste from excavation are mixed together before being delivered to the deposition area.
- *By co-mingling*, where extractive waste from mineral processing and extractive waste from excavation are transported separately and allowed to mix together in the deposition area. These extractive wastes are deposited as one stream. Depositing them in layers helps the reduction of the oxygen flux and the water infiltration, with the aim of controlling potential ARD generation.
- *By co-placement*, where extractive waste from mineral processing and extractive waste from excavation are deposited together but not mixed to create a single stream, e.g. excavation waste can be used to create internal embankments or retaining walls to create cells in which extractive waste from mineral processing is deposited.

(Yilmaz 2011)

The deposition method, when selected, is planned in the design phase and implemented in the operational phase. The design of the EWF is linked to the deposition method.

- <u>*Planning and design phase*</u>

The EWF and the extractive waste management are designed based on the selected deposition method.

- *Operational (construction, management and maintenance) phase*
  The extractive waste is deposited using the selected method and monitoring of physical and chemical stability is carried out.

3. Achieved environmental benefits

- Helping to ensure the physical stability of the extractive waste by:
  - preventing or reducing negative effects on the stability of the deposited extractive waste that are linked to the presence of any residual water.
    By mixing extractive waste from excavation with extractive waste from mineral processing, the drainage of EWIW improves and the consolidation rate increases.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the leaching of pollutants.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.

4. Environmental performance and operational data

Test results showed that typical hydraulic conductivity values for non-compacted co-mixtures (typically 10^{-5}-10^{-6} m/s) are higher than for compacted mixtures (~ $5x10^{-8}$ m/s) (Yilmaz 2011).

The MTWR BREF (EC-JRC 2009) reports the following:

- The operator of the Swedish iron ore operations at Kiruna and Malmberget Mines has, for several years, worked on the development of alternative methods of transporting and depositing their "waste-rock" (dry coarse extractive waste < 100 mm) and extractive waste from concentrating operations (fine extractive waste from mineral processing < 3 mm). The objectives of this activity have primarily been to bring down the significant investment and operation costs of trucking (used for extractive waste from excavation) and of dam construction (used for the fine extractive waste from mineral processing).
- A major test had been conducted, in which a mixture of dry and wet extractive waste from mineral processing was pumped with heavy-duty slurry pumps. The tests and site-specific evaluation showed that the operation was not competitive with traditional transportation techniques, mainly due to wear in pumps and pipelines. The resulting co-disposal, however, showed that the slurry stream formed a rounded moraine-like formation, similar to those created by melting ice during the withdrawal of glacial ice. The density of the deposited extractive waste was found to be higher than that of conventionally placed extractive waste, i.e. the use of available volume is more efficient. In addition, it was concluded that, if measures are taken in order to control the groundwater level in the deposition area, stable and high deposits may be created with this disposal method.
- The promising properties of the co-deposited extractive waste from excavation and extractive waste from mineral processing had encouraged research into ways to achieve the advantages of co-disposal combined with traditional transportation techniques. One operator had developed the concept of drained-cell disposal and has carried out laboratory, pilot-scale and full-scale tests to develop applicable design criteria, to evaluate the operational, hydraulic and geotechnical aspects and to investigate the influence of a cold climate on the stability of the deposit.
- The drained cells were evaluated in preliminary studies at the Malmberget and Kiruna Mine sites.
- In Italy, the technique to build up heaps in layers of different permeability was successfully used for the disposal of the overburden material in the S. Barbara (Arezzo, Tuscany) coal mine facilities. The high-permeability layers can drain water off, so that the time required for pore pressure dissipation in the low-permeability layers is dramatically reduced. This technique improved the short-term stability of the heaps, providing sufficient safety for an acceptable building velocity.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- The optimal mixture ratio depends on different factors such as water content, hydraulic conductivity, porosity, voids ratio, saturation degree, strength, stability, density, cohesion, friction angle, consolidation, liquefaction and compression.

7. Economics
- This technique may allow the reduction of the closure costs.

8. Driving force for implementation
- Risk prevention.
- Economic benefits.

9. Example sites
- Kiruna and Malmberget (SE)
- S. Barbara, Arezzo (IT)
- Neves Corvo (PT)

10. Reference literature
(EC-JRC 2009)
(Yilmaz 2011)

4.2.2.2 Chemical stability of extractive waste

4.2.2.2.1 Techniques to prevent or minimise pollutant leaching

4.2.2.2.1.1 Techniques to reduce the extractive waste alkalinity

1. Description
Partial or complete neutralisation of extractive waste resulting from alumina refining (red muds).

2. Technical description
This BAT candidate is relevant for extractive waste with high alkalinity. It is particularly relevant for extractive waste from alumina refining (red muds).

Caustic reagents are usually recovered during the mineral processing (Bayer process) by washing solids from the settlers in several stages in countercurrent.

Neutralisation of the residual caustic reagents, present in the red muds after the mineral processing, may be achieved using different reagents such as:
- acids (e.g. sulphuric or hydrochloric);
- carbon dioxide (active neutralisation by mixing residues with carbon dioxide, or passive neutralisation using natural carbon dioxide present in the air; the carbon dioxide reacts with soluble sodium species present in the red muds and produces sodium carbonate/bicarbonate);
- sulphur dioxide (pH reduction using flue-gases);
- brines (Virotec process); or
- seawater (washing red muds with seawater reduces the pH by precipitation of hydroxyl and aluminate anions).

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The removal of alkaline substances/reagents from the extractive waste and resulting from the mineral processing is included in the design.
- *Operational (construction, management and maintenance) phase*
  The alkalinity reduction of extractive waste is carried out.

3. Achieved environmental benefits
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the release of pollutants to soil, groundwater and surface water.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the discharge of alkaline EWIW into the receiving surface water body.

4. Environmental performance and operational data
The performance levels will depend on the reagents used, the characteristics of the red muds and the time factor. In literature, pH levels between 8 and 10 have been reported (IAI 2015).

5. Cross-media effects
- Reagents consumption.

6. Technical considerations relevant to applicability
- Site location, e.g. in the case of neutralisation with seawater, proximity to the sea.

7. Economics
- No information provided.

8. Driving force for implementation
- Effective neutralisation of red muds may prevent their classification as hazardous extractive waste.
- Effective neutralisation of red muds may reduce costs for the treatment of EWIW.

9. Example sites
- Queensland Alumina Limited, Gladstone, Queensland, Australia
- Rio Tinto Alcan Yarwun, Gladstone, Queensland, Australia

10. Reference literature
(IAI 2015)

4.2.2.2.1.2 Techniques to compact, consolidate and deposit extractive waste

Prevention and minimisation of pollutant leaching by applying these BAT candidates (described in Section 4.2.2.1.4) is relevant for non-inert extractive waste.

4.2.2.2.1.3 Progressive rehabilitation

Prevention and minimisation of pollutant leaching by applying this BAT candidate (described in Section 4.3.1.3.1) is relevant for non-inert extractive waste.

4.2.2.2.1.4 Temporary covers

Prevention and minimisation of pollutant leaching by applying this BAT candidate (described in Section 4.3.1.3.2) is relevant for non-inert extractive waste.

4.2.2.2.2 Techniques to prevent or minimise Acid Rock Drainage (ARD)

4.2.2.2.2.1 ARD management system

The ARD properties of the extractive waste are duly taken into account in the O&CMS (see Section 4.1.1.1) and the EMS (see Section 4.1.1.2).

This technique is relevant for PAG extractive waste.

The management of PAG extractive waste follows a risk-based approach. During the Environmental Risk and Impact Evaluation the accurate characterisation and understanding of the extractive waste is of critical importance. The management process is an iterative process, and is originally performed in the planning and design phase, but is renewed and re-evaluated continuously throughout the whole life cycle. Opportunities to segregate NAG and PAG extractive waste are evaluated in the planning phase. Results of ARD extractive waste block modelling can be integrated with the mineral resource block modelling, if available, in order to show how segregation of NAG and PAG extractive waste can be achieved at the individual mine bench level for example (INAP 2014b). The assessment process for PAG extractive waste always covers the "cradle-to-grave" approach, i.e. any preferred management option during the operational phase also includes an acceptable closure strategy. Initial material characterisation is done in the planning and design phase. Furthermore, the initial characterisation results have to be continuously followed up and confirmed by extractive waste characterisation during the operational phase, according to the MTWR BREF (EC-JRC 2009).

4.2.2.2.2.2 Segregation of PAG and NAG extractive waste by sorting and selective handling/deposition

This BAT candidate is relevant for PAG extractive waste.

The selective management of PAG extractive waste is described in Section 4.1.3.2.2. There are a number of prevention, control and treatment options, developed for PAG extractive waste, applicable to the operational and closure phases (INAP 2014h).

4.2.2.2.2.3 Desulphurisation

1. Description
The PAG extractive waste fractions can be partly or fully separated by froth flotation and handled separately, before the final disposal into the extractive waste deposition area (including the EWF).

2. Technical description
This BAT candidate is relevant for PAG extractive waste.

This method is somewhat similar to selective material handling, but is carried out as part of the mineral treatment in the mineral processing plant.

<u>Flotation</u> is the predominant technique for the separation of PAG extractive waste. For example, pyrite can be recovered from siliceous extractive waste with good recovery rates, using xanthates and frothing agents in a dedicated flotation circuit.

According to the MTWR BREF (EC-JRC 2009), the flotation of PAG extractive waste is used in some plants to recover pyrite as a sulphur source for sulphuric acid production. The technique is well known. Both acid and alkaline processes are used. The pyritic product has a high reactivity and therefore carefully designed measures for deposition are required. Suitable disposal alternatives for the pyritic product could be subaqueous placing back of extractive waste into surface excavation voids or free water cover ponds with an impermeable basal structure, e.g. artificial liners, where the water will cover the extractive waste at all times (see Section 4.3.1.3.4.2.1).

In open pits, the water cover is sufficiently deep and additional liners are placed if fracture zones are detected in the pits.

One criterion is that the resulting pyrite content in the depyritised material needs to be sufficiently low to secure buffering.

Separation of sulphide minerals reduces the volume of PAG extractive waste with a high sulphide content to be disposed of. It has to be partially or totally performed by froth flotation and selective handling before disposing of the extractive waste from mineral processing. A small volume of sulphide-rich concentrate and a large stream of extractive waste with a low sulphur content are generated, according to the Closedure project (Punkkinen *et al.* 2015b).

Desulphurisation is applied in the life cycle phases of the extractive waste management listed below:

- <u>*Planning and design phase*</u>
  The EWF and the extractive waste management are designed based on the selected desulphurisation method.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The extractive waste from mineral processing is deposited after desulphurisation and monitoring of physical and chemical stability is carried out.

3. Achieved environmental benefits

- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD and the release of heavy metals to soil, groundwater and surface water.
- Implementation of the waste hierarchy principles by:
  - recovery of pyrite as a sulphur source.

4. Environmental performance and operational data

- According to the MTWR BREF (EC-JRC 2009), at the <u>Aitik site</u>, it was expected, based on hydrogeological modelling, that only a small fraction of the decommissioned pond would be dewatered during dry periods. It was expected to perform depyritisation of the extractive waste during the final couple of years of production, so that a top layer of extractive waste with a low sulphur content would be created. This concept included the separation and the separate management of the pyrite fraction with a sulphur content between 30 % and 35 % and the depositing of it into a separate section of the pond. Deposition of the pyrite was planned in a pond with permeable dams, raised concurrently with the surrounding structures. The planned area of the pyrite pond was 0.5-1 % of the total area (6-12 ha). This pond was planned to be mainly water-saturated, but at closure it could also be covered using the concept of a soil/dry cover.

5. Cross-media effects

- Energy and reagents consumption for the pyrite flotation.

6. Technical considerations relevant to applicability

- The viability of this technique is ruled by the pyrite content it is necessary to remove. It is applicable if the ARD potential of the bulk amount of extractive waste from mineral processing can be altered significantly (i.e. converted from acid-generating to non-acid-generating waste) by lowering the pyrite content.

7. Economics

- According to the MTWR BREF (EC-JRC 2009), flotation and separate management of the pyrite will entail significant costs.

8. Driving force for implementation
- Legal and environmental requirements.
- Need for less extensive decommissioning measures.

9. Example sites
- Pyhäsalmi Mine Oy (FI)
- Aitik Mine (SE)

10. Reference literature
(Benzaazoua *et al.* 2000; Benzaazoua and Kongolo 2003)
(Bois *et al.* 2004)
(EC-JRC 2009)
(Hesketh *et al.* 2010)
(Punkkinen *et al.* 2015b)

4.2.2.2.2.4 Blending with buffering materials

1. Description
This technique consists of adding buffering materials to the extractive waste from mineral processing and/or the extractive waste from excavation in order to minimise the ARD.

2. Technical description
This BAT candidate is relevant for PAG extractive waste.

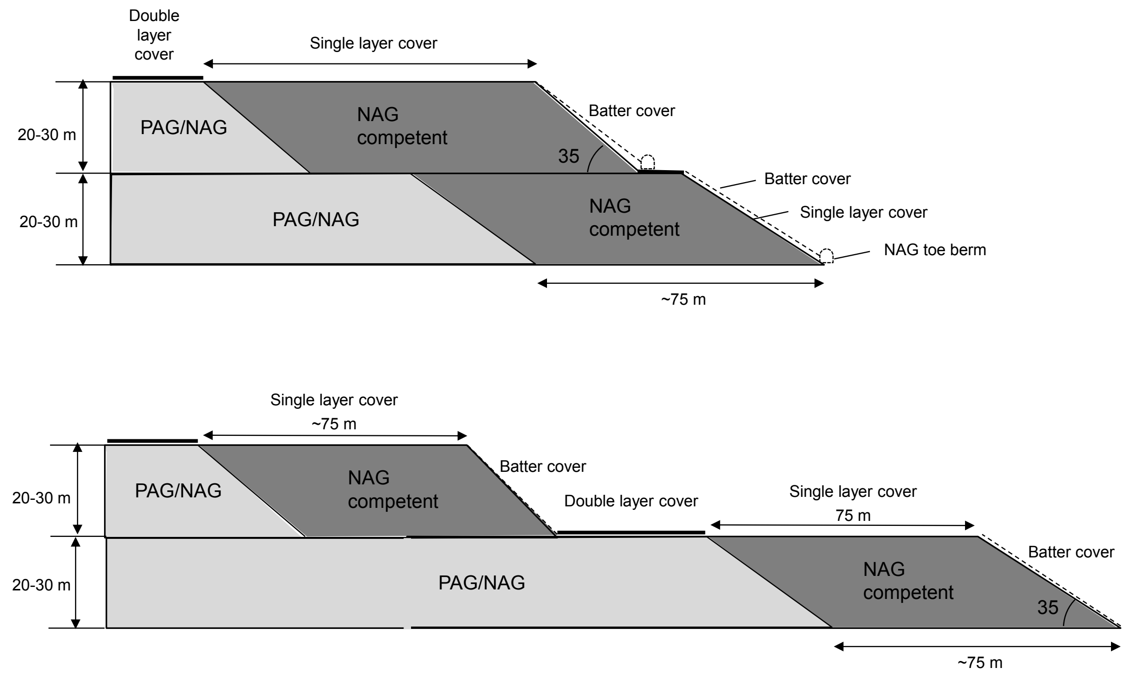
The addition of buffering materials (such as limestone, cement-based and pozzolanic materials) is normally practised before applying a dry cover (see Section 4.3.1.3.4.1). This helps to immobilise the weathering products readily available at the time of the decommissioning of the site.

PAG extractive waste can be encapsulated with acid-consuming materials.

It is also theoretically possible to use this as a decommissioning method, as an addition of enough buffering material would delay or even eliminate a drop in pH and the production of ARD. However, to accomplish such a long-term buffering effect in deposited PAG extractive waste normally requires large amounts of buffering materials, which would need to be brought in to the site at a prohibitively high cost, according to the MTWR BREF (EC-JRC 2009).

Cement-based and pozzolanic materials (e.g. fly ash) can also be applied in the management of extractive waste resulting from oil and gas extraction to solidify and/or stabilise the extractive waste. These processes are especially effective for stabilisation of metal compounds that are converted into insoluble metal hydroxides by the high pH of the cement mixture. Hydrocarbons and salts do not interact with the cement matrix and are physically rather than chemically bound within the matrix.

Encapsulating and layering involves the placement of PAG extractive waste and acid-consuming materials (typically waste-rock) in geometries designed to control or limit the ARD (see Figure 4.26). An additional layer of NAG or neutralising materials is designed and constructed in the bottom structure, underneath the PAG extractive waste. The bottom structure further reduces the ARD generated through the pile.



Source: adapted from (INAP 2014h)

Figure 4.26: Example of encapsulating and layering PAG extractive waste with NAG material

Blending is applied in the life cycle phases of the extractive waste management listed below:

- Planning and design phase
  The EWF and the extractive waste management are designed based on the selected blending method.
- Operational (construction, management and maintenance) phase
  The extractive waste from mineral processing is deposited after blending and monitoring of physical and chemical stability is carried out.

3. Achieved environmental benefits

- Helping to ensure the chemical stability of extractive waste by:
  - o preventing or minimising ARD and of the release of heavy metals to soil, groundwater and surface water.

4. Environmental performance and operational data

- For effective blending of PAG extractive waste from excavation with limestone, it is essential that all size fractions within the blend are at least acid-base neutral (i.e. the neutralisation potential ratio (NPR = NP/AP) is at least 3).
- Experience at Freeport (Indonesia) and Ok Tedi (Papua New Guinea) indicates that well-mixed PAG extractive waste from excavation and limestone needs to have a bulk net neutralisation potential (NNP = NP–AP) greater than 150 kg $CaCO_3$/t (or a net acid production potential (NAPP) of less than 150 kg H_2SO_4/t) (INAP 2014h).

5. Cross-media effects

- Consumption of buffering materials.

6. Technical considerations relevant to applicability

- Blending is only applicable if the buffering materials are available on or close to the site and preferably as part of the extractive waste generated.
- Blending is not a stand-alone technique; it is usually associated with an impermeable basal structure to prevent risks of groundwater pollution (see Sections 4.3.1.1.1 and 4.3.1.1.2).

- The applicability of this technique may be restricted by adverse climatic conditions and the chemical armouring of alkaline materials.
- The effectiveness of this technique is limited by high concentrations of organic compounds, salt and bentonite that interfere with the curing process. Furthermore, it is influenced by the general balance between PAG and NAG extractive waste, the particle size of PAG extractive waste, the type and reactivity of acid-consuming material, the geometry of the deposition area and the nature and flow of water through the deposition area.

7. Economics
- If the buffering materials are not available on site, the transport costs can be prohibitively high.

8. Driving force for implementation
- Legal and environmental requirements.
- Availability of land and blending materials.

9. Example sites
- Freeport (Indonesia) and Ok Tedi (Papua New Guinea) (INAP 2014h)

10. Reference literature
(Andrina *et al.* 2006)
(EC-JRC 2009)
(INAP 2014h)
(Miller *et al.* 2003)
(Tornivaara 2015a)

4.2.2.2.2.5 Impermeable basal structure

4.2.2.2.2.5.1 Impermeable natural soil basal structure

Prevention and minimisation of ARD by applying this BAT candidate (described in Section 4.3.1.1.1) is relevant for PAG extractive waste.

4.2.2.2.2.5.2 Impermeable artificial basal structure

Prevention and minimisation of ARD by applying this BAT candidate (described in Section 4.3.1.1.2) is relevant for PAG extractive waste.

4.2.2.2.2.6 Progressive rehabilitation

Prevention and minimisation of ARD by applying this BAT candidate (described in Section 4.3.1.3.1) is relevant for PAG extractive waste.

4.2.2.2.2.7 Temporary covers

Prevention and minimisation of ARD by applying this BAT candidate (described in Section 4.3.1.3.2) is relevant for PAG extractive waste.

4.2.2.2.2.8 Permanent covers

4.2.2.2.2.8.1 Permanent dry covers

Prevention and minimisation of ARD by applying these BAT candidates (described in Section 4.3.1.3.4.1) is relevant for PAG extractive waste.

4.2.2.2.2.8.2 Permanent wet covers

Prevention and minimisation of ARD by applying these BAT candidates (described in Section 4.3.1.3.4.2) is relevant for PAG extractive waste.

4.2.2.2.3 Techniques to prevent or minimise self-ignition of extractive waste

This BAT candidate is relevant for extractive waste with self-ignition potential.

During the information exchange process, some operators stressed the importance of preventing or minimising the self-ignition of extractive waste. This is obtained by the reduction of the combustible matter content, by compaction of extractive waste using appropriate mechanical equipment and by landscaping and geomorphic reclamation (see Section 4.3.2.1.4). No further details were provided to develop a full description.

4.2.2.3 Reduction of dangerous substances presence in extractive waste

4.2.2.3.1 Techniques to reduce the weak acid dissociable cyanide (WAD CN) concentration in the pond

Several techniques exist to reduce the free CN and/or WAD CN content in the extractive waste. Based on the data and information exchanged, these include the use of:
- an SO_2 and air mixture; or
- hydrogen peroxide; or
- ozonation; or
- Caro's acid; or
- chlorination; or
- ferrous sulphate complexation.

Based on the collected data, a detailed description of the techniques is provided for SO_2/air and H_2O_2.

4.2.2.3.1.1 Cyanide destruction using SO_2/air

1. Description
Destruction of cyanides by oxidation through the SO_2/air process.

2. Technical description
This BAT candidate is relevant for extractive waste containing cyanides.

The SO_2/air process, which is used in all European sites to treat the slurry prior to discharge into the extractive waste deposition area (including the EWF), is usually described using the following reactions:

- Oxidation:

$$CN^-_{free} + SO_2 + O_2 + H_2O \leftrightharpoons OCN^- + H_2SO_4 \quad (1a)$$

$$M(CN)_4^{2-} + 4SO_2 + 4O_2 + 4H2O \leftrightharpoons 4OCN^- + 4H_2SO_4 + M^{2+} \quad (1b)$$

where $M^{2+} = Zn^{2+}, Cu^{2+}, Ni^{2+}, Cd^{2+}$ etc.

- Neutralisation using lime:
  $H_2SO_4 + Ca(OH)_2 \leftrightarrows CaSO_4 \times 2H_2O$ (2)

- Precipitation:
  $M^{2+} + Ca(OH)_2 \leftrightarrows M(OH)_2 + Ca^{2+}$ (3a)
  $2\ M^{2+} + Fe(CN)_6^{4-} \leftrightarrows (M)_2\ Fe(CN)_6$ (3b)
  where M= Zn, Cu, Ni, Cd, Fe, etc.

  The presence of copper ions catalyses these reactions. They bind to the cyanide forming stable complexes of copper (I), which can be destroyed using the oxidation of both copper and cyanide. The higher the concentration of copper, the more stable those complexes are. On the other hand, high copper contents in the ore will require more cyanide in the leaching and, if the CN destruction efficiency remains the same, the residual cyanide concentration will be higher, according to the MTWR BREF (EC-JRC 2009).

  The influence of sulphur dioxide is not fully explained, but it is assumed that some intermediary compounds are generated that accelerate the reactions.

  The oxygen dispersion is related to the viscosity. When the viscosity is high, the levels of Dissolved Oxygen (DO) are lower and the kinetics of the reaction slow down, according to the MTWR BREF (EC-JRC 2009).

- Finally, cyanate ions may hydrolyse to ammonia according to the following reaction:
  $OCN^- + H^+ + 2\ H_2O \leftrightarrows HCO_3^- + NH_4^+$ (4)

The process requires a solid/liquid separation downstream to remove the TSS.

Cyanide destruction is applied in the following life cycle phases of the extractive waste management:
- *Planning and design phase*
  Planning of the treatment capacities and operational conditions based on the extractive waste characteristics and the mineral processing.
- *Operational (construction, management and maintenance) phase*
  Treatment of extractive waste prior to deposition.

3. Achieved environmental benefits
- Reduction of the presence of dangerous substances in the extractive waste by:
  - reducing the cyanide concentration of the extractive waste in the pond.

4. Environmental performance and operational data
The reaction is typically carried out at a pH of ~ 7.5 to 9.5, and lime is added automatically to neutralise the acid (H^+) formed in the reaction to maintain the pH in this range.

The SO_2 required in the reaction is supplied as sodium metabisulphite ($Na_2S_2O_5$). Oxygen (O_2) is also required in the oxidation reaction and this is generally supplied in the form of compressed air. Copper (Cu^{2+}) is required as a catalyst, which is usually added as a solution of copper sulphate ($CuSO_4$-$5H_2O$). A mixer is used in the reactor to make sure that air and reagents dissolve into the sludge effectively. The amount of pumped air is kept constant. The amount of sodium metabisulphite is measured to correspond with the amount of cyanide used in the reactor.

The CN destruction is capable of reducing the WAD CN concentration in the slurry from 140 mg/l to below 2 mg/l, if the copper content in the ore is not too high. If the feed to the cyanide leaching contains more than 0.1 % Cu, it is not possible to achieve such low levels of WAD CN in the extractive waste from mineral processing. At high copper concentrations, several stages of CN destruction may be necessary, according to the MTWR BREF (EC-JRC 2009).

Table 4.27 provides an overview of reported CN concentrations at several sites.

Table 4.27: CN levels at three European sites using cyanidation

Site:	Boliden [a]	Ovacık [a]	Rio Narcea [a]
Extractive waste leachate: Free CN (mg/l) pH	120	200 10.5	400-450 (NaCN) 10.5
Measurement frequency	Daily	Every 2 hours	Continuously online
Min.	70	180	
Max.	50	220	
Treatment outflows: Free CN WAD CN Total CN pH	0.87	0.33 0.4 7-8	0 10-30 8.5
Measurement frequency	1-3 per day	Every 2 hours	Every 3 hours
Min.	0.31 (total)	0.06 (WAD)	1 (WAD)
Max.	1.94 (total)	0.88 (WAD)	40 (WAD)
In the extractive waste deposition area (including the EWF): Free CN WAD CN Total CN pH	0.3	0.23 0.39 7-8	0 20-30 8.5
Measurement frequency	Sporadic	Daily	Daily
Min.	0.05 (total)	0.04 (WAD)	10 (WAD)
Max.	0.74 (total)	0.71 (WAD)	30 (WAD)
Extractive waste deposition area (including the EWF) discharge: Free CN WAD CN Total CN pH	0.06	No discharge	No discharge 0 0.5-1.0 8-8.5
Measurement frequency	Daily		Daily
Min.	0		0.2 (WAD)
Max.	0.33		2 (WAD)

[a] *MTWR BREF (EC-JRC 2009)*

- According to the MTWR BREF (EC-JRC 2009), at the Boliden mineral processing plant, monitoring of the CN destruction and the water quality of the discharge from the extractive waste from mineral processing and clarification pond was being carried out in 2001. Results show that 99.5 % of the CN_{free} was destroyed. Further degradation of the CN occurs naturally in the pond. Similar results were reported from Ovacık and Rio Narcea.

- At the Kittilä Mine, the WAD CN concentration of the leached extractive waste pumped to the leached extractive waste pond (CIL pond) is much lower than the limit value of 25 mg/l (Directive 2006/21/EC). The cyanide level is monitored several times a day. All water is pumped from the leached extractive waste pond back to the process and no water is released from the site.
  After the cyanide leaching, leached extractive waste is led to cyanide destruction tanks. The cyanide concentration of the leached extractive waste entering the destruction tanks is on average 150-300 mg/l.

- At the Ovacık and Mastra Mines, the total cyanide content in the extractive waste from mineral processing was reported to be less than 1 ppm in Ovacık and less than 10 ppm in Mastra.

- From information on Canadian mines: a total cyanides content in the extractive waste slurry of less than 5 ppm is estimated as achievable (MEND 2014).

To ensure good performance, it is important to manage the cyanide dosage in cyanide leaching and accurately control the sodium metabisulphite and copper sulphate feeding in the cyanide destruction tanks.

5. Cross-media effects
- Ammonia generation
- Iron-cyanide sludge generation.

6. Technical considerations relevant to applicability
- The system is only applicable in combination with equalisation (homogenisation of waste streams) prior to treatment, in order to ensure the stability of the coagulation technology and good performance.

7. Economics
The MTWR BREF (EC-JRC 2009) reports the following:
- The CAPEX for the installation of the SO_2/air method for CN destruction in 2001 were in the range of EUR 259 000 (USD 360 000, year 2009) to EUR 792 000 (USD 1 1000 000, year 2009). Capital costs include costs for the reactor, agitator, air compressor, SO_2 delivery system and copper sulphate delivery system. They do not include the extractive waste pump box and pump, or the lime system.
- The OPEX varied from EUR 1.7 to EUR 4.3 per kg of WAD CN (from USD 2.4 to USD 6 per kg of WAD CN, year 2009). They include the costs of SO_2, lime, copper sulphate and power.

- Costs generated by the process come mainly from the compressed air, sodium metabisulphite and copper sulphate feedstock. Compressed air is fed at a rate of approximately 300 m^3/h. Sodium metabisulphite costs ~ EUR 150/h while copper sulphate costs EUR 60-100/h on average during operation.

8. Driving force for implementation
- Re-use or recycling of water in the mineral processing plant.
- Legal requirements.

9. Example sites
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Ovacık Gold Mine (TR)
- Rio Narcea (ES)
- Mastra Mine (TR)

10. Reference literature
(EC-JRC 2009)
(MEND 2014)
(US EPA 1993)

4.2.2.3.1.2 Cyanide destruction using hydrogen peroxide

1. Description
Destruction of cyanides by treating extractive waste from mineral processing with hydrogen peroxide in order to enhance oxidation and destroy cyanides.

2. Technical description
This BAT candidate is relevant for extractive waste containing cyanides.

Similarly to the SO_2/air process, cyanide containing slurried extractive waste can be treated efficiently with hydrogen peroxide in order to enhance oxidation and destroy cyanides.

- Oxidation:

$CN^-_{free} + H_2O_2 \leftrightarrows OCN^- + H_2O$ (1a)

$M(CN)_4^{2-} + 4\ H_2O_2 \leftrightarrows 4\ OCN^- + 4\ H_2O + M^{2+}$ (1b)

where $M^{2+} = Zn^{2+}, Cu^{2+}, Ni^{2+}, Cd^{2+}$ etc.

- Precipitation:

$2\ M^{2+} + Fe(CN)_6^{4-} \leftrightarrows (M)_2\ Fe(CN)_6\ (s)$ (2)

where M= Zn, Cu, Ni, Cd, Fe, etc.

- Finally, cyanate ions may hydrolyse to ammonia according to the following reaction:

$OCN^- + H^+ + 2\ H_2O \leftrightarrows HCO_3^- + NH_4^+$ (3)

Unlike the SO_2/air process, no sulphates are generated.

Cyanide destruction is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Planning of the treatment capacities and operational conditions based on the extractive waste characteristics and the mineral processing.
- *Operational (construction, management and maintenance) phase*
  Treatment of extractive waste prior to deposition.

3. Achieved environmental benefits
- Reduction of the presence of dangerous substances in the extractive waste by:
  - reducing the cyanide concentration of the extractive waste in the pond.

4. Environmental performance and operational data
The reaction is carried out at an alkaline pH (9.0-9.5) (Botz 1999).

The consumption of hydrogen peroxide is often ~ 1 kg H_2O_2 per tonne of ore treated, according to the MTWR BREF (EC-JRC 2009).

As for the SO_2/air process, neutralisation is necessary to maintain the alkaline conditions and is performed by addition of lime.

The process outflow needs further solid/liquid separation to remove precipitates.

5. Cross-media effects
- Ammonia generation.
- Iron-cyanide sludge generation.

6. Technical considerations relevant to applicability
- The system is only applicable in combination with equalisation (homogenisation of waste streams) prior to treatment in order to ensure the stability of the coagulation technology and good performance.

7. Economics

- The degradation of cyanides by treating extractive waste from mineral processing with hydrogen peroxide is more expensive than using sodium metabisulphite.

- According to the MTWR BREF (EC-JRC 2009), the cost of H_2O_2 is around EUR 600 per tonne of a 70 % H_2O_2 solution. The CAPEX for the treatment plant are around EUR 100 000, but vary widely depending on the throughput, the hydrogen peroxide consumption and on the ore mineralogy.

8. Driving force for implementation

- Water recovery.
- Legal requirements.

9. Example sites

- No information provided.

10. Reference literature

(Botz 1999)
(EC-JRC 2009)
(MEND 2014)

4.2.2.3.1.3 Application of safety measures for cyanide destruction

This BAT candidate is relevant for extractive waste containing cyanides.

Safety measures can be applied when destroying cyanides, by designing:

- the size of the cyanide destruction circuit with a capacity twice the actual requirement;
- the installation of a backup system for lime addition;
- the installation of backup power generators.

Safety measures are applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Safety measures for cyanides destruction are included in the design.
- *Operational (construction, management and maintenance) phase*
  Safety measures for cyanides destruction are implemented.

4.2.2.3.2 Techniques to reduce the hydrocarbon concentrations in drilling extractive wastes

4.2.2.3.2.1 Thermal desorption

1. Description

This technique consists of applying heat to drilling muds and other drilling extractive wastes in order to separate hydrocarbons from drill cuttings.

2. Technical description

This BAT candidate is relevant for drilling extractive wastes from oil and gas drilling activities, in particular for drill cuttings.

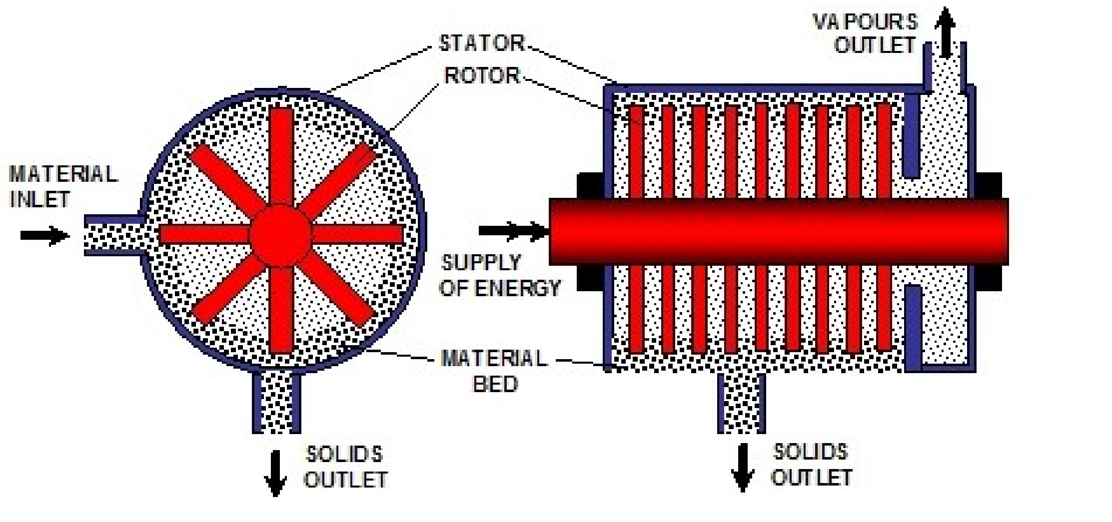
A thermal desorption system is a non-oxidising process using heat to desorb hydrocarbons from drilling muds and other drilling extractive wastes. Many thermal systems burn fuel to provide heat to volatilise the oil, but there are some systems that use electric energy to generate heat.

Thermal desorption systems are generally of the following types:

- *drum type:* a rotating drum is fed with drill cuttings; heat is usually transferred from an external source to the desorption chamber by a fluid;
- *screw type:* auger rotation enables the transfer of the cuttings from the feed hopper into a desorption chamber where the indirect heat desorbs the hydrocarbons as in the drum type;
- *friction-based:* heat is generated by friction between drill cuttings and rotating arms within the desorption chamber.

Systems working at a temperature from 250 °C to 350 °C are applied to oil-based mud (OBM) drilling fluids. These are heated to a temperature higher than the evaporation temperature of the base oil (~ 300 °C) and the drilling muds are separated into its three main components (the mineral solids (i.e. drill cuttings), the base oil and the water).

Several different thermal separation technologies are available on the market. Kinetic energy can be converted to thermal energy by creating friction in the drilling extractive waste. To this end, a shaft with a series of hammer arms is mounted inside a drum-shaped chamber (approximately 1 m in diameter and 1 m in length) (see Figure 4.27). Prior to start-up, sand is fed into the chamber and the shaft is set in motion. The particles will consequently be forced towards the inner wall of the chamber where the end of the hammer arms beats the particles, creating the frictional heat. When the temperature is high enough, the drilling mud is fed into the chamber. The liquid phase of the drilling muds flash evaporates. It leaves the chamber after a few seconds as steam water and oil vapour, which are both recondensed separately at a later stage. This recondensed oil can be re-used in the production of new OBM drilling fluid. The clean and dried drilling cuttings leave the chamber when the load on the motor reaches its set point. New drilling muds are fed into the chamber when the temperature decreases slightly. The process in controlled by a fully automatic Programmable Logic Controller (PLC) system.



Source: provided by the TWG

Figure 4.27: Example of thermal desorption equipment

Thermal desorption of drilling muds is applied in the life cycle phases of the extractive waste management listed below:

- <u>Planning and design phase</u>
  Thermal desorption of drilling muds is planned prior to oil and gas drilling operations. The management of extractive waste resulting from oil and gas extraction may take place without the planning and design of an EWF.
- <u>Operational (construction, management and maintenance) phase</u>

Thermal desorption of drilling muds is planned prior to drilling operations and implemented during the drilling phase.

3. Achieved environmental benefits

- Reduction of the presence of dangerous substances in the extractive waste by:
    - reducing the hydrocarbon concentrations in drilling muds and other drilling wastes.
- Change in the status of the oil-based drilling muds from hazardous to non-hazardous extractive waste.
- Re-use of the recondensed oil in the production of new oil-based drilling muds.

4. Environmental performance and operational data

The thermal desorption is capable of producing dry, clean, solid drilling cuttings with a Total Petroleum Hydrocarbon (TPH) content below 0.5 % (Therma-Flite 2016) or 1 % by weight (Halliburton 2007).

The reported levels of ROC are usually less than 1 % and can be as low as 0.03 % (IOGP 2016).

5. Cross-media effects

- Energy consumption for thermal desorption.

6. Technical considerations relevant to applicability

- This technique is applicable in combination with a solid/liquid control technique (e.g. a shale shaker) (see Section 4.2.2.1.1).

7. Economics

- No information provided.

8. Driving force for implementation

- Legal and environmental requirements.
- Compliance with the waste hierarchy principles; to prevent, re-use, recycle and subsequently reduce the amount of waste produced.

9. Example sites

- No specific example has been reported by onshore drilling sites. Some information has been provided by offshore drilling sites (i.e. NOV Brandt, South Esplanade East, Torry, Aberdeen (UK)). Even though the latter are outside the scope of the present review, some techniques might be applicable to the onshore sites as well.

10. Reference literature

(AECOM 2016)
(IOGP 2009, 2016)
(Halliburton 2007)
(Therma-Flite 2016)

4.2.2.3.2.2 Mechanical cuttings dryer

1. Description

This technique consists of applying a high gravity force on the cuttings in order to separate fluids from solids, e.g. drill cuttings.

2. Technical description

This BAT candidate is relevant for drilling extractive wastes from oil and gas drilling activities, in particular for drill cuttings.

Two type of cutting dryers are usually available:

- *Centrifugal*:

  - a high G-force (> 400 g) is applied on drill cuttings by rapid rotation of a basket;
  - vertical and horizontal basket configurations are available.
- *Vacuum*:
  - a combination of pressure differential and high-velocity air is used to separate fluids from the cuttings.

3. Achieved environmental benefits

- Reduction of the presence of dangerous substances in the extractive waste by:
  - reducing the hydrocarbon concentrations in drilling muds and other drilling wastes.
- Re-use of the recondensed oil in the production of new oil-based drilling muds.

4. Environmental performance and operational data

The reported levels of ROC usually range from 1 % to 5 % (IOGP 2016).

5. Cross-media effects

- Energy consumption.

6. Technical considerations relevant to applicability

- This technique is applicable in combination with a solid/liquid control technique (e.g. a shale shaker) (see Section 4.2.2.1.1).

7. Economics

- No information provided.

8. Driving force for implementation

- Legal and environmental requirements.
- Compliance with the waste hierarchy principles; to prevent, re-use, recycle and subsequently reduce the amount of waste produced.

9. Example sites

- No specific example site. The technique is widely applied at drilling muds management sites.

10. Reference literature

(AECOM 2016)
(IOGP 2016)

4.2.2.3.2.3 Land farming

1. Description

An organic matter decontamination technique that consists of bringing about the biological oxidation of organic substances contained in drilling extractive wastes by spreading these wastes onto the land surface and stimulating the natural microflora by adding fertilisers, ploughing and irrigating.

2. Technical description

This BAT candidate is relevant for drilling muds and other drilling extractive wastes from oil and gas drilling activities containing hydrocarbon residues.

<u>Land farming</u> is a technique aimed at removing toxic oil compounds contained in soils by bringing about their biological oxidation through the stimulation of the natural microflora (such as yeast, fungi or bacteria) by adding fertilisers, ploughing and irrigating. While physical and chemical treatments are based on pollutant transfer between gaseous, liquid and solid media, in bioremediation pollutants are degraded.

Land farming is planned prior to drilling operations and implemented during the drilling phase.

3. Achieved environmental benefits
- Reduction of the presence of dangerous substances in the extractive waste by:
    - o reducing the hydrocarbon concentrations in drilling muds and other drilling extractive wastes from oil and gas drilling activities.
- Reduction of the contamination of soil, groundwater and surface water.
- Degradation of toxic oil compounds in soil.
- Enhancing natural revegetation.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- Cross-contamination of soil.
- Volatilisation of organic matter and emissions to air.
- Land is required to accommodate all the contaminated extractive waste.

6. Technical considerations relevant to applicability
- This technique can be applied on site and off site. It can be used in a variety of weather conditions. Its application does not require special equipment.
- The effectiveness of this technique depends on numerous factors such as the type and concentration of contaminants, the nutrients' characteristics, the presence of inhibitors, the concentration of microorganisms, the aeration and the land availability.
- The removal of hydrocarbons by means of land farming is a long-term treatment.
- It may be more effective than other methods and complete detoxification may be achieved.

7. Economics
- No information provided.

8. Driving force for implementation
- Legal and environmental requirements.

9. Example sites
- Oilfield of Ayoluengo (ES) (22)

10. Reference literature
(IOGP 2009)

4.2.2.3.2.4 Composting

1. Description
An organic matter decontamination technique that consists of bringing about the biological oxidation of organic substances contained in drilling extractive wastes from oil and gas drilling activities in controlled conditions, either in the open air or within a vessel.

2. Technical description
This BAT candidate is relevant for drilling extractive wastes from oil and gas drilling activities, in particular for drill cuttings.

Organic matter contained in the drilling extractive wastes is decomposed by microorganisms.
The result of the composting process is typically humus and biomass.

Usually, three types of composting can be differentiated:
- *Aerated windrow composting:* drilling extractive wastes such as cuttings are deposited into rows of long piles called "windrows" and are periodically turned mechanically or manually

in order to aerate the mass and provide oxygen to microorganisms. On the one hand, the size of the pile has to be small enough to allow oxygen to flow to the windrow's core in order to maintain aerobic conditions. On the other hand, the windrow has to be large enough to generate sufficient heat and maintain the temperature necessary for the microorganisms.

- *Aerated static pile composting:* drilling extractive wastes such as cuttings are deposited onto a large pile. Oxygen flow to the core of the pile is achieved by loosely piling the extractive wastes and adding bulking agents or by introducing a network of pipes that will promote air and oxygen flow and thus aerobic conditions.
- *In-vessel composting:* composting is carried out in a vessel, e.g. drum, silo, concrete-lined trench, where temperature, moisture and oxygen are controlled. Aeration is usually done mechanically by means of vessel agitation or extractive waste turning.

3. Achieved environmental benefits

- Reduction of the presence of dangerous substances in the extractive waste by:
    - reducing the hydrocarbon concentrations in drilling muds and other drilling wastes.
- Change in the status of the oil-based drilling muds from hazardous to non-hazardous extractive waste.

4. Environmental performance and operational data

- The composting rate is dependent on the temperature and the drilling fluids. The kinetics of biological degradation of aromatic and branched-chain molecules are low compared to aliphatic and straight-chain molecules.
- Removal of salt and metals might be necessary prior to composting.
- Composting is suitable for treatment of drilling wastes with high levels of ROC (> 20 %).
- Blending of drilling wastes with organic materials to provide the appropriate proportions of carbon, nitrogen and moisture is usually necessary.
- Common organic materials used for blending are:
    - sawdust;
    - woodchips;
    - straw; and
    - chicken manure.
- The following operating conditions have been reported as recommended for composting:
    - a carbon:nitrogen ratio (C:N) of ~ 30:1;
    - an optimum moisture content of ~ 50 %;
    - a recommended ratio of cuttings to organic matter of 1:1 has been reported as optimum.
- Nitrogen and phosphorus nutrients (fertilisers) may be needed to enhance biodegradation.

The reported levels of ROC are less than 1 % (AECOM 2016).

The total extractable hydrocarbon concentration can be reduced from ~ 8 % to 0.4 % and ~ 15 % to 0.6 % after 22 months of composting. In some cases, levels below 0.1 % were achieved.

5. Cross-media effects

- Open-air composting of drilling muds and other drilling extractive wastes from oil and gas drilling activities can lead to the transfer of hydrocarbons from semi-solid phases to the air phase before their degradation.

6. Technical considerations relevant to applicability

- This technique is applicable in combination with a solid/liquid control technique (e.g. a shale shaker) (see Section 4.2.2.1.1).
- A high salt content may negatively affect the microbial activity.

7. Economics

- No information provided.

8. Driving force for implementation
- Legal and environmental requirements.

9. Example sites
- No information provided.

10. Reference literature
(AECOM 2016)
(IOGP 2009, 2016)

4.3 Risk-specific BAT candidates for the prevention or minimisation of water status deterioration, air and soil pollution

4.3.1 Techniques to prevent or minimise groundwater status deterioration and soil pollution

4.3.1.1 Basal structures and physical barriers

The most efficient technique to prevent seepage into the ground is a proper identification of site and management options (see Section 4.1.2.2), i.e. an area where a natural impermeable geological barrier is available or where the geohydrological conditions favour the prevention of seepage.

Correct placement of the EWF, taking into consideration the hydrogeology, may be enough to prevent groundwater status deterioration in cases with favourable soil and groundwater characteristics.
Therefore, the site selection is of the utmost importance when it comes to prevention of water status deterioration and soil pollution.

At sites where a natural impermeable geological barrier cannot be found and the hydrogeological conditions are not favourable, constructed impermeable basal structures may be needed to prevent seepage into the ground (soil and groundwater).

Basal structures can vary from a simple natural soil basal structure to more complex layered basal structures that contain artificial materials (such as geosynthetics). Typically, the structure is complex with drainage and seepage control layers, artificial layers, leakage detection systems, extra clay liner, etc., which means the thickness of a basal structure can easily be over 1 m (Kauppila *et al.* 2013).

4.3.1.1.1 Impermeable natural soil basal structure

1. Description
This technique consists of selectively placing and compacting low-permeability natural soils as the basal structure to avoid contaminated seepage into the soil and groundwater.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps. It is relevant for non-inert extractive waste.

If seepage into the ground has to be avoided and a natural impermeable geological barrier does not exist, the bottom of the extractive waste deposition area (including the EWF) is made impermeable by selectively placing and compacting low-permeability natural soils (such as natural clay, marl, peat), with a hydraulic conductivity lower than 10^{-9} m/s, as the basal structure. Humic material is removed before lining, according to the MTWR BREF (EC-JRC 2009).

Impermeable natural soil basal structures are designed to restrict the seepage of leachate through the base of the EWF over the whole life cycle.

Impermeable natural soil basal structures are included in the integrated design.

The basal structure is designed based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see Section 4.1.2.1.1), the water balance (see Section 4.2.1.3.4.1) and based on the design criteria resulting from dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2).

A common additive for amending the hydraulic conductivity of soils is sodium or calcium bentonite. It is blended with soils, in particular when they do not contain a sufficient percentage of clay.

The basal structure is applied in all the life cycle phases of the extractive waste management:

- _Planning and design phase_
  Design and planning of the basal structure characteristics.
- _Operational (construction, management and maintenance) phase_
  Construction of the basal structure. Monitoring and control (QA/QC) of the works are carried out, while also applying techniques to reduce the extractive waste alkalinity and implementing an ARD management system.
- _Closure and after-closure phase_
  In the closure phase, monitoring of the impermeable natural soil basal structure is carried out, while applying management systems.
  In the after-closure phase, monitoring of the impermeable natural soil basal structure is carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing pollution due to the infiltration of polluted seepage into the ground; due to the thickness of the layers of the basal structure, the EWIW takes significant time to pass through them.
    Concentration of solutes in the seepage may be reduced as a result of dispersion, diffusion and adsorption by materials constituting the natural soil basal structure.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD.
- Reduction of energy and auxiliary raw material consumption by using low-permeability materials available on site.

4. Environmental performance and operational data

The minimum thickness of this layer is usually 0.3-0.5 m (see Table 4.28). The increase in thickness of the basal structure does not always imply a proportional reduction of the seepage rate.

Typical natural soil basal structure material contains at least 30 % fines and can contain up to 50 % gravel by weight (US EPA 2016). Both the horizontal and vertical hydraulic conductivity are less than $1x10^{-9}$ m/s, according to the Ohio-EPA (OH EPA 2014) and based on site-specific data reported by operators via the questionnaires.

Table 4.28: Examples of natural soil multilayered basal structure systems reported by operators via the questionnaires

Site		Natural soil basal structure	Characteristics
Rämepuro Gold Mine pond		At least 0.5 m of dense natural peat overlaid with 1 m of blasted waste-rock (0-300 mm)	Peat permeability < 1×10^{-8}-1×10^{-9} m/s. Blasted waste-rock applied on the peat for controlled compaction for 2-4 months.
Cobre Las Cruces pond		A 300 m wide natural barrier made with impermeable marls compacted in layers of 0.5 m	Compaction breaks down the laminated continuous structures, reducing the horizontal conductivity. Compaction levels > 95 % of the maximum dry unit weight (Modified Proctor specification)
Potash extractive waste heaps	Various sites in Germany and Spain	Basal surface partially filled with clay depending on the natural terrain's hydraulic conductivity which varies from 10^{-11} m/s (clay) to 10^{-6} m/s (limestone and sandstone)	Clay increases the compaction and decreases the permeability
		After removing topsoil, a natural layer mixed with a maximum of 4 % salt-resistant clay is applied with a minimum thickness of 0.3 m. The layer is mechanically compacted.	Target hydraulic conductivity of the basal structure: ~ 10^{-9} m/s
Kevitsa Mine (heaps)		1 m of peat + 0.2 m of blasted rock	Hydraulic conductivity of the compacted peat layer: 3×10^{-10}-10^{-11} m/s

5. Cross-media effects

- Seepage may occur through the entire area of the basal structure, particularly in the case of large EWFs.
- Increase of the hydraulic conductivity in the long term due to cracks, to the dissolution of soil minerals when in contact with acidic/basic solutions or to the variation of clay mineral structures.
- Potential negative effect on the physical stability, particularly in the case of clay basal structures with a thickness greater than 0.3 m laid on steep surfaces.

6. Technical considerations relevant to applicability

- This technique is applicable in combination with ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2).
- This technique is applicable in new surface-based extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.
- This technique is applicable when extractive waste should remain water-saturated after closure (for ponds).
- This technique is particularly suitable for PAG extractive waste and where extractive waste has the potential to leach metals, cyanides and other contaminants.
- The requirements of the basal structure depend on the geochemical characteristics of the extractive waste to be deposited (for example their acid and neutralising properties, the potential concentrations of harmful substances and their solubility in the short and long term), the groundwater characteristics and the hydrogeological features of the site, according to Kauppila (Kauppila *et al.* 2013) and the SME Handbook (Kerr and Ulrich 2011). For example, in "potash heaps", available technology needs to be adapted according to the site conditions: not all tailings heaps require the same basal structure system.
- This technique is only applicable when large amounts of impermeable natural soils are available.

- It is not needed if the natural ground in its natural state under the extractive waste deposition area (including the EWF) is an impermeable continuous layer (with a hydraulic conductivity < 10^{-9} m/s and thickness > 0.5 m).
- Soil available on site can be heterogeneous and sometimes difficult to compact to create a dense enough impermeable layer.
- Soil basal structures are usually protected against erosion, cracking by desiccation, freezing and osmotic consolidation, according to the SME Handbook (Kerr and Ulrich 2011).

7. Economics
- The costs of the impermeable natural soil basal structure are related to the design properties of the soil (such as thickness, compressibility, permeability and strength). Costs related to materials extraction, transportation and compaction are usually considered.

The costs of construction and maintenance depend on the availability of natural materials:
- costs are usually lower compared to the case of impermeable artificial basal structures if suitable materials are available on or near the site, according to the Closedure project (Tornivaara 2015e);
- however, if there is a lack of suitable natural materials, impermeable artificial basal structures may be more cost-effective than natural materials.

8. Driving force for implementation
- Safety requirements.
- Legal requirements according to the national mining laws and other environmental laws. EIA in combination with baseline expert studies: for example, setting limits on seepage rates (performance-driven requirement) or mandating a specific basal structure design (prescriptive regulations).

9. Example sites
- Proyecto Cobre Las Cruces (ES)
- El Cogulló (ES)
- El Fusteret (ES)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)
- Pampalo Mine and Rämepuro Mine (FI)
- Kevitsa Mine (FI)

10. Reference literature
(EC-JRC 2009)
(Kauppila *et al.* 2013)
(Kerr and Ulrich 2011)
(OH EPA 2014)
(Rodriguez *et al.* 2015)
(Tornivaara 2015e)
(US EPA 2016)

4.3.1.1.2 Impermeable artificial basal structure

1. Description
This technique consists of using geosynthetics and drainage systems in the basal structure to provide a very low hydraulic conductivity, at least lower than 10^{-9} m/s, to avoid polluted seepage into the soil and groundwater.

2. Technical description

This BAT candidate is relevant for ponds, dams and heaps. It is relevant for non-inert extractive waste.

Impermeable artificial basal structures are especially useful when the geotechnical properties of soils limit their usage in the basal structure. They are also needed when the extractive waste characteristics or the national/local legal requirements impose the placement of an impermeable basal structure to seal the extractive waste deposition area (including the EWF) from the environment, according to the Closedure project (Tornivaara 2015e).

Impermeable artificial basal structures are included in the integrated design.

The basal structure is designed based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see Section 4.1.2.1.1), the water balance (see Section 4.2.1.3.4.1) and based on the design criteria resulting from dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2).

There are two typical configurations of ponds with an impermeable artificial basal structure:

- *Liner systems extending up the face of the embankment/dam*. Special design details on the drainage pipe penetration sections through the artificial basal structure system are required.
- *Liner systems extending beneath the embankment/dam*. In this case, the downstream slope of the embankments/dam has to be designed by using the lower foundation shear strength (Davies *et al.* 2002).

According to the MTWR BREF (EC-JRC 2009), all liner systems will eventually suffer leakage, the rate of which will depend on:

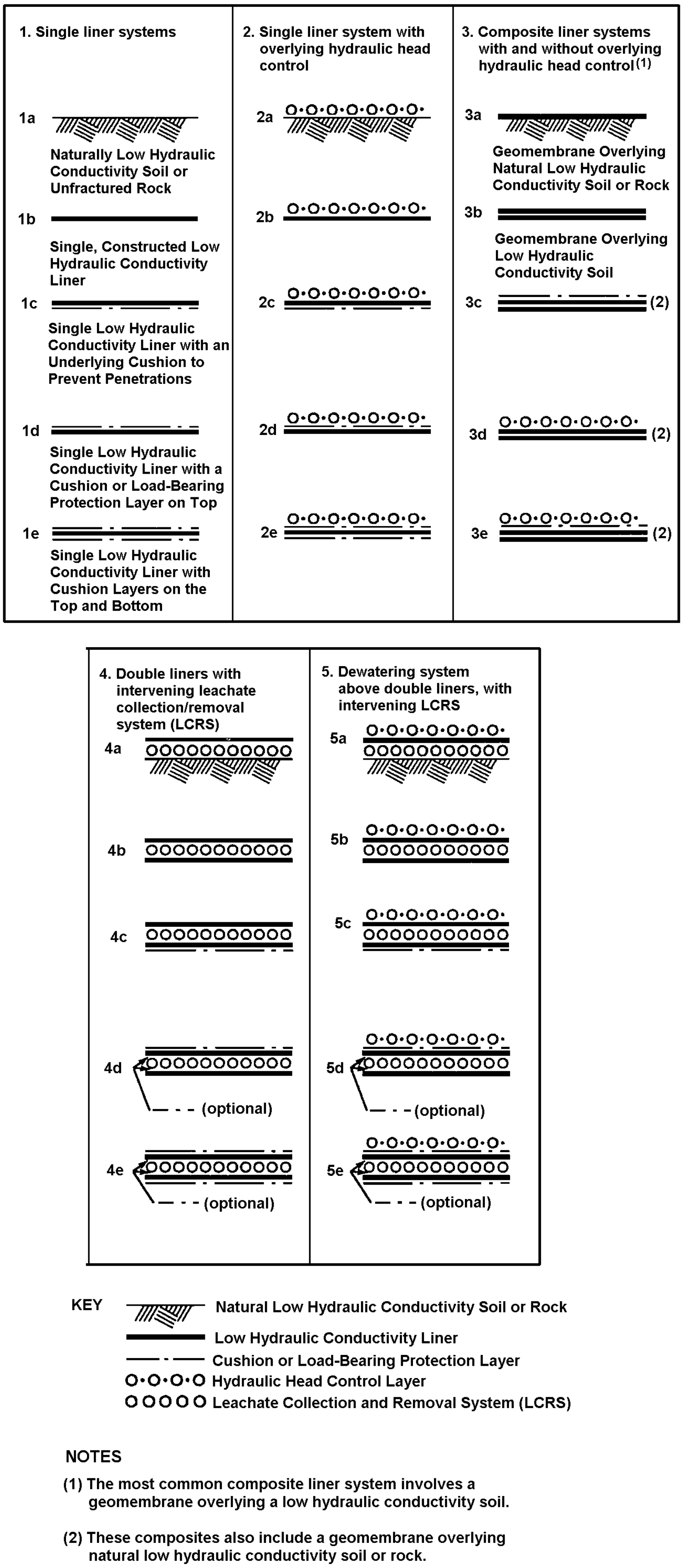
- the magnitude of the *hydraulic head* above the liner;
- the length of time the hydraulic head is applied to the liner;
- the thickness and effectiveness of the *liner material*, including the geosynthetics.

The geosynthetics commonly used in the different liner systems are listed below:

- *GeoMembranes (GM)* (hydraulic conductivity < 10^{-14} m/s), which can be used as liner systems for ponds containing extractive waste from mineral processing or process solutions, for encapsulation of heaps with extractive waste from excavation or as liner systems for heap leaching facilities. They are commonly made of HDPE, LLDPE (Linear Low-Density PolyEthylene), PP (PolyPropylene) or PVC (PolyVinyl Chloride), according to the Closedure project (Tornivaara 2015e).
- *GeoTextiles (GT),* which are used in drainage and filtration systems and/or for erosion control, according to the Closedure project (Tornivaara 2015e). They can be used as cushion layers over the GM.
- *Geosynthetic Clay Liner (GCL)* (hydraulic conductivity < 10^{-10} m/s), which can be used as a barrier (and also below a GM liner). The GCL is composed of bentonite, supported by GMs or GTs. It is used in areas where natural clay is absent or where a limited thickness is an important factor. It can be replaced or reinforced by a compacted natural soil layer or GMs, according to the US Environmental Protection Agency (US EPA 2016) and the Closedure project (Tornivaara 2015e).

Several configurations can be used (see Figure 4.28), such as the following:

- *Single composite liner* typically consisting of a GM placed over compacted soil.
- *Double liner system* typically consisting of two GMs and compacted fines (or a composite liner consisting of a GM and natural/synthetic clay liner). It is recommended to construct leakage detection, collection and removal layer systems above the primary liner or between the liners (or both). The lower GM liner is placed over compacted soil bedding, according to the Closedure project (Tornivaara 2015e).



Source: (EC-JRC 2009)

Figure 4.28: Types of liner systems available

After consolidation, extractive waste, particularly if well drained, can have a similar permeability to an impermeable natural soil basal structure. The consolidation may take many years following loading and until the extractive waste is at a sufficient depth and/or drained. In this case, the impermeable artificial basal structure (such as with geosynthetics) provides the principal containment until the extractive waste is consolidated. Thereafter the extractive waste tends to be the controlling basal structure. Thus the long-term life expectancy of the geosynthetic is less of a concern, according to the MTWR BREF (EC-JRC 2009).

The basal structure is applied in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Design and planning of the basal structure characteristics.
- *Operational (construction, management and maintenance) phase*
  Construction of the basal structure. Monitoring and control (QA/QC) of the works are carried out.
- *Closure and after-closure phase*
  In the closure phase, monitoring of the impermeable artificial basal structure is carried out, while applying management systems.
  In the after-closure phase, monitoring of the impermeable artificial basal structure is carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

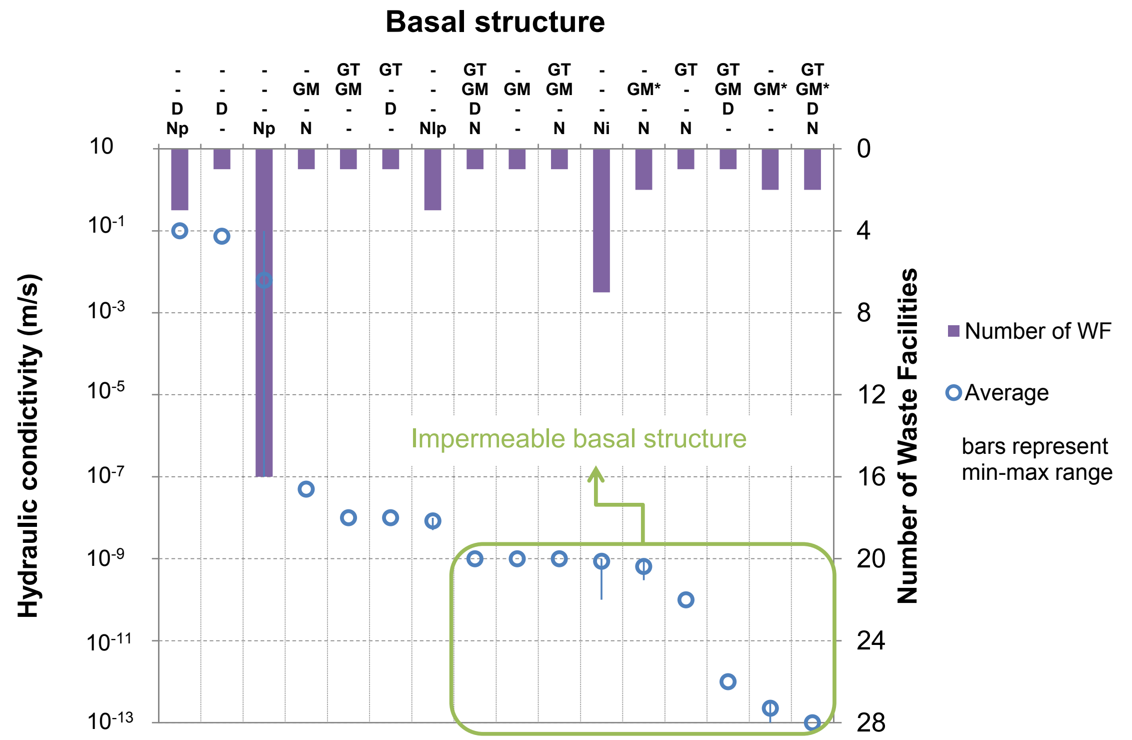
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing pollution due to the infiltration of polluted seepage into the ground by means of a structure that is highly impermeable and resistant to chemical and bacterial activity;
  - providing a good level of impermeability relative to the thickness of the layer, according to the Closedure project (Tornivaara 2015e).
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD.
- Prevention or minimisation of air pollution by:
  - providing a good barrier to gases, according to the Closedure project (Tornivaara 2015e).

4. Environmental performance and operational data

A common single composite liner configuration consists of:

- a compacted natural soil, usually 100-500 mm of clay, as the basal layer, in contact with the ground or the bedrock;
- a GCL or a GT, 250 g/m^2 to 700 g/m^2, as the protective layer;
- a GM, usually 1-2 mm thick HDPE, as the waterproof layer;
- an additional layer of GT to protect the GM;
- a drainage layer.

From data collected via the questionnaires, it is observed that the use of geosynthetics enables the achievement of very low hydraulic conductivity values below 10^{-12}-10^{-13} m/s (see Figure 4.29).



NB: N=Natural soil; Np=Permeable natural soil; Nlp=Low-permeability natural soil; Ni=Impermeable natural soil; D=Drainage layer; GM= Geomembrane; GM=Synthetic GM; GT=Geotextile.*
The green box shows the basal structures with low hydraulic conductivity.

Figure 4.29: Basal structure hydraulic conductivity depending on the basal structure based on the site-specific data reported by operators via the questionnaires

The liner system materials have to resist extreme conditions, often beyond the recommended general design limits. Manufacturers provide specific material property specifications and there are different methods available for testing geosynthetics, such as ASTM, ISO and GRI standards.

The integrity of the impermeable artificial basal structure is a key factor for the long-term performance of an EWF. When designing an EWF with an impermeable artificial basal structure, it is necessary to account for the possibility of leakage and confirm that low leakage rates (within standard industrial factors for construction defects in liners) will not result in significant environmental pollution. Otherwise some form of secondary containment (or leakage collection layer) is desirable (e.g. clay, peat, bentonite).

For PAG extractive waste, the liner systems are tested with acid drainage fluids before their final installation (Kossoff *et al.* 2014).

5. Cross-media effects

- Geosynthetic liners are supplemented with overlaying protective soil layers and support layers below.

6. Technical considerations relevant to applicability

- This technique is applicable in new surface-based extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.
- This technique is applicable in combination with ground investigation (see Section 4.2.1.3.1), dam construction materials selection (see Section 4.2.1.3.2) and geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2).
- This technique is applicable when extractive waste should remain water-saturated after closure (for ponds).

- Impermeable artificial basal structures are applied where:
    - the EWIW would otherwise seep into the ground;
    - there is a need to keep the water within the pond, in order, for example, to re-use process water or because water is contaminated (e.g. CN), or to avoid dusting by keeping the beach saturated;
    - it is necessary to ensure that extractive waste remains water-saturated after closure.
- This technique is particularly suitable for PAG extractive waste and where extractive waste has the potential to leach metals, cyanides or other contaminants.
- Geosynthetic basal structures may be not suitable due to structural stability issues, demonstrated by a proper geotechnical analysis (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2).
- The applicability of this technique depends on the soil or bedrock characteristics, the extractive waste characteristics, the site and the deposition techniques, according to the MTWR BREF (EC-JRC 2009).
- A liner can never be guaranteed to prevent all leakage and its lifetime is difficult to predict:
    - There is a lack of geotechnical and environmental data about the long-term field performance of impermeable artificial basal structures. Their lifetime is usually predicted based on laboratory tests on geosynthetics, according to the Closedure project (Tornivaara 2015e).
    - Seaming problems, UV radiation and low temperatures creating brittle stress cracking can decrease the effectiveness of the geosynthetic liner, according to the MTWR BREF (EC-JRC 2009).
    - It is impossible to repair or substitute a liner system put in place. Retro drilling over the area affected by leaching and injection of bentonite are very difficult and costly operations. Other options consist of building perimeter-intercepting trenches or hydraulic barriers around the EWF. These options are very expensive, particularly considering the average extension of the EWF. They are also limited in depth; therefore their effect on the bedrock might be limited.
- The GCL has a low shear strength and small leachate attenuation capacity. Its performance can be affected by dissolution reactions at extreme pH, pore structure and shrinkage at elevated temperatures.

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements.

9. Example sites
- Lisheen Mine (IE)
- Ovacık Gold Mine (TR)

10. Reference literature
(Caldwell and Kavazanjian 2012)
(Crouse *et al.* 1999)
(Davies *et al.* 2002)
(EC-JRC 2009)
(Kossoff *et al.* 2014)
(Tornivaara 2015e)
(US EPA 2016)

4.3.1.1.3 Seepage barriers

1. Description
This technique consists of using cut-off trenches, slurry walls or grout curtains to prevent or reduce the infiltration of polluted seepage into the ground.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps. It is relevant for non-inert extractive waste.

According to the MTWR BREF (EC-JRC 2009), seepage barriers serve to prevent or reduce seepage into the ground and include the following:
- *Cut-off trenches*. They are easy to install and low-cost solutions; however they are effective only for shallow pervious layers.
- *Slurry walls*. They are low-permeability barriers; however they are expensive and not well suited for steep terrain or bouldery ground; an impervious lower boundary is required.
- *Grout curtains*. They can reach great depths and are not affected by topography; however they are expensive and have limited effectiveness due to the permeability of the grouted zone.

It should be noted that, in reality, seepage control at a site often involves a combination of the methods listed above. Also, in addition to the barriers, which are constructed only for controlling the transportation of seepage, the contaminants in the seepage can be treated by certain reactive barriers (see Section 6.2.1).

Seepage barriers are applied in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Design and planning of the seepage barriers.
- *Operational (construction, management and maintenance) phase*
  Seepage barriers are constructed. Monitoring and control (QA/QC) of the works are carried out.
- *Closure and after-closure phase*
  Monitoring and maintenance are carried out.

3. Achieved environmental benefits
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing pollution due to the infiltration of polluted seepage into the ground.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- Material consumption for the seepage barrier construction.
- Possible disadvantages of these measures in connection with the stability of the dam should be considered in each case.

6. Technical considerations relevant to applicability
- No information provided.

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements and local legislation.

9. Example sites
- No information provided.

10. Reference literature
(EC-JRC 2009)

4.3.1.1.4 Lining the surface of temporary storage of drilling muds and other extractive wastes

1. Description
This technique consists of using an impermeable liner across all the surface areas where drilling muds and other extractive wastes from oil and gas exploration and production are temporarily stored in bunded containers/tanks.

2. Technical description
This BAT candidate is relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.

An impermeable liner is placed across all the surface areas where drilling muds and other extractive wastes from oil and gas exploration and production are temporarily stored in bunded containers/tanks ((UK EA 2016) and (IOGP 2016)).

The technique is applied in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  Design and planning of the impermeable liner characteristics.
- *Operational (construction, management and maintenance) phase*
  Construction of the impermeable liner. Monitoring and control (QA/QC) of the works are carried out.

3. Achieved environmental benefits
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing pollution due to the infiltration of polluted seepage into the ground.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements and local legislation.

9. Example sites
- No information provided.

10. Reference literature
(UK EA 2016)
(IOGP 2016)

4.3.1.1.5 Temporary storage of drilling muds and other extractive wastes in containers/tanks

1. Description
This technique consists of temporarily storing drilling muds and other extractive wastes from oil and gas exploration and production in bunded containers/tanks.

2. Technical description
This BAT candidate is relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.

Drilling muds and other extractive wastes from oil and gas exploration and production are temporarily stored in bunded containers/tanks ((UK EA 2016) and (IOGP 2016)).

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Design and planning of the temporary storage in bunded containers/tanks.
- *Operational (construction, management and maintenance) phase*
  The drilling muds and other extractive wastes are temporarily stored in bunded containers/tanks. Monitoring and control (QA/QC) of the storage are carried out.

3. Achieved environmental benefits
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - o preventing or reducing pollution due to the infiltration of polluted seepage into the ground.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements and local legislation.

9. Example sites
- No information provided.

10. Reference literature
(UK EA 2016)
(IOGP 2016)

4.3.1.2 Water streams management techniques

4.3.1.2.1 Diversion of water run-off systems during operation

See Section 4.3.2.1.2.

4.3.1.2.2 Drainage system techniques

4.3.1.2.2.1 Drainage systems for ponds and dams

See Section 4.2.1.3.5.1.

4.3.1.2.2.2 Drainage systems for heaps

See Section 4.2.1.3.5.2.

4.3.1.2.3 Landscaping and geomorphic reclamation

See Section 4.3.2.1.4.

4.3.1.3 Covering techniques

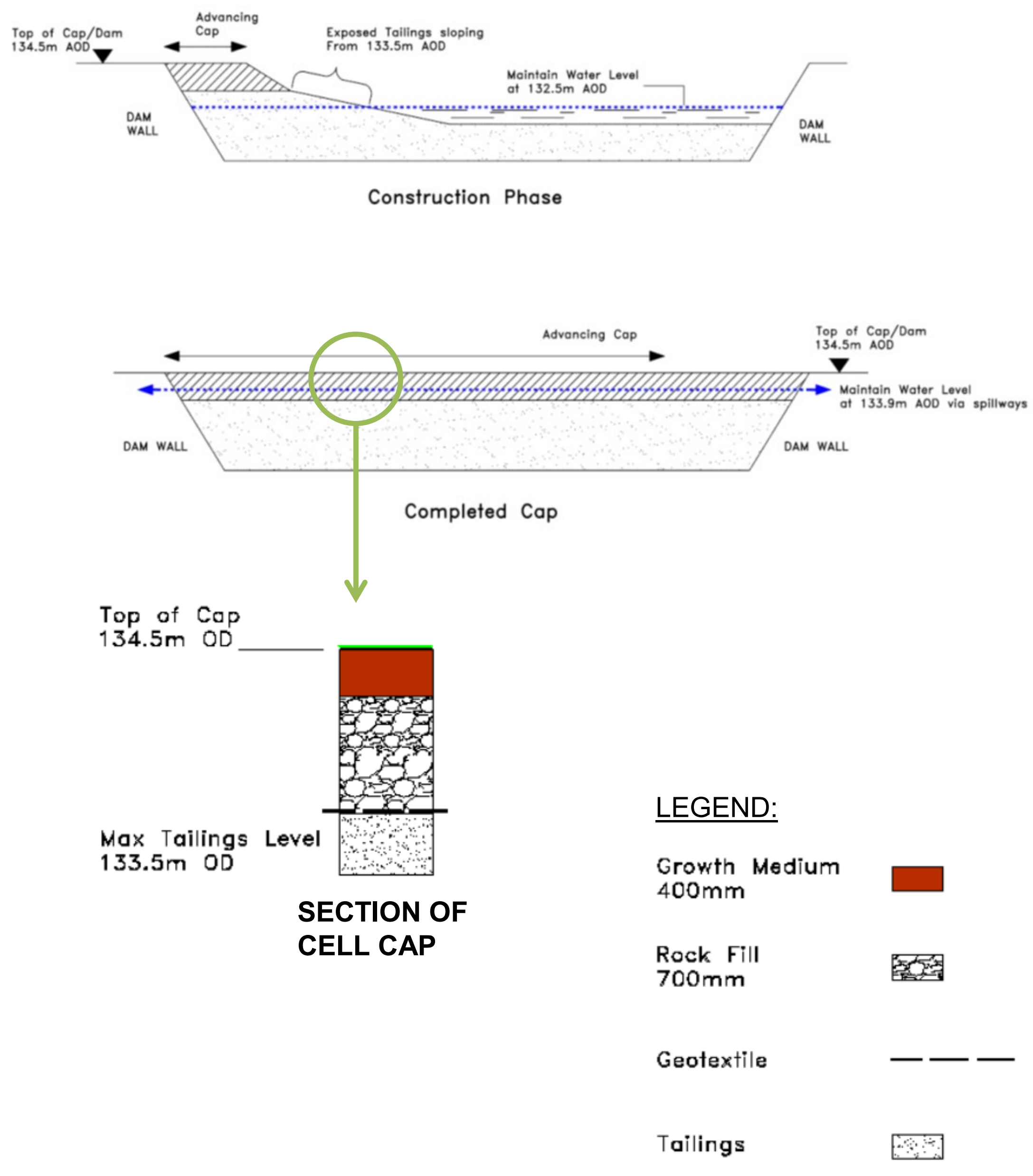
4.3.1.3.1 Progressive rehabilitation

1. Description
Progressive rehabilitation of ponds, dams, heaps and excavation voids where extractive waste is placed back involves starting the rehabilitation activities during the operational phase.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back.

<u>Progressive rehabilitation of ponds</u> can be implemented by means of the following activities:
- creation of extractive waste beaches by spigotting;
- formation of a rock cap on the beaches with an inward slope that allows run-off;
- inclusion of a dam wall impermeable liner protection.

The progressive rehabilitation scheme implemented at the Lisheen Mine is shown in Figure 4.30.



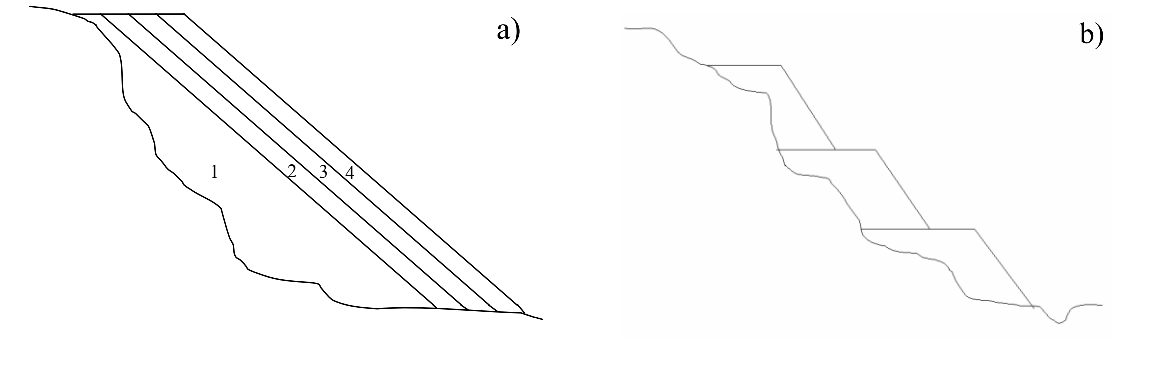
Source: Lisheen Mine questionnaire

Figure 4.30: Progressive rehabilitation scheme of the Lisheen mine

Progressive rehabilitation of heaps

- With bottom-up heaps, operators can reclaim the final slopes progressively in order to prevent dust emissions. Rehabilitation is done according to the future use of the area, the existing vegetation in the surroundings and the needs of the local community. A quick rehabilitation with pioneer seeds (grasses, bushes, trees) will successfully prevent dusting and will create valuable biotopes for the fauna and flora, at a reasonable cost to the operator. With a top-down heap where extractive waste is deposited from a hillside at its natural angle of repose (see Figure 4.31.a), such as in some mountainous regions, the slope rehabilitation cannot take place before the end of the heap construction. In that case, resloping of the heap might be expensive and the footprint may have to be significantly increased in order to ensure safety and enable revegetation. Heap reprofiling, cover and revegetation can start when depositing activity stops, such as in the Kisladag gold mine. Another option is to construct the heap in benches wide enough to allow for the resloping of one bench at a time.

In this way, the extractive waste will already be placed as close as possible to its final location (see Figure 4.31.b).



Source: (EC-JRC 2009)

Figure 4.31: a) Example of a top-down heap where extractive waste is deposited from a hillside b) Example of an alternative construction of a top-down heap where extractive waste is deposited from a hillside

Ongoing revegetation occurring during operation can be accelerated by different measures:

- Loosely tipping extractive waste from mineral processing to a depth of 2 m in the outer area, to accommodate root formation.
- Blending with materials such as fly ash, lime and dolomite rock in order to increase buffering capacity, water retention and nutrient capacity.
- Applying either a thick (around 1.8 m, when the extractive waste properties require that option) or a thin arable soil layer (50-100 mm). This soil will help the plant root formation and bushes can be planted directly in the extractive waste. This has the advantage that the young plant can accustom itself to the extractive waste conditions.
- Applying mineral fertilisers to compensate for the lack of nutrients. Organic fertilisers contain nutrients, which are organically bound, but which are released by microbial degradation. Additionally, they improve soil structure, activate soil organisms and enhance water retention capacity.
- Applying surface mulching (such as straw, hay, wood chaff) to enhance protection against adverse climatic conditions, as well as for humus enrichment, and to improve the water retention capacity, especially in the early stages of vegetation.
- In extremely dry seasons, irrigating at night time only.

Materials used for rehabilitation of extractive waste deposition areas (including EWFs) comply with European and National legislation.

Revegetation is carried out in accordance with the stability of the dams and therefore designed and controlled by experts, as it can potentially cause serious problems with root penetration.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Design and planning of the covering structure characteristics.
- *Operational (construction, management and maintenance) phase*
  Construction of the covering structure. Monitoring and control (QA/QC) of the works are carried out.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:

    - preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Helping to ensure the chemical stability of extractive waste by:
    - preventing or minimising leaching of pollutants;
    - preventing or minimising ARD and the release of heavy metals to soil, groundwater and surface water.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
    - preventing water erosion;
    - increasing the stability by means of the extractive waste consolidation.
- Prevention or minimisation of air pollution by:
    - preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste.
- Implementation of the waste hierarchy principles by:
    - re-using excavated materials (such as glacial till or peat) and overburdens as part of the dry cap.

4. Environmental performance and operational data
- Design specifications for the progressive rehabilitation of the pond at the Lisheen Mine:
    - Formation of a multilayer rock and soil cap on the extractive waste beaches composed of:
        - woven geotextiles placed directly on extractive waste (minimum lap length of 750 mm);
        - 700 mm of limestone rocks (D_{max} 500 mm);
        - 400 mm of topsoil;
        - inward slope is between 1 % and 2 %.
    - Inclusion of a dam wall impermeable liner protection obtained by means of:
        - placing a non-woven geotextile (500 g) directly onto the liner (minimum lap length of 750 mm);
        - extending the geotextile on the beaches by 2 m;
        - placing a woven geotextile (minimum lap length of 750 mm) on the non-woven geotextile and extending it on the exposed extractive waste beaches;
        - placing a granular gravel material (D_{max} 75 mm) on the top of the dam wall;
        - finally, placing the larger limestone rock particles and the advancement of the rock cap on the top.
    - Performing settlement monitoring.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- Progressive rehabilitation of ponds can be widely applied in several cases. However, it cannot be practised if the entire area functions as a single operational unit. For instance, this may be the case when a site wants to facilitate the maturation and consolidation of the extractive waste, especially if the upstream method of perimeter embankment raising is employed.
- Progressive rehabilitation of heaps constructed using the top-down method is not applicable during operation.
- It is not applicable if the non-hazardous extractive waste will be re-used or recycled during the operation according to a specific timeframe as defined in the closure and after-closure planning (see Section 4.2.1.1.1).

7. Economics
- The costs of progressive rehabilitation are spread over a long period.
- The costs of heap or pond revegetation vary from EUR 0.1 to EUR 0.5 EUR per m^2. Costs of an engineered cover on a heap or pond vary from EUR 3.0 to EUR 10 per m^3. Both costs are scale- and method-dependent, according to the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation
- Safety requirements.
- Optimisation of the EWF closure process, e.g. possibility to revise the closure method in the operational phase if any unexpected issue occurs. This allows synergies of staff and resources to be used during the operational phase.
- Providing reassurance to the local community.

9. Example sites
- Põhja-Kiviõli II oil shale open pit (EE)
- Lisheen Mine (IE)
- Galmoy mines (IE)
- Kışladağ Gold Mine (TR)

10. Reference literature
(EC-JRC 2009)

4.3.1.3.2 Temporary covers

1. Description
This technique consists of covering the external slopes and/or the dry extractive waste surfaces (e.g. beaches) with inorganic or organic materials, impregnating the surfaces of extractive waste from mineral processing with chemicals and bituminous emulsions and consolidating extractive waste from mineral processing taking into account its chemical characteristics.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back.

Temporary covers include the following activities:
- Covering the external slopes or the dry extractive waste surfaces (e.g. beaches) with inorganic materials (such as sand, waste-rock and topsoil) or with organic materials (such as compost, bark, straw and peat), while ensuring that the use of such covers does not lead to any additional adverse environmental or human health impacts. In the latter case, a vegetative cover is also applied.
- Impregnating the surfaces of extractive waste from mineral processing with chemicals and bituminous emulsions (such as lime slurry, silica compound, cement, bitumen or bentonite), which can repel water or bind particles. Chemicals can be sprinkled from a helicopter.
- Consolidating the extractive waste from mineral processing using its chemical characteristics, to assist for example in particle binding.

The technique is applied in the life cycle phases of the extractive waste management listed below:
- <u>Planning and design phase</u>
  Design and planning of the covering structure characteristics.
- <u>Operational (construction, management and maintenance) phase</u>
  Construction of the covering structure. Monitoring and control (QA/QC) of the works are carried out.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising leaching of pollutants;
  - preventing or minimising ARD and the release of heavy metals to soil, groundwater and surface water.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing water erosion;
  - increasing the stability of the dam by means of the stabilisation of the beaches.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the EWIW generation.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.

4. Environmental performance and operational data

- At the KGHM Polska Miedź S.A Żelazny Most tailings pond the external slopes of the dam are covered by 100 mm of sand and turf. The grass is fertilised once a year. Dry beaches are temporarily sprinkled with bituminous (asphalt emulsion) by helicopter. Finally, the material from the beaches is utilised for upstream dam construction.
- At the Pyhäsalmi site, spraying of lime slurry has been used to prevent the wind erosion of fine particles of extractive waste from mineral processing. Spraying has been carried out by equipment originally made for agricultural uses. This consists of a tank mounted onto a tractor and pump and hose system. This equipment has the capability to disperse the lime slurry in more or less even layers to the desired areas. When drying, the lime forms a hard surface layer, which lasts throughout the dry summer period. It should be noted that at Pyhäsalmi the lime slurry spraying is only carried out for the purpose of the mechanical and physical prevention of dusting, according to the MTWR BREF (EC-JRC 2009).

5. Cross-media effects

- Consumption of organic and inorganic materials.
- Consumption of chemicals and bituminous emulsions.
- Fuel consumption for transportation and placement of materials.

6. Technical considerations relevant to applicability

- Temporary covers are not applicable when the beaches are raised continuously.
- The beach needs to be stable enough for machinery to work on it in order to spread the material; otherwise, alternative costly methods such as using helicopters are required for the placement of the material.
- Temporary covers are not applicable if extractive waste deposited on heaps is removed again from the heap on a regular basis during operation and when this would require the removal of the cover.
- Temporary covers may not be suitable to cover steep heaps due to structural stability issues, demonstrated by a proper geotechnical analysis (see Section 4.2.1.3.6.2).
- It could inhibit the maturation of the extractive waste from mineral processing, particularly in the case of red muds.

7. Economics

- The costs of spraying a cementitious emulsion is ~ EUR 0.15 per m^2, which is relatively high considering the required area (5-6 ha) and the need for spraying every year (springtime), according to the MTWR BREF (EC-JRC 2009).

- The cost of dust spraying with asphalt emulsions is ~ EUR 0.031 per tonne at the KGHM Polska Miedź S.A. Żelazny Most tailings pond, including the costs for emulsion and distribution by helicopter and ground equipment. The yearly total sprinkled surface was ~ 1 080 ha, according to the MTWR BREF (EC-JRC 2009).

- Additional costs are related to material crushing and placement.

8. Driving force for implementation
- Legal requirements, including national/local legislation.
- Local environmental air quality standards.

9. Example sites
- Zinkgruvan Mine (SE)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

From the MTWR BREF
- Pyhäsalmi Mine Oy (FI)

10. Reference literature
(EC-JRC 2009)

4.3.1.3.3 Vegetative covers

1. Description
A vegetative cover layer typically consists of placing a soil layer or multiple layers sufficient to support root development and to maintain a suitable degree of moisture and a vegetative layer consisting of growing media and soil improvers, including compost, with the necessary micro and macro nutrients. They can be used temporarily or permanently.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back.

A vegetative cover layer typically consists of placing a single soil layer or multiple soil layers to promote a vegetative growth. The layer is designed to provide sufficient support for root development and to maintain a suitable degree of moisture. A vegetative layer consists of growing media and/or, if necessary, soil improvers, including compost, with the necessary micro and macro nutrients, and it is ensured that the use of such a layer does not lead to any additional adverse environmental or human health impacts.

When using a vegetative cover on top of covered PAG extractive waste, vegetation with shallow roots is used to prevent breakage of the underlying cover (e.g. low-flux or impermeable cover).

The technique is applied in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Design and planning of the covering structure characteristics.
- *Operational (construction, management and maintenance) phase*
  Construction of the covering structure. Monitoring and control (QA/QC) of the works are carried out.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  In the after-closure phase, the vegetative covers are monitored and maintained, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - o preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - o preventing or reducing water erosion.
- Prevention or minimisation of surface water status deterioration by:
  - o preventing or minimising the EWIW generation.
- Prevention or minimisation of air pollution by:
  - o preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.
- Reducing the evaporation from the underlying layer(s) of natural soil. For example, the use of compost together with the sowing of legumes (preferably with a grass clover mixture) contributes to bring nutrients to the soil.
- Prevention or minimisation of the visual impact from the management of extractive waste.
- If native vegetation is used, promotion of biodiversity and reduction of impacts on the ecosystem.
- By the direct vegetation of red muds, avoiding the need to borrow external topsoil.

4. Environmental performance and operational data

Revegetation success criteria are usually established and reseeding may be required. The type of vegetation needs to be controlled: deep-rooting species can be pulled up to prevent breaching of the layers.

For the direct vegetation of red muds subjected to the aforementioned procedures, the Bauxite Residue Disposal Area (BRDA) can be seeded with a mixture of 100 kg of native plant species per ha. A vegetated cover can be achieved in 1 year. It is highly desirable to establish native species on the cap that will not root deeply.

- At the Aughinish site, the plant nutrient contents in restored red muds are within typical ranges reported for grasslands. Stable ecosystems are identified in the vegetated residues. The placing of 1 m of top cover over an area of 170 ha would require more than 2 Mt of topsoil, which in this case are avoided.

Direct vegetation of extractive waste from alumina refining (red muds) disposed of in the BRDA can be successfully implemented by sequentially applying the following procedures:

- ploughing and weathering the red muds to reduce the pH to less than 11.5;
- improving the substrate texture by adding sand and gravel recovered from the Bayer process itself;
- adding gypsum ($CaSO_4$) to reduce the exchangeable sodium content and to reach a neutral pH;
- adding organic nutrients and compost.

5. Cross-media effects

- Consumption of fertilisers and water.

6. Technical considerations relevant to applicability

- Materials used in the vegetative covers are generally widely available.
- The applicability may be restricted by the height and slope of the heap design.

7. Economics

- The costs of revegetating a heap of extractive waste from excavation or a pond containing extractive waste from mineral processing vary from EUR 0.1 to EUR 0.5 EUR per m^2, depending on the scale and method used, according to information provided in the MTWR BREF (EC-JRC 2009). Sophisticated recultivation solutions may involve higher costs.

- Applying vegetative covers on very soft but maturing extractive waste could be very expensive to develop and operate, according to the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation
- Safety requirements.
- Legal and environmental local requirements.

9. Example sites
- Aughinish Alumina Ltd (IE)
- Nordkalk Oy Lappeenranta (FI)
- Rusal Kirkvine Jamaica

10. Reference literature
(Courtney *et al.* 2003; Courtney and Timpson 2005a, b; Courtney *et al.* 2009a; Courtney and Mullen 2009; Courtney *et al.* 2009b; Courtney *et al.* 2010; Courtney *et al.* 2011; Courtney and Harrington 2012a, b; Courtney *et al.* 2013; Courtney *et al.* 2014)
(EC-JRC 2009)
(Schmalenberger *et al.* 2013)

4.3.1.3.4 Permanent covers

According to the design for closure approach, a best practice is to update the closure and after-closure planning by updating the design assumptions and providing the final closure plan in the closure phase (see Section 4.2.1.1.1).

See Section 4.4.3 for the techniques to be implemented to reduce the visual impact.

4.3.1.3.4.1 Permanent dry covers

A dry cover is a cap-and-cover solution to cover extractive waste with a single soil layer or a layered structure of numerous soils, natural and/or artificial materials (such as geosynthetics). It should be noted that the term "dry cover" does not mean that it does not contain water. This term is merely used to differentiate between this type and "water covers".

Covering (or capping) is an effective technology for isolating contaminants and reducing their mobility, but without addressing contaminant toxicity or volume.

4.3.1.3.4.1.1 Permeable dry covers

1. Description
This technique consists of covering the extractive waste with a single layer or multiple layers of soil or equivalent materials permeable to water and oxygen, while ensuring that the use of such a layer or layers does not lead to any additional adverse environmental or human health impacts.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back. It is relevant for covering non-hazardous extractive waste.

<u>A permeable cover</u> is a cap-and-cover solution typically constructed of a single layer or multiple layers of unselected and uncompacted soil or equivalent materials, while ensuring that the use of such a layer or layers does not lead to any additional adverse environmental or human health

impacts, (such as till, clay, coarse gravel/rock) available close to or at the extractive waste deposition area (including the EWF), according to the MTWR BREF (EC-JRC 2009), the MEND report (MEND 1994) and Lottermosser (Lottermoser 2010). According to the Closedure project (Kauppila 2015a), it includes:

- *vegetative covers* (see Section 4.3.1.3.3);
- *non-vegetative covers* (coarse gravel or riprap).

This type of cover does not fully prevent access of water or oxygen into the extractive waste. Infiltration of water can be reduced by using materials with a low hydraulic conductivity and/or high water retention capacity such as clayey till, green liquid dredges, and fly ash. In addition, nearly saturated soil layers (such as clay layers, clayey till) can also reduce oxygen infiltration since diffusion of oxygen is slower in water than in air, as reported in the Closedure project (Kauppila 2015a) and in the MiMi project (Höglund *et al.* 2004).

If the soil in the permeable cover has sufficient capacity to hold the rainwater until it is removed by evapotranspiration, no deep percolation penetrates into the cover. For the design of this kind of covers, a sound understanding of soil characteristics, evapotranspiration and climatic factors is needed (ITRC 2010i).

Water run-off is collected by means of diversion structures (see Section 4.3.2.1.2). Water that has entered into contact with the cover and the extractive waste can be sent to treatment, according to the Closedure project (Kauppila 2015a).

The technique is applied in the life cycle phases of the extractive waste management listed below:

- <u>*Planning and design phase*</u>
  Design and planning of the covering structure characteristics.
- <u>*Closure and after-closure phase*</u>
  In the closure phase, construction of the covering structure. Monitoring and control (QA/QC) of the works are carried out.
  In the after-closure phase, the permeable dry covers are monitored and maintained, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the EWIW generation.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - increasing the long-term stability;
  - preventing or reducing water erosion.
- Prevention or minimisation of air pollution.
  - prevention and reduction of wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.
- Providing a substrate for vegetation and encouraging evapotranspiration through the vegetative cover growth.

4. Environmental performance and operational data

The typical layer thickness of the single-layer or multilayer soil cover is 0.3-1.5 m. The thickness depends on the extractive waste type and site-specific requirements but it should be thick enough to support vegetation.

Soil covers may require long-term maintenance, since they are vulnerable to vegetation, animal and human activity including vehicle traffic, and may be prone to erosion. Clay layers are prone to cracking and other deterioration, e.g. due to freezing/thawing, desiccation, burrowing, root penetration or erosion (MEND 1994).

5. Cross-media effects

- Material consumption.

6. Technical considerations relevant to applicability

- Permeable covers are not suitable for covering of PAG extractive wastes unless an oxygen-consuming layer is included in highly engineered composite covers which will then be considered an oxygen-consuming dry cover (see Section 4.3.1.3.4.1.3).
- Permeable covers may not be suitable to cover steep heaps due to structural stability issues, demonstrated by a proper geotechnical analysis (see Section 4.2.1.3.6.2).
- The effectiveness of the cover acting as a barrier to oxygen transport depends on the moisture retention capacity of the material (EC-JRC 2009; Höglund *et al.* 2004; INAP 2014h; Kauppila *et al.* 2013; MEND 1994).

7. Economics

- The main costs for permeable covers are the material costs and the cost for the use of heavy equipment. They depend on the material availability, the size of the area and the thickness of the cover layer. The single-layer or multilayer soil cover is usually the least expensive dry cover.

- The costs presented in literature have a range of EUR 1.85-5.54 per m^2, according to the Closedure project (Kauppila 2015a).

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements.

9. Example sites

NI

10. Reference literature

(EC-JRC 2009)
(Höglund *et al.* 2004)
(INAP 2014h)
(ITRC 2010i)
(Kauppila *et al.* 2013; Kauppila 2015a)
(Lottermoser 2010)
(MEND 1994)

4.3.1.3.4.1.2 Impermeable and low-flux dry covers

1. Description

This technique consists of covering the extractive waste with multiple functional layers in order to inhibit the oxygen influx and to limit the meteoric water infiltration.

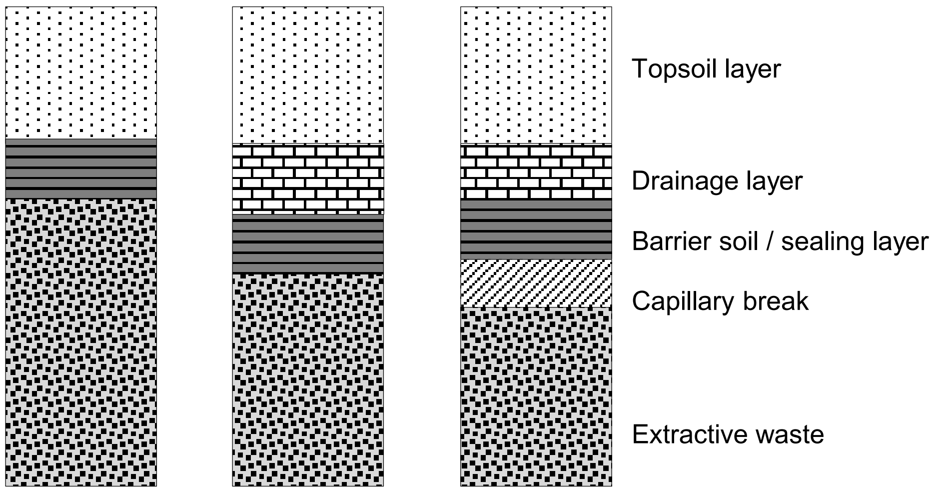
2. Technical description

This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back. It is relevant for covering non-inert extractive waste.

The main function of a multilayered impermeable cover is to inhibit the influx of atmospheric oxygen and to limit the infiltration of meteoric water to the underlying reactive extractive waste. Also, upward movement of oxidation products or process water constituents is controlled.

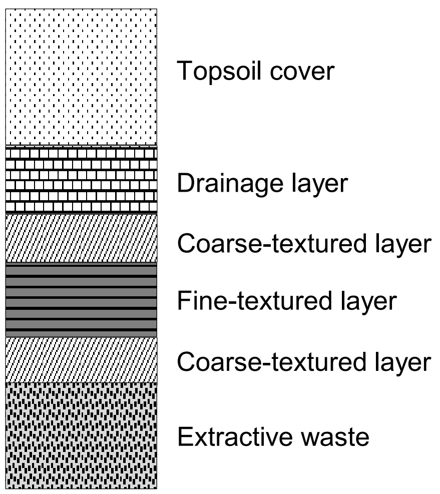
A multilayer soil cover is composed of two or more soil layers that are constructed with natural granular soil and placed on top of the extractive waste. Each layer is compacted individually in order to reduce the hydraulic conductivity and/or increase the water saturation degree, thereby decreasing the effective oxygen diffusion. Different cover types range from relatively simple layered structures to complex covers containing several different layers and soil types, according to the GARD Guide (INAP 2014h) and the Closedure project (Punkkinen *et al.* 2015f). How effective the cover is depends on the moisture content in the covering layers.

Figure 4.32 describes three different multilayer soil cover designs with varying structural complexity. Figure 4.33 shows an example of a capillary barrier system.



Source: adapted from (EC-JRC 2009)

Figure 4.32: Different examples of multilayer soil covers



Source:adapted from (EC-JRC 2009)

Figure 4.33: A capillary barrier system

The most complex design includes the following, from the bottom to the top layer:

- A coarse layer combined with the impermeable layer and the extractive waste.
- A capillary break system composed of a coarse layer, which prevents dewatering by capillary transport downwards and the possible diffusive transport of dissolved elements upwards. If the low-hydraulic-conductivity barrier layer is dewatered, there is an increased risk of cracks, followed by an increased transport of oxygen. The structure may also include a capillary barrier system, where a fine-textured soil layer is "sandwiched" between coarse-textured layers (see Figure 4.33) (INAP 2014h).
- A barrier layer composed of two or more layers of natural granular soil (such as clays and clayey tills, loess, silty sands, sand, gravel, bentonite).
- A woven geotextile to prevent mixing of the coarser and the finer materials. It allows the passage of water, but prevents soil from moving through to lower layers. Bentonite can be added to decrease the hydraulic conductivity.
- A drainage layer to lower the hydraulic gradient and to reduce infiltration.
- A topsoil layer.
- A vegetative layer on the top to prevent erosion. Important questions arise as to whether the roots of the local species, likely to inhabit the remediated pond at some point in the future, will penetrate the impermeable layer, and how thick the protective cover has to be to prevent this. Also, frost/thaw effects are usually considered, as these can cause cracks and the formation of macropores, thereby leading to an increased hydraulic conductivity. After the protective cover has been applied, grass is usually used on top of the cover to prevent erosion of the protective cover.

A multilayer cover with geosynthetics can prevent or significantly reduce water and oxygen transportation into the extractive waste (INAP 2014h; Kauppila *et al.* 2013), and thus minimise ARD and metal leaching from PAG extractive waste.

When geosynthetic liners are a part of a multilayer cover structure, they are usually placed between the barrier layer and the drainage layer (INAP 2014h).

Many different types of geosynthetic materials can be used, such as GMs (LLDPE, HDPE), GCLs and Bituminous GMs (BGMs) (INAP 2014h; Kauppila *et al.* 2013).

GCLs have the ability to self-repair holes due to the swelling properties of the bentonite. A geosynthetic cover structure requires an upper protective layer (sunlight protection, growth medium) and a lower protective layer (prevention of point loading, prevents interaction) and needs careful sealing (INAP 2014h; Kauppila *et al.* 2013). It is worth noting that GCLs are prone to desiccation and chemical interaction (Na/Ca exchangeable replacement) when exposed to high seasonal variations (dry/wet).

The low-flux cover is similar to an impermeable dry cover, but does not contain any geosynthetic layer.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Design and planning of the covering structure characteristics.
- *Closure and after-closure phase*
  In the closure phase, construction of the covering structure. Monitoring and control (QA/QC) of the works are carried out.
  In the after-closure phase, the impermeable and low-flux dry covers are monitored and maintained, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
    - o preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste;

  - reducing water and oxygen infiltration into the extractive waste and oxygen diffusion into void spaces.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the EWIW generation.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD and the release of heavy metals;
  - providing resistance to chemical and bacterial activity.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - the stabilisation of the extractive waste;
  - preventing or reducing water erosion.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.
- Providing a substrate for vegetation.

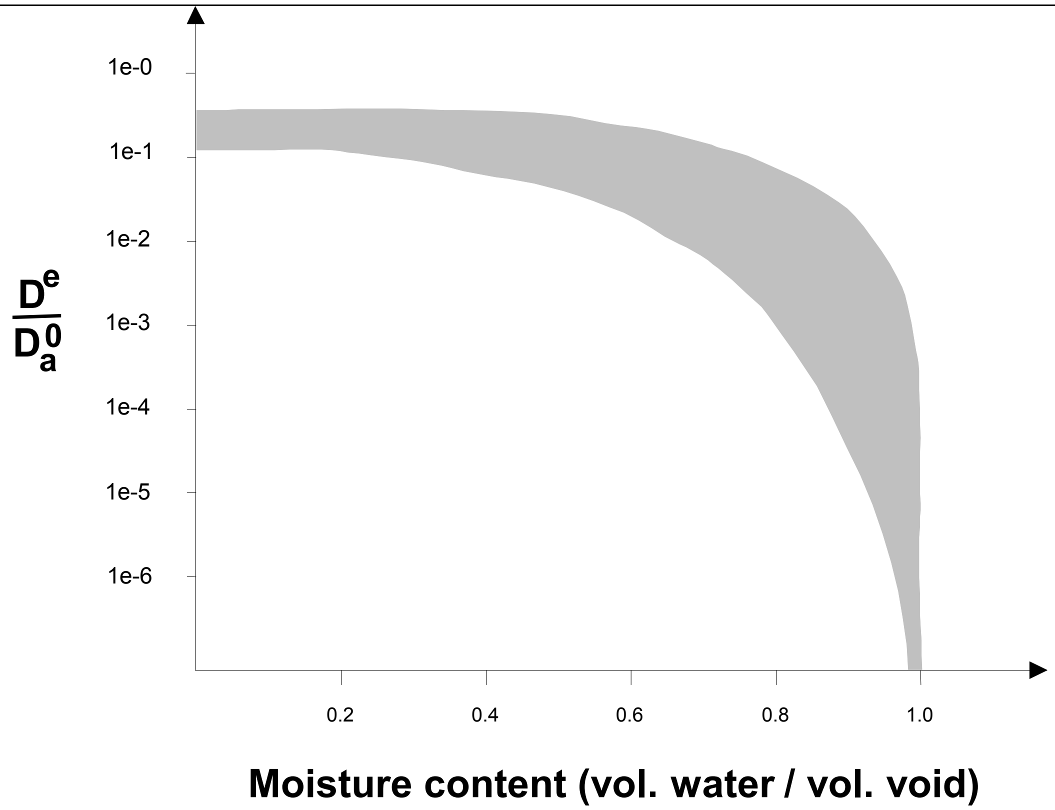
4. Environmental performance and operational data

The typical total thickness ranges between 0.5 m and 3.0 m and the hydraulic conductivity of the impermeable layer is generally < 10^{-9} m/s (see Table 4.29).

Table 4.29: Impermeable soil covers' design and performance from literature sources

Site/references	Cover thickness and materials	Efficiency and reduction mechanisms
Nordic sites (EC-JRC 2009)	1.0-1.5 m of till cover	Decrease the oxidation rate by 80-90 %
Kristineberg (SE) (EC-JRC 2009)	0.5 m of compacted clay and 1.5 m of protective till. Frost penetration to max. 0.9 m.	Oxidation reduction by > 99 %. Water infiltration reduction by > 95 %. Reduction of the amount of metals leaching by > 99.8 %.
Post closure after failure in Aznalcóllar (ES) (EC-JRC 2009)	5 m compacted clay ($k=10^{-10}$ m/s) and 0.5 m protective cover	A stabilising berm put in place. Dam resloped to 3:1 (H:V). Drainage channels built on top.
Decommissioning of the ponds at Saxberget (SE) (EC-JRC 2009)	PAG extractive waste (~ 2 % S, < 1 % Zn and 0.5-1 % calcite). 0.3 m compacted clayey till ($k=5x10^{-9}$ m/s) and 1.5 m protective layer.	
Galgbergsmagasinet Sweden (EC-JRC 2009)	1 m of material with high organic content (paper mill sludge, fly ash and wood waste. $k=5x10^{-9}$ m/s) compacted in two layers of 0.5 m+0.5 m of wood waste and coarse till	Reduction of oxygen infiltration. Inhibition of the acidophilic leaching bacteria. Formation of a favourable. environment for sulphate-reducing bacteria. Risk that the combination of organic compounds and iron hydroxides in the upper part of the deposit could produce bacterial iron reduction that would dissolve co-precipitated heavy metals.
For multilayered covers to reduce acid-rock drainage (Kauppila *et al.* 2013)	≥ 1.5-2 m	
Paste covers with carbonate-containing waste (Kauppila *et al.* 2013)	≥ 1.5-2 m	

Different investigations have demonstrated that the relationship between the diffusion rate and the degree of water saturation is strong and highly non-linear. Figure 4.34 shows the ratio between the effective diffusion coefficient for porous material with a given water saturation and diffusion in air as proposed by Collin, according to the MTWR BREF (EC-JRC 2009).



Source: (EC-JRC 2009)

Figure 4.34: Ratio between the effective diffusion coefficient in a porous partially water-saturated material and diffusion in air

At the Neves Corvo site, the thickened extractive waste deposition cells are rehabilitated by capping with a low-flux cover. Maintaining a final water cover has not been considered sustainable in a semi-arid climate zone. Furthermore, by modelling of the long-term performance of the closed extractive waste deposition area (including the EWF) with paste/thickened extractive waste and a dry cover, it has been evaluated that expected long-term impacts on groundwater generally have the same order of magnitude as those from placing extractive waste back into excavation voids under a free water cover.

Table 4.30 illustrates an example of a multilayer cover with geosynthetics taken from Nordic countries' experience.

Table 4.30: Cover layers in a synthetic multilayer cover structure

Layer	Material (traditional)	Thickness*	Required material properties
Topsoil cover	Vegetation layer, humus soil	≥ 1 m	Surface-erosion-resistant. Sufficient protection against frost.
Filter bed	Sand, gravel, geotextiles	≥ 0.1 m	Filter criteria, strength
Drainage layer		≥ 0.5 m	Hydraulic conductivity k > 10^{-4} m/s. Minimum slope gradient 5 %. Fine-grained material content < 5 %.
Blocking layer	Sand, geosynthetic materials		Grain size distribution and grain shape. Bursting strength.
Artificial barrier liner	Plastic geomembranes, geosynthetic clay liners, bituminous geomembranes	≥ 0.002 m	Resistant to strain caused by differential settlement
Impermeable mineral barrier layer	Clay, silt, moraine, sand-bentonite	≥ 0.5 m	Hydraulic conductivity k < 10^{-9} m/s (infiltration rate 5 %), exception: k < 10^{-8} m/s (infiltration rate 20-25 %). Risk of cracking, chemical changes of the material and settlement of the fill. Dissolution of carbonate minerals.
Filter bed (when needed)	Sand, gravel, geotextiles	≥ 0.1 m	
Primary cover	Natural soil (contaminated soil)	≥ 0.3 m	

** Thickness requirements for landfill; to be used only as indicative.*
Source: Closedure project (Wahlström et al. 2009)

5. Cross-media effects

- Covering material consumption.
- Fuel consumption for the transportation of the materials.

6. Technical considerations relevant to applicability

- Impermeable covers are suitable for covering PAG extractive waste, or extractive waste with the potential to leach metals, cyanides and other contaminants, or for controlling radon emissions from uranium extractive waste.
- Impermeable covers may not be suitable to cover steep heaps due to structural stability issues, demonstrated by a proper geotechnical analysis (see Section 4.2.1.3.6.2).
- The applicability of these covers depends on a variety of conditions such as location, characteristics of the extractive waste, seasonal climatic variations (e.g. freezes/thaws and wet/dry cycles), characteristics and availability of covering materials. The efficiency of a dry cover can decrease in the long term as a consequence of different destructive processes that may cause cracks or other discontinuities in barrier layers. Such processes are erosion, frost action, drying, differential settlement, root penetration, digging animals and man-made intrusion. The risk of cracks increases when the low-hydraulic-conductivity layer is dewatered, thus leading to increased oxygen transport into the extractive waste.
- When geosynthetic materials are used, limiting factors for their applicability are:
    - possible limited design life (50-100 years) for their ageing;
    - geotechnical stability concerns for steep slope applications;
    - possible vulnerability issues such as puncture by surface traffic, cracking due to sunlight, improper seaming, and degradation due to low acidity conditions/cation exchange (GCLs).
- Cover structures consisting of compacted clay layers are applicable with difficulties in cold climates. They can be applied if they are thicker than the freezing depth (INAP 2014h; MEND 2012; Punkkinen *et al.* 2015f).
- The applicability of bentonite layers may be restricted in the case of dry climatic conditions (desiccation cracks formation) or if cation exchange reactions occur.

7. Economics

The following costs are reported in literature for impermeable and low-flux covers:

- The costs of cover construction are highly site-specific. The costs given in literature range from at least EUR 3.1 per m^2 (USD 3.5 per m^2, year 2015) for a relatively simple barrier type (cover system consisting of 300 mm of loose vegetated till over 500 mm of compacted till) to EUR 45 per m^2 (USD 50 per m^2, year 2015) for multilayer complex infiltration-reducing soil covers (Punkkinen *et al.* 2015f). However, most multilayer covers cost at least EUR 9 per m^2 (USD 10 per m^2, year 2015) (Punkkinen *et al.* 2015f). According to Robertson and Shaw (Roberston and Shaw undated), costs for complex covers containing multiple soils usually range from EUR 18 to EUR 27 per m^2 (USD 20-30 per m^2, year 2015) or EUR 0.30 to EUR 0.45 per tonne of waste-rock (USD 0.33-0.50 per m^2, year 2015) (Punkkinen *et al.* 2015f).
- The cost range for complex multilayer soil covers is usually EUR 18-27 per m^2 (USD 20-30 per m^2, year 2015), according to the Closedure project (Punkkinen *et al.* 2015e).
- The cost of the dry cover at the pond in Aznalcóllar was in the order of EUR 27 million (USD 37 million, year 2009) for the project (EUR 22/m^2), according to the MTWR BREF (EC-JRC 2009).
- The cost of dry covers increases if suitable materials are not available near the extractive waste deposition area (including the EWF).

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements.

9. Example sites

- Somincor Neves Corvo Mine (PT)
- Saxberget, Kristineberg, Galgbergsmagasinet (SE) multilayer soil covers
- After the failure of the pond in Aznalcóllar (ES) multilayer soil covers were introduced
- In the Closedure project 2015, the following multilayer soil covers are mentioned: uranium ponds, Pécs (HU) (Mylona *et al.* 2007); Whistle mine, Ontario (Canada) (Ayres *et al.* 2007; MEND 2004); Upshur Mining Complex, Poirier Mine Normetal, Mount Washington, Kam Kotia (INAP 2014h); Kjøli Mine, Waite Amulet, Iron Mountain Mine, P.T. Kelian Equatorial Mining Gold Mine, SPPA Potash Tailings, Spoil Heap in Northern France, Mount Washington, Poirier Mine Site, Weedon Mine Site, Somex Mine Site, Summitville Mine (MEND 2002).

10. Reference literature

(Ayres *et al.* 2007)
(EC-JRC 2009)
(Höglund *et al.* 2004)
(INAP 2014h)
(ITRC 2010i)
(Kauppila *et al.* 2013)
(MEND 2002, 2004, 2012)
(Mylona *et al.* 2007)
(Punkkinen *et al.* 2015e; Punkkinen *et al.* 2015f)
(Roberston and Shaw undated)
(Wahlström *et al.* 2009)

4.3.1.3.4.1.3 Oxygen-consuming dry covers

1. Description

This technique consists of using organic materials for covering PAG extractive waste to consume oxygen and reduce its infiltration.

2. Technical description

This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back. It is relevant for covering PAG extractive waste.

Certain organic materials are capable of forming an oxygen-consuming cover in which the decomposition of organic material generates a significant BOD (INAP 2014h), thus reducing the oxygen concentration at the extractive waste/cover interphase (MEND 1994) and diminishing oxygen transport to the underlying extractive waste, according to the MTWR BREF (EC-JRC 2009). Furthermore, the use of organic material also promotes higher infiltration rates (INAP 2014h), maintaining the material on top of the extractive waste saturated and thus inhibiting the oxygen diffusion.

Different organic waste materials, such as wood waste, peat, sewage sludge, compost, manure, and hay/straw/silage, can be used as oxygen-consuming covers, while ensuring that the use of such covers does not lead to any additional adverse environmental or human health impacts (see Table 1 in Closedure project 2015. Use of organic waste materials in top cover (Punkkinen *et al.* 2015d)).

The ability of the material to retain pore water depends on the material type and its stage of compaction. Naturally, precipitation and evaporation also affect this capacity. The oxygen consumption takes place as a result of bacterial oxidation of organic carbon according to S. Roberston and Kirsten Inc.(MEND 2001a) cited by Punkkinen and co-authors (Punkkinen *et al.* 2015d). Both aerobic and anaerobic degradation processes take place in the biological decomposition of organic material. Decomposition of the organic material in aerobic conditions takes place in the upper part of the layer, while anaerobic conditions prevail in the lower parts of the layer. The different conditions generate an "oxygen trap" that minimises the effects of oxidation of the underlying PAG extractive waste layers (Peppas *et al.* 2000).

A coarse capillary break layer between the organic layer and extractive waste prevents water drainage from the organic structure.

The performance of organic covers depends on the capacity of the material to consume oxygen, the moisture content, the degree of compaction and the chemical stability of the organic layer. The expected lifetime of these covers depends on the rate of decomposition of the organic materials.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Design and planning of the covering structure characteristics.
- *Closure and after-closure phase*
  In the closure phase, construction of the covering structure. Monitoring and control (QA/QC) of the works are carried out.
  In the after-closure phase, the oxygen consuming dry covers are monitored and maintained, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the EWIW generation.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD and the release of heavy metals.

- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - ensuring the long-term stability;
  - preventing or reducing water erosion.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.
- Providing a recycling option for organic wastes.
- Providing a substrate for vegetation.

4. Environmental performance and operational data

The content of organic material in the cover structure needs to be high so that efficient oxygen consumption and transportation can be achieved, according to the MTWR BREF (EC-JRC 2009). The concentrations of oxygen, carbon dioxide, and methane, as well as the moisture content, are monitored.

The long-term efficiency of the oxygen consumption barrier is the single most important thing to consider in the cover design process. If the addition of organic material is not done at regular intervals, the construction of an organic cover is only a short-term solution (Lottermoser 2010). For example, it is estimated that, for covers using wood waste, the effective lifespan is approximately 10 years for a 1 m cover and 50 years for a 2-3 m cover, according to the Closedure project (Punkkinen *et al.* 2015d).

5. Cross-media effects

- Consumption of organic materials.
- Fuel consumption for transporting organic materials if not available close to the extractive waste deposition area (including the EWF).
- Presence of pollutants in the EWIW arising from the organic cover.

6. Technical considerations relevant to applicability

- The oxygen-consuming cover structure is not applicable to certain types of NAG and PAG extractive waste where Dissolved Organic Carbon (DOC) originating from the cover and present in the leachate may increase metal leaching from the extractive waste through complexation reactions.
- It is applicable if organic materials are available close to the extractive waste deposition area (including the EWF).

7. Economics

- Organic oxygen-consuming covers are relatively cheap solutions.

- For example, although the total reclamation costs for the East Sullivan Mine were approximately EUR 6.7-7 million (USD 7.5-8 million, year 2015), the construction of an organic cover was achieved at a very low cost for the mine company, according to the Closedure project (Punkkinen *et al.* 2015d).

- As the organic structure needs regular reapplication and maintenance, the cost can increase significantly. It is also influenced by the distance between the source material and the EWF.

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements.
- Availability of organic materials close to the extractive waste deposition area (including the EWF).

9. Example plants
- Galgberget and Garpenberg Mine (SE), and East Sullivan Mine site in Quebec (Canada), according to the Closedure project (Punkkinen *et al.* 2015d).

10. Reference literature
(EC-JRC 2009)
(INAP 2014h)
(Lottermoser 2010)
(MEND 1994, 2001a)
(Peppas *et al.* 2000)
(Punkkinen *et al.* 2015d)

4.3.1.3.4.2 Permanent wet covers

4.3.1.3.4.2.1 Free water covers

1. Description
A free water cover is a closure method where extractive waste is covered by a free water layer in order to isolate contaminants and reduce erosion, dusting and oxygen infiltration.

2. Technical description
This BAT candidate is relevant for ponds and dams and for excavation voids where extractive waste is placed back. It is relevant for covering PAG extractive waste (ITRC 2010g; Kauppila *et al.* 2013).

The maximum concentration of DO in water is around 30 times lower than in the atmosphere and the oxygen diffusion coefficient is 10^4 times lower in water (at 20 °C) than in air (saturated air, 15 % oxygen). This implies that if a water cover can be established, sulphide oxidation is reduced.

In a shallow water cover (< 2 m), oxygen diffusion can be further prevented by covering the extractive waste with fine-grained till.

PAG extractive waste from mineral processing in contact with air and water may oxidise and produce ARD and dissolved metals. Oxidation of the sulphides can be avoided by permanently depositing the extractive waste under a water cover.

Free water covers may refer to:
- *deposition of extractive waste into constructed ponds, usually with water- and solids-retaining dams (see Section 4.2.1.3.3.1.1.1) and an impermeable basal structure (see Sections 4.3.1.1.1 and 4.3.1.1.2)*;
- *placing back extractive waste into excavation voids covered by water (subaqueous in-pit disposal)*.

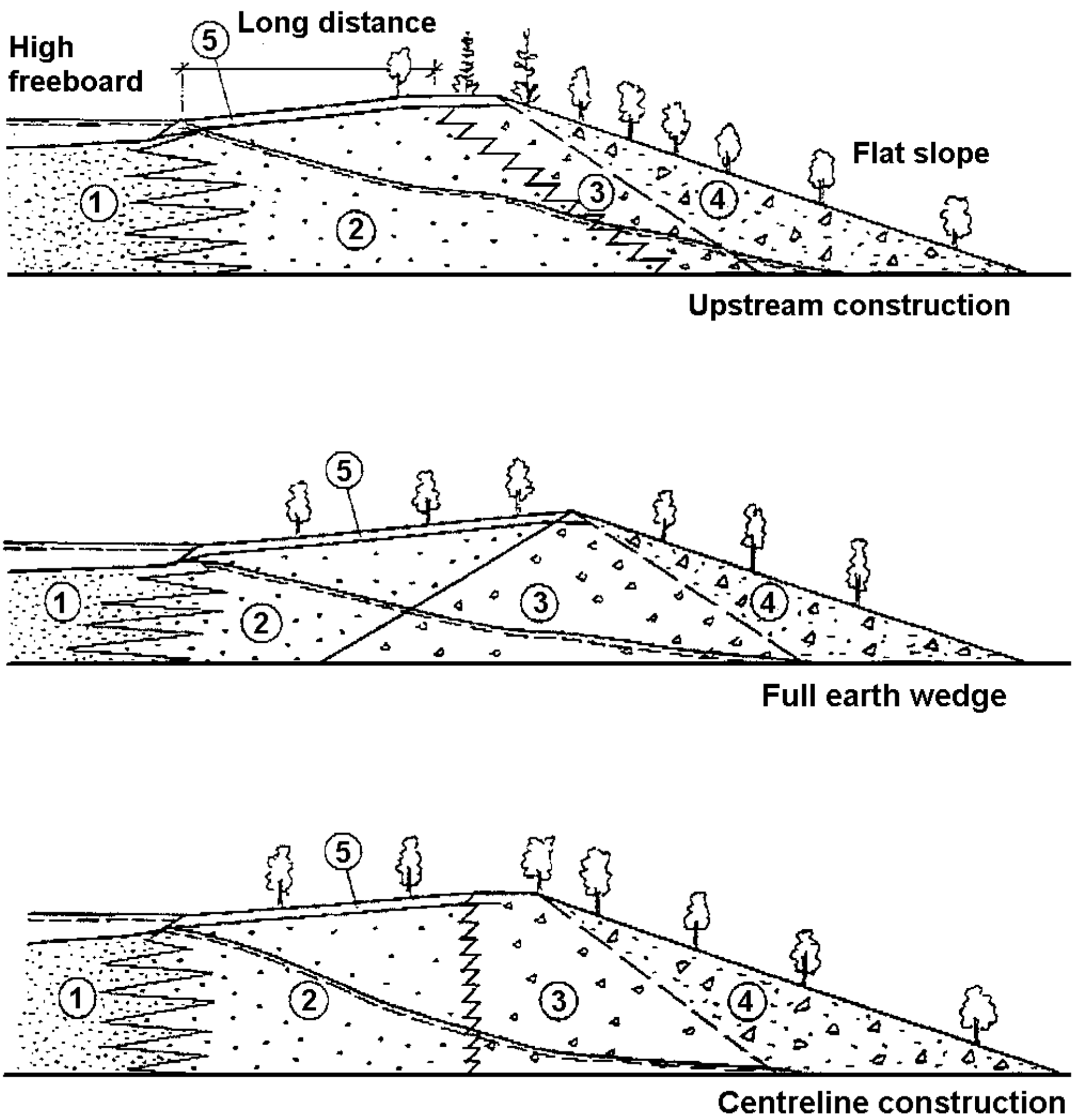
Subaqueous tailings disposal in natural water-containing bodies, including sublacustrine, subriverine and subsea disposal, are not considered free water covers and are not part of this BAT candidate.

In the deposition of extractive waste into constructed ponds, the pond needs to be designed and built to satisfy the requirements for long-term stable dams and to meet the conditions for permanent flooding of the surface. An overflow channel or fitting spillways have to be constructed. Possible contaminated water has to be processed through active or passive treatments. The effects of wave action can be minimised with sufficient water depth and the implementation of wave break structures (MEND 1998).

According to the MTWR BREF (EC-JRC 2009), the following requirements need to be fulfilled for a permanent free water cover:

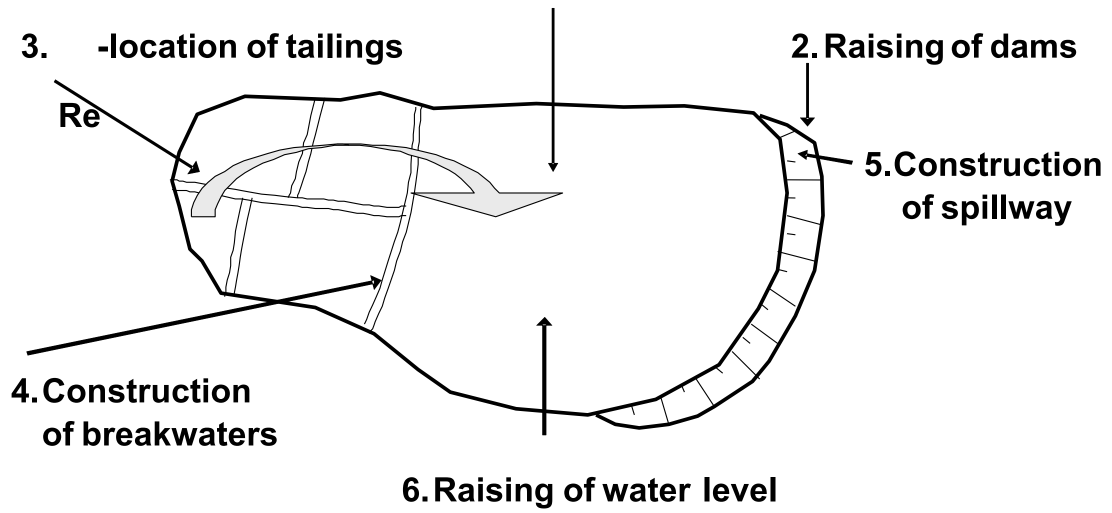
- the refill of water to the pond has to be sufficient to guarantee the water cover and a stable water chemistry at all times;
- the dam has to be stable enough to provide an acceptable level of safety during operation, closure and after-closure (see Figure 4.35);
- a positive water balance, which can guarantee a minimum water depth at all times;
- long-term stable outlets with sufficient discharge capacity even during extreme events;
- a sufficient water depth within the pond to avoid the resuspension of extractive waste by wave action (breakwaters can be used to reduce the required water depth) (see Figure 4.36).

In addition, an impermeable basal structure may be needed to keep the extractive waste water saturated.



NB: Basal structures are not represented in this figure.
Source: (EC-JRC 2009)

Figure 4.35: Dams for permanent water covers: 1. Fine extractive waste from mineral processing, 2. Coarse extractive waste from mineral processing, 3. Support fill, 4. Support fill, long-term stable, 5. Impervious cover and erosion protection



Source: (EC-JRC 2009)

Figure 4.36: Measures implemented at Stekenjokk EWF

Two different variations can be used in the placing back of extractive waste into excavation voids covered by water (MEND 1995):

- *Underwater disposal.* A pit lake or wetland is situated upon the extractive waste placed back into surface excavation voids through the groundwater level increase following cessation of the pumping activity. Surface barriers (fine-grained material) and groundwater barriers can also be also added. A protective layer between extractive waste placed back and bedrock can be installed to mitigate groundwater contamination (Kauppila *et al.* 2013).
- *Elevated water tables.* The surface excavation void is filled up to the original ground surface level. The water table is usually raised above the extractive waste until a clean layer of water covers the extractive waste. In general, the water level is raised by the infiltration of water through the extractive waste. Surface and groundwater barriers (suitable for extractive waste with a low permeability) or impermeable bottom liners (used in areas where the groundwater table is depressed) can be used to prevent infiltrated water from leaving the extractive waste.

In order to constrain the convective outflow and diminish the potential contaminant release, the hydraulic gradient of the water table has to be reduced to near zero across the pit and/or diffusion is made the main transport mechanism (MEND 1995).

The risk of groundwater contamination can be reduced by filling the fractures and gaps between the extractive waste and the bedrock walls with fine-grained rock powder or NAG extractive waste (Kauppila *et al.* 2013).

The technique is applied in all the life cycle phases of the extractive waste management:

- Planning and design phase
  Design and planning of the free water cover.
- Operational (construction, management and maintenance) phase
  Wet covers are implemented during the deposition to prevent oxidation and ARD for example.
- Closure and after-closure phase
  If not already in place during the operational phase, free water covers are adapted to the specifics of the closure phase and implemented.

In the after-closure phase, the free water covers are monitored and maintained, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.
At the closure and after-closure phase, the water reaches its final level.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD and the release of heavy metals;
  - reducing oxygen infiltration.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing or reducing water erosion.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.

4. Environmental performance and operational data

It can be argued that it is not possible to completely eliminate sulphide oxidation since the water cover will always contain oxygen. However, experimental results indicate that the sulphide oxidation rate was negligible at the Stekenjokk EWF. Steady trends of falling sulphate concentrations in the discharge of the pond were observed. After 10 years, the sulphate concentration in the EWIW was close to background values, according to the MTWR BREF (EC-JRC 2009). The performance of the measures applied at Stekenjokk EWF were monitored over 8 years using sulphate as a tracer for sulphide oxidation.

- The analysis indicates that the water cover efficiently reduced the sulphide oxidation rate of the deposited extractive waste. Expressed as the oxygen flux through the water cover to the extractive waste, the upper limit of the sulphate outflow of the pond corresponded to an upper limit of the effective oxygen flux of $1x10^{-10}$ kg O_2/m^2s.
- This was comparable to that obtained from engineered composite dry cover solutions. The water cover was both efficient and cost-effective compared to a dry cover (EC-JRC 2009).

In the case of placing back extractive waste into excavation voids covered by water, high extractive waste volumes can be deposited (ITRC 2010g). However, the swell factor of reactive extractive waste is commonly around 30 % and has to be taken into consideration.

5. Cross-media effects

- Potential release of metals, metalloids and salts from soluble secondary minerals to the groundwater.

6. Technical considerations relevant to applicability

- Free water covers are only applicable to ponds containing PAG extractive waste where the dry cover option is not retained.
- Primary physical design considerations for the applicability of this technique are the long-term physical stability of the dam, including extreme events such as earthquakes, storms and flooding, the water balance management and the water chemistry (MEND 1995, 1998, 2001b). There are space and material restrictions for construction of permanent water-retaining dams (Kauppila *et al.* 2013; MEND 1998).
- The depth of the water layer depends on the surface to be covered (INAP 2014h).
- This method is applicable to new extractive waste deposition areas (including EWFs) or hydraulically separated extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface if:

  - it is demonstrated that the water cover poses lower long-term risks to human health and the environment than a dry cover, through a proper risk and impact evaluation; and
  - hydrological conditions provide sufficient water to maintain a suitable water barrier (see Section 4.2.1.3.4.1).
- The hydrogeology of the excavation voids and the surrounding area play an important role when assessing the applicability of this method. Bedrock should have a low permeability, a minimal groundwater gradient and no significant fractures or faults (Kauppila *et al.* 2013).
- This method is not applicable in the following instances:
  - If the water balance is negative (see Section 4.2.1.3.4.1), e.g. in arid or semi-arid regions, as it is important to reach a stable anoxic state and maintain a water saturation level that will remain continuous and complete (Lottermoser 2010).
  - If secondary minerals can dissolve and worsen the acid-generating potential of the extractive waste. When considering the deposition of oxidised sulphidic waste under water, it has to be taken into account that soluble secondary minerals may dissolve and potentially release metals, metalloids and salts to the water (Lottermoser 2010; MEND 1998).
- Not all surface excavation voids are necessarily appropriate for placing back extractive waste into excavation voids covered by water (Lottermoser 2010; Punkkinen *et al.* 2015a). For example, this technique is not suitable when the surface excavation void is used to access the underground extraction site.
- The depth of the water layer is designed to isolate the extractive waste from the atmospheric oxygen and the wind action. If the water layer is too shallow, an additional isolating layer (e.g. soil layer with low permeability) is needed on the top of the extractive waste.

For additional considerations on the applicability of the method of placing back extractive waste into excavation voids covered by water - see Table 2 in Closedure project, Subaqueous in-pit disposal (Punkkinen *et al.* 2015a).

7. Economics
- Costs of flooding a pond containing extractive waste vary from EUR 0.5 to EUR 1.5 EUR per m^2, depending on the scale and method used, according to the MTWR BREF (EC-JRC 2009).

- For example, the water covers implemented at the Stekenjokk EWF had an investment cost of EUR 1.4 per m^2 (USD 2 per m^2, year 2009) compared to the costs of studied dry covers of EUR 8.6 per m^2 (USD 12 per m^2, year 2009).

The costs of placing back extractive waste into excavation voids covered by water are lower in comparison to dry covers.

- General cost estimates for the placing back of extractive waste into excavation voids covered by water are EUR 1.1-2.2 (USD 1-2, year 2001) per tonne of extractive waste disposed of from excavation and EUR 1.1-3.3 (USD 1-3, year 2001) per tonne of extractive waste disposed of from mineral processing, without including site-specific factors (MEND 2001b).
- The costs can be reduced by starting the placing back of extractive waste into excavation voids covered by water as early as possible during the operation.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements.

9. Example sites
- Stekenjokk (SE)

- Deposition of extractive waste into constructed ponds: Hjerkinn Tailings Pond (NO); Lokken (NO); Equity Silver, British Columbia; Quirke Lake Tailings Test Site, Elliot Lake, Ontario; Solbec-Cubra, Quebec (Canada) - (MEND 1997) as reported in the Closedure project (Larkins 2015)
- Deposition of extractive waste in constructed ponds with material additions to increase chemical and physical stability: Stekenjokk (SE) (sand layer and water breaks). Quirke Lake Tailings Test Site, Elliot Lake, Ontario; Solbec-Cubra, Quebec (addition of lime) (Canada) - (MEND 1997) as reported in the Closedure project (Larkins 2015)
- Placing back extractive waste into excavation voids: Udden (SE) - (MEND 1995) as reported in the Closedure project (Punkkinen *et al.* 2015a). Collins Bay B-Zone, Saskatchewan, and Island Copper, British Columbia; Owl Creek (with alkaline blending), Ontario; Rabbit Lake (with groundwater barriers), Saskatchewan; Solbec (with top barrier), Quebec; Stratapound CNE (with top barrier), New Brunswick; Deilmann (with top barrier), Saskatchewan; Gunnar (flooded pit studies), Saskatchewan and Cluff "D" (flooded pit studies), Saskatchewan (Canada) - (MEND 1995) as reported in the Closedure project(Punkkinen *et al.* 2015a).
  Uranium mines in northern Saskatchewan (Canada) as reported in the SME Handbook (Kerr and Ulrich 2011).
  Robinson, Montana (US) - (MEND 1995) as reported in the Closedure project(Punkkinen *et al.* 2015a)

10. Reference literature
(EC-JRC 2009)
(INAP 2014h)
(ITRC 2010g)
(Kauppila *et al.* 2013)
(Kerr and Ulrich 2011)
(Larkins 2015)
(Lottermoser 2010)
(MEND 1995, 1997, 1998, 2001b)
(Punkkinen *et al.* 2015a)

4.3.1.3.4.2.2 Wet covers

1. Description
The wet cover technique consists of allowing the water to infiltrate the extractive waste, thus forming a wet cap on the top, and adding organic matter, to enhance the establishment of wetland vegetation in the pond.

2. Technical description
This BAT candidate is relevant for ponds and dams and for excavation voids where extractive waste is placed back. It is relevant for covering low-PAG extractive waste or paste PAG extractive waste.

Wet covers allow the water to infiltrate the extractive waste, thus forming a wet cap on the top. Organic matter is added to enhance the establishment of wetland vegetation in the pond.

<u>Wetland establishment</u> as a closure method uses the same principle as the free water cover (see Section 4.3.1.3.4.2.1), but with a reduced water depth, since the plant cover stabilises the bottom, thereby avoiding the resuspension of extractive waste from mineral processing.

It should be noted that in this case the principal idea of a wetland establishment is not the treatment of the water, but the establishment of a self-generating and sustainable cover that reduces the requirements for the water depth and that acts as an oxygen-consuming barrier when organic matter is deposited on top of the water-saturated extractive waste.

The extractive waste deposition area is shaped to collect the rainwater. This method requires the reinforcement of dams in order to endure the annual fluctuations in water level. Furthermore, an impermeable basal structure may be needed (see Sections 4.3.1.1.1 and 4.3.1.1.2) (Kauppila *et al.* 2013).

The technique is applied in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Design and planning of the wet cover.
- *Operational (construction, management and maintenance) phase*
  Wet covers are implemented during the deposition to prevent oxidation and ARD for example.
- *Closure and after-closure phase*
  If not already in place during the operational phase, wet covers are adapted to the specifics of the closure phase and implemented.
  In the after-closure phase, the wet covers are monitored and maintained, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate isolation of extractive waste.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD and the release of heavy metals to soil, groundwater and surface water.
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - ensuring the long-term stability;
  - preventing or reducing water erosion.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting from exposed surfaces of extractive waste.
- Prevention or minimisation of odour emissions from the management of extractive waste.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- Consumption of organic materials.

6. Technical considerations relevant to applicability

- This method is not applicable if the water balance is negative (see Section 4.2.1.3.4.1), e.g. in arid or semi-arid regions.

7. Economics

- Costs of establishing wetlands vary from EUR 0.1 to EUR 1 per m^2, depending on the scale and method used, according to information provided in the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation

- Safety requirements and reduction of failure risks because less water is stored in the pond.
- Legal and environmental requirements.
- Reduced ARD.
- Habitat for species.

9. Example sites

- Several UK coal extractive waste deposition areas (including EWFs), such as Rufford Lagoon No. 8.

- Lisheen (IE) and Kristineberg (considered/planned) (SE)

10. Reference literature
(EC-JRC 2009)
(Kauppila *et al.* 2013)

4.3.1.4 Groundwater and soil pollution remediation techniques

4.3.1.4.1 Permeable reactive barriers

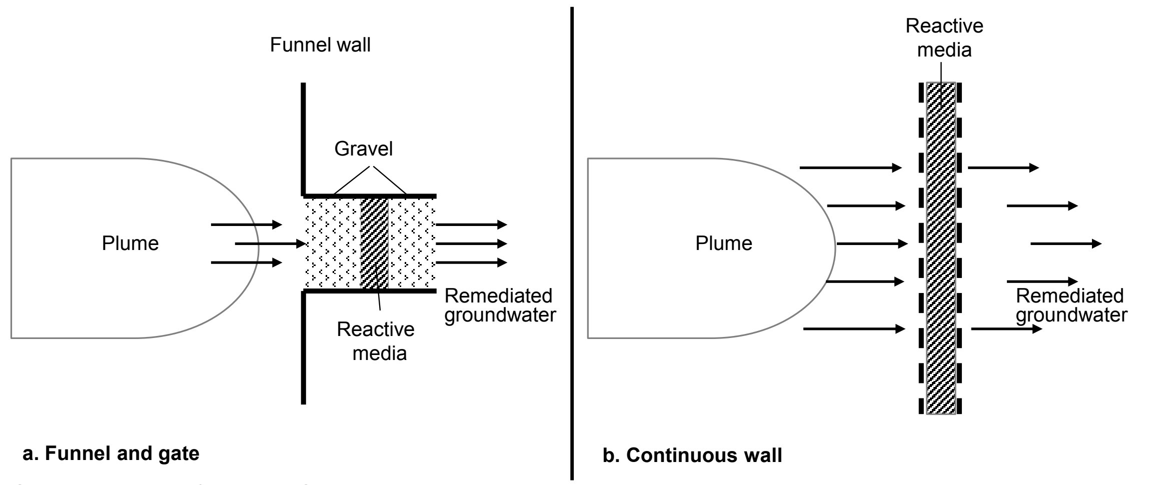
1. Description
This technique consists of a continuous permeable treatment zone to intercept and remediate a contaminant plume. It removes contaminants from the groundwater plume flow in a passive manner by physical, chemical or biological processes.

2. Technical description
This BAT candidate is relevant for PAG extractive waste or for extractive waste with metal leaching potential.

A plume of contaminated groundwater passes through a Permeable Reactive Barrier (PRB), typically under natural pressure conditions, and treated water comes out the other side. The PRBs either directly degrade or immobilise target chemicals in groundwater or change the geochemical conditions of the groundwater system to promote the destruction or immobilisation of the target chemicals.

The most commonly used PRB configurations are the following:
- *Continuous PRBs* transecting the plume flow with reactive media.
- *Funnel-and-gate PRBs* using impermeable walls (e.g. sheet pilings, slurry walls) as a funnel to direct the contaminant plume to a gate containing the reactive media. They have a greater impact on altering the groundwater flow than the continuous ones (see Figure 4.37).
  In both design options, it is necessary to install the PRBs into the bedrock and to keep the reactive zone permeability equal to or greater than the permeability of the aquifer to avoid diversion of the flowing waters around the reactive zone (ITRC 2010j; US EPA 2014).

Other options are available, such as passive collection with reactor cells (see Figure 4.37).



Source: adapted from (ITRC 2010j)

Figure 4.37: Examples of permeable reactive barriers

The treatment zone may be created directly using reactive materials, such as iron (zero-valent iron (ZVI)), or indirectly by using materials designed to stimulate secondary processes, such as by adding carbon substrate and nutrients to enhance microbial activity.

The PRBs are implemented as remediation techniques. They are implemented during the operational and/or closure and after-closure phases. In the planning and design phase, such a technique may be planned as part of the basal structure.

- *Operational (construction, management and maintenance) phase*
  Implementation of PRBs to treat contaminated plumes from extractive waste deposition areas (including EWFs).
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - reducing the contamination of soil and groundwater; examples of pollutants abated are radionuclides, metals and metalloids (As, Cr VI, Ni, Pb, U, Fe, Mn, Se, Cu, Co, Cd and Zn) and anion contaminants (sulphates, nitrates and phosphates) (US EPA 2014);
  - control of pH (ITRC 2010j).

4. Environmental performance and operational data

Example of removal efficiencies obtained by applying PRBs are reported in Table 4.31.

Table 4.31: Permeable reactive barriers' removal efficiencies from literature

Permeable reactive barriers	Materials used	Influent flow concentration (mg/l) and substance	Removal efficiency
Northumberland (UK) (Mäkinen 2015b)	Organic matter Limestone	8 700 sulphate	40 % sulphate 50 % Fe
Aznalcóllar (ES) (Mäkinen 2015b)	Organic matter Limestone Metallic iron	1 100 sulphate	40 % sulphate 47 % Al 80 % Zn 76 % Cu
Nickel Rim (Canada) (EC-JRC 2009; Mäkinen 2015b)	Organic matter Limestone gravel clay (300 mm)	2 400-3 800 sulphate 740-1 000 Fe Up to 10 Ni	21-97 % sulphate 88-99 % Fe Up to 99 % dissolved Ni pH increased from 5.8-7.0
(EC-JRC 2009)	Limestone peat		90 % metals
Uranium extractive waste site in Durango, Colorado (US) (US EPA 2014)	-	0.359 Se	98 % Se
Monticello Mill Tailings site (US) (US EPA 2014)	Zero-valent iron		Successful reduction of U, Va, As, Se, Mb, Ni during the first 4 years
East Helena metal smelting facility - pilot scale (US) (US EPA 2014)	Zero-valent iron	25 As	92 % As

- At the Nickel Rim mine, monitoring was planned to continue for a minimum of 3 years with sampling occurring twice a year.

5. Cross-media effects

- Consumption of raw materials such as iron (ZVI), compost, limestone, zeolites, and granular activated carbon.
- Disposal of treatment media after the concentration of contaminants.

6. Technical considerations relevant to applicability

- Permeable reactive barriers are often intended as an on-site remediation technique and a long treatment period may be required, depending on the size of the contaminated area. They may not be a stand-alone technology and may require additional techniques to improve the environmental performance.
- Permeable reactive barriers can be used for acid and alkaline waters when contaminants can be treated by bacteriological reduction.
- If the PRB involves bacterial activity, the pH is in a range of ~ 5.0-7.0. The pH of ARD is usually lower; therefore the pH has to be raised to achieve sulphide precipitation (e.g. by adding limestone). However, too high a pH precipitates metals, which can result in rapid clogging. Therefore the PRB needs to be well adjusted in order to be effective.
- Permeable reactive barriers are not applicable for the remediation of a contaminated plume with high salt levels.
- Biofouling and mineral precipitation may limit the PRBs' permeability. They can therefore have a limited treatment capacity due to clogging and have to be renewed periodically. The rate of clogging depends on several factors, such as metals and solids concentrations and water amounts.
- The groundwater flow regime and plume location have to be clearly identified to ensure that the water actually flows through this barrier. Moreover, the hydraulic, geochemical and microbial performances of the barrier have to be understood. Column tests are used to assess its longevity. Depending on different site conditions, a lifetime of 10-30 years before any maintenance operations is expected.

7. Economics

- Permeable reactive barriers have high CAPEX (US EPA 2014).

- At the Northumberland site, the CAPEX was approximately EUR 82 625 (GBP 60 000, year 2015) and annual operation and maintenance costs less than EUR 6 885 (GBP 5 000, year 2015). It is not reported if these costs include both the barriers and the additional wetlands, according to the Closedure project (Mäkinen 2015b).
- At Monkstown, Northern Ireland, the total treatment costs for PRBs were EUR 1.06 million (USD 1.4 million, year 2013) (US EPA 2014), divided as follows:
    - 32 % for site investigation;
    - 56 % for applying the technique (three fifths of which were for the installation, a fifth for soil removal and another fifth for design, pilot-scale evaluation and operation);
    - 12 % for groundwater monitoring (of which more than 90 % was for monitoring and the rest for trace tests).
- At the Durango site, treatment costs were ~ EUR 5.9 per m^3 (USD 29.68 per 1 000 gallons, year 2013) treated.
- According to the MTWR BREF (EC-JRC 2009), at the Nickel Rim mine, the CAPEX was approximately EUR 21 600 (USD 30 000, year 2009), including design, construction, materials and the reactive mixture. The construction costs of these kind of barriers are estimated to be ~ EUR 100/m^3. The costs of renewing the materials are estimated to be around the same level.

8. Driving force for implementation

- Legal and environmental requirements.
- Local conditions that require the implementation of a PRB.

9. Example sites

- Northumberland (UK), Aznalcóllar (ES) as reported in the Closedure project (Mäkinen 2015b)
- Nickel Rim (Canada)
- Durango site (Colorado), Monticello Mill Tailings (Utah), Tenmile Creek (Montana) (US) as reported in the Closedure project (Mäkinen 2015b)

10. Reference literature

(EC-JRC 2009)
(ITRC 2010j)
(Mäkinen 2015b)
(US EPA 2014)

4.3.1.4.2 Phytotechnologies

1. Description

This technique consists of using plants to treat or capture contaminants in various media.

2. Technical description

This BAT candidate is relevant for PAG extractive waste or for extractive waste with metal leaching potential.

Phytoremediation mechanisms include:

- extraction of contaminants from soil or groundwater;
- hydraulic control of contaminated groundwater;
- control of water run-off, erosion and infiltration by vegetative covers.

Contamination is removed by phytotechnologies by means of:

- concentration of contaminants in plant tissue, which needs to be properly removed, in particular the aerial part;
- degradation of contaminants by various biotic or abiotic processes;
- volatilisation or transpiration of volatile contaminants from plants to the air;
- immobilisation of contaminants in the root zone.

There are five basic phytoremediation techniques (Table 4.32). They depend on the type of contaminants, the media affected and the containment mechanisms.

Table 4.32: Summary of phytotechnology techniques

Mechanism	Description	Remediation goal
Phytosequestration or Phytostabilisation	The ability of plants to sequester certain contaminants in the rhizosphere through exudation of phytochemicals and on the root through transport proteins and cellular processes.	Containment
Rhizodegradation	Exuded phytochemicals can enhance microbial biodegradation of contaminants in the rhizosphere.	Remediation by destruction
Phytohydraulics	The ability of plants to capture and evaporate water off the plant and take up and transpire water through the plant.	Containment by controlling hydrology
Phytodegradation	The ability of plants to take up and break down contaminants in the transpiration stream through internal enzymatic activity and photosynthetic oxidation/reduction.	Remediation by destruction
Phytovolatilisation	The ability of plants to take up, translocate, and subsequently transpire volatile contaminants in the transpiration stream.	Remediation by removal through plants

Source: (ITRC 2010k)

Phytotechnologies are implemented as remediation techniques. In the planning and design phase, such a technique may be planned as part of the covering structure (i.e. vegetative cover).

- *Operational (construction, management and maintenance) phase*
  Implementation of phytotechnologies to treat contaminated soil or groundwater.
- *Closure and after-closure phase*
  Implementation of phytotechnologies as part of the covering structure to reduce the level of contaminants in the soil.
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - reducing the contamination of soil and groundwater; examples of pollutants abated are metals and metalloids (particularly Cr and Se) and radionuclides (U, Ce and Sr).
- Control of water erosion, run-off and infiltration.
- Restoration and land reclamation that imply benefits for habitat, plants and wildlife.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- Land availability.
- Plants capturing metals or other non-degrading contaminants need to be disposed of.

6. Technical considerations relevant to applicability

- Phytotechnologies are passive techniques, applicable on sites in remote locations. They can be applied as a stand-alone technology or as part of a system of remediation technologies. More time may be required to phytoremediate a site as compared with other, more traditional remediation technologies (US EPA 2014).
- This technique is applicable in combination with covering techniques (see Section 4.3.1.3).
- It is applicable to organic and inorganic contaminants, soil, sediments, surface water and groundwater.
- The applicability of this technique depends on the type, extent and concentration of contaminants, site layout, weather conditions, soil characteristics, hydrological and hydrogeological conditions and maintenance requirements, the appropriateness of the selected plants and their characteristics (i.e. root penetration).
- The applicability may be restricted in the case of seasonality of plant growth, pests, infestations, a limited availability of water for irrigation, high salt levels, a very low pH and a high sodium content (US EPA 2014).

7. Economics

- Phytotechnologies require significant operation, maintenance and monitoring for several years after planting. Costs for irrigation, fertilisation, weed control and pest control have to be considered. As a general rule of thumb, 10-15 % of the initial CAPEX is usually added as a contingency for replanting (ITRC 2010k).

8. Driving force for implementation

- Risk prevention.
- Local conditions.

9. Example sites

- Phytosequestration: Ely Copper Mine, VT; Magmont Mine, MO; Black Butte Mercury Mine, OR; Valzinco mine, VA; Copper basin, TN; Annapolis Lead Mine Site, MO; UP Mines, MI (US) (ITRC 2010k)
- Phytohydraulics: Kerramerican NPL, ME (US) (ITRC 2010k)
- Phytosequestration, phytohydraulics: Gribbons Basin, MI; Sequatchie Valley Coal Mine, TN; Bark Camp, PA (US) (ITRC 2010k)

10. Reference literature

(ITRC 2010k)
(US EPA 2014)

4.3.1.5 Monitoring of emissions to soil and groundwater

4.3.1.5.1 Techniques to model emissions to soil and groundwater (seepage)

No specific candidate technique for modelling was identified, even though modelling of seepage into the soil and groundwater was reported by several operators.

Different models (1D, 2D or 3D) can be used for this purpose.

When carried out, operators participating in the questionnaire exercise reported modelling of seepage as part of the EIA.

Additional information can be retrieved from:

- VTT guidelines for mine water management (Punkkinen *et al.* 2016);
- USGS website:
  - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations: http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/
  - Geochemical characterisation of seepage and drainage water quality from two sulphide mine tailings impoundments: AMD versus Neutral Mine Drainage (NMD): https://pubs.er.usgs.gov/publication/70035862 (Heikkinen *et al.* 2009)
- North-West University website:
  - Development of a geochemical model to predict leachate water quality associated with coal mining practices: https://repository.nwu.ac.za/handle/10394/15731 (Van Zweel 2015)

4.3.1.5.2 Techniques to monitor emissions to soil and groundwater

1. Description

This technique consists of identifying the possible emission sources and monitoring the emissions to soil and groundwater, including monitoring of groundwater characteristics and quality and monitoring of soil quality, and the efficiency of the measures applied for prevention and reduction of these emissions.

2. Technical description

This BAT candidate is relevant for non-inert extractive waste.

Monitoring of the groundwater table level is also relevant for inert waste if it can affect the structural stability of the extractive waste deposition area (including the EWF).

The site-specific geological and hydrogeological conditions determine the monitoring requirements rather than the size of the extractive waste deposition area (including the EWF).

A monitoring plan for emissions to soil and groundwater includes the following activities:

- Identification of the possible emission sources. This may include modelling of diffuse emissions to soil and groundwater, which also encompass fugitive emissions (such as leakage). Results from the water balance analysis may be considered (see Sections 4.2.1.3.4.1 and 4.2.1.3.4.2).
- Planning the monitoring of emissions to soil and groundwater and reviewing and verifying the efficiency of the measures applied for prevention and reduction of these emissions. This may include:
    - o the monitoring of the groundwater characteristics together with the groundwater quality; and/or
    - o the monitoring of soil quality, particularly in the vadose zone.

Monitoring parameters and frequencies are properly selected according to the site-specific conditions (particularly geological and hydrogeological conditions, considering also seasonal variations, possible rates of dispersion and the environmental hazard of contamination), with particular regard to the potential risk of groundwater status deterioration and soil pollution, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions.

If the emissions to soil and groundwater from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed.

Monitoring is planned in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.

The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.

Monitoring of groundwater is performed by means of specific wells drilled for the purpose of monitoring or by using existing wells.

Predictive modelling tools may be used to complement the monitoring of emissions to soil and groundwater.

Monitoring of soil and groundwater is planned in the design phase and implemented in the operational and closure and after-closure phases.

- *Planning and design phase*
  A monitoring plan is set up.
- *Operational (construction, management and maintenance) phase*
  The monitoring plan is implemented and adapted based on the monitoring findings.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:

  - determining whether the implemented measures are effective or if additional corrective measures are necessary to prevent or minimise groundwater status deterioration and soil pollution.
- Prevention and reduction of negative environmental impacts from the management of extractive waste. Optimisation of the extractive waste management and treatment strategies.
- Mitigation of accidents.
- Ensuring a high level of protection of the environment as a whole.
- Maintaining the appropriate operation, closure and after-closure of the extractive waste management site.

4. Environmental performance and operational data

Table 4.33 shows the reported monitoring parameters and frequencies for emissions to soil and groundwater (based on input received via the information exchange process, including via the questionnaires). Monitoring frequencies and parameters may also depend on legal requirements which are not part of the scope of this work.

Table 4.33: Reported monitoring parameters and frequencies for emissions to soil and groundwater (based on input received via the information exchange process, including questionnaires)

Reported monitoring parameters	Reported frequencies
Emissions to groundwater	
Groundwater characteristics*: - table level - flow velocity and direction**	Monthly to yearly
Groundwater quality	Monthly to yearly
Composition of seepage	Quarterly to yearly
Emissions to soils	
Soil quality	Every 6 months to 5 years

** Groundwater characteristics are monitored downstream of the extractive waste deposition area(s) (including the EWF) and around it.*

*** Groundwater flow velocity and direction are measured in at least 3 wells (one up-gradient and two down-gradient) intercepting the same aquifer.*

Groundwater quality parameters are, for example, temperature, electrical conductivity, pH, and redox potential. Dispersion of pollutants is usually accompanied by changes in electrical conductivity, pH or redox potential (e.g. leakage of brines). Instruments which log these parameters continuously and send their data to a central computer can serve as early warning systems for detecting pollution dispersion.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- The cost of groundwater sampling and analysis ranges from a few tens of euros to a few hundred euros depending on the analysis complexity. A cost of EUR 200/m for drilling and casing a groundwater monitoring well is reported in the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements.
- Surveillance and early warning.

9. Example sites

- Generally applied in Europe. Groundwater monitoring is carried out on in many sites that participated in the questionnaire exercise (36 sites out of 87).

10. Reference literature

(EC-JRC 2009)
(Kauppila *et al.* 2013)

4.3.1.5.3 Techniques to detect seepage to soil and groundwater

1. Description

This technique consists of identifying the seepage by using leakage detection systems underneath an impermeable basal structure, seepage detection systems underneath permeable basal structures, leakage detection systems for the temporary storage of drilling muds and other extractive wastes from oil and gas exploration and production and/or in control wells.

2. Technical description

Leakage detection systems underneath an impermeable basal structure are relevant for ponds, dams and heaps. They are relevant for non-inert extractive waste from excavation and non-inert extractive waste from mineral processing.

Seepage detection systems underneath permeable basal structures are relevant for ponds, dams and heaps. They are relevant for non-inert extractive waste from excavation and non-inert extractive waste from mineral processing.

Leakage detection systems for the temporary storage of drilling muds and other extractive wastes are relevant for drilling muds and other extractive wastes from oil and gas exploration and production.

Control wells are relevant for non-inert extractive waste from excavation and non-inert extractive waste from mineral processing. They are relevant for drilling muds and other extractive waste from oil and gas exploration and production.

In order to prevent and control the emissions to soil and groundwater, the following techniques are implemented to detect the seepage:

- <u>leakage detection systems underneath an impermeable basal structure</u> (manual or automatic); or
- <u>seepage detection systems underneath permeable basal structures</u> in the case of existing EWFs (e.g. at the Boliden Tara Mines flowmeters are used); or
- <u>leakage detection systems for the temporary storage</u> of drilling muds and other extractive wastes from oil and gas exploration; or
- <u>control wells</u> (usually in piezometric wells).

Seepage detection systems are implemented in the life cycle phases of the extractive waste management listed below:

- <u>*Planning and design phase*</u>
  Seepage monitoring systems, such as leakage detection systems underneath an impermeable basal structure, control wells and leakage detection systems for the temporary storage of drilling muds and other extractive wastes from oil and gas exploration and production, are included in the design.
- <u>*Operational (construction, management and maintenance) phase*</u>
  Planned detection systems are constructed during the operational phase and monitoring and control of works is carried out (QA/QC).
  In the case of existing permeable basal structures, seepage detection systems underneath these structures are implemented in the operational phase.

In some cases, additional seepage detection systems, such as control wells, can be implemented in the operational phase.

- *Closure and after-closure phase*
  Seepage monitoring is usually carried out in the closure and after-closure phase.
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - o supporting the monitoring of emissions to soil and groundwater.
- Prevention and reduction of negative environmental impacts from the management of extractive waste.
- Mitigation of accidents.
- Ensuring a high level of protection of the environment as a whole.
- Maintaining the appropriate operation, closure and after-closure of the extractive waste management site.

4. Environmental performance and operational data

The number of monitoring points and the monitored parameters will depend from site to site depending on potential contaminants.

According to the site-specific data reported by operators via the questionnaires, the total number of monitoring points varies widely, from 1 to 1 994, with a median value of 6 monitoring points per EWF.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- Leakage detection systems underneath an impermeable basal structure are designed in a way that allows proper maintenance. In some cases, this may imply positioning the detectors in the close vicinity of a large structure, on the expected downstream pathway of the seepage, rather than directly underneath a structure where maintenance is impossible. Leakage detection systems underneath an impermeable basal structure are only applicable to new extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EFWs) that will cover new land surface.
- Seepage detection systems underneath permeable basal structures are applicable to existing permeable basal structures. They are not applicable if installation of the seepage detection system underneath the permeable basal structures is technically unfeasible.

7. Economics

- No information provided.

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements.
- Surveillance and early warning.

9. Example sites

- Generally applied in Europe.

10. Reference literature

(EC-JRC 2009)

(Stuart 2011)

4.3.2 Techniques to prevent or minimise surface water status deterioration

4.3.2.1 Techniques to prevent or minimise Extractive Waste Influenced Water generation

4.3.2.1.1 Re-use or recycling of excess water in the extraction, mineral processing and/or extractive waste management

1. Description
Re-use (without treatment) or recycling (after treatment) of excess water in the extraction, mineral processing and/or extractive waste management.

2. Technical description
This BAT candidate is relevant for excess EWIW.

The water used for the management of extractive waste (e.g. water used for the transport) and the water in contact with the extractive waste and collected (e.g. drainage water and water run-off from the extractive waste deposition sites) are generally collected in ponds or tanks for further re-use or recycling.

Usually, excess water from the management of extractive waste is stored in a pond called a reclaim, sedimentation, settling, clarification, decant, polishing and/or regulation pond.

The excess water may be recycled or re-used in the extraction or mineral processing plant (if water is used in the process) or extractive waste management, with or without treatment (depending on the water quality and technical requirements), thereby also reducing the overall consumption of water.

Drainage water and water run-off from the EWF are collected in trenches or channels and pumped back into the reclaim pond whereas excess water is collected after natural decantation/settling of solid particles.

The excess water management requires specific techniques to ensure the safety and stability of the EWF (see Section 4.2).

Re-use/recycling of excess water is planned in the design phase and implemented in the operational phase:

- *Planning and design phase*
  Planning and design of the water re-use/recycling: e.g. integrated water management plan, planning and design of the facilities to collect excess water, transport it and, if necessary, treat it.
- *Operational (construction, management and maintenance) phase*
  Excess water from the management of extractive waste is re-used or recycled.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
    - preventing or minimising the EWIW generation;
    - reducing the volume of water intakes (raw water);
    - reducing the volumes of discharged EWIW.
- Reduction of reagents consumption for the mineral processing.

4. Environmental performance and operational data

Re-use or recycling of excess EWIW may considerably reduce water intakes for the mineral processing and for the management of waste, e.g. the transport of extractive waste into the EWF.

Based on the data provided by operators, up to 100 % of the reclaimed water can be re-used/recycled.

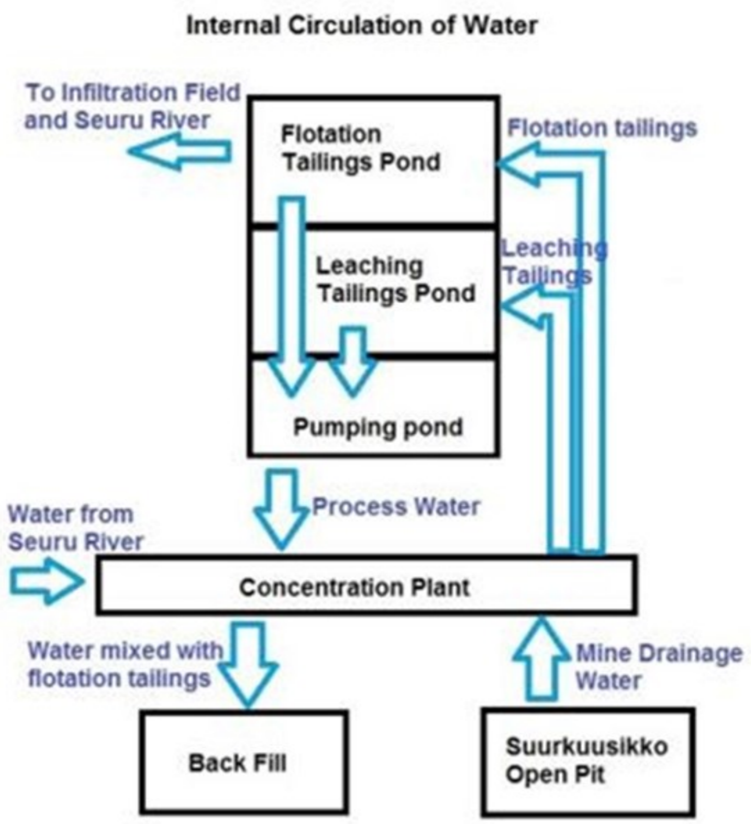
If the excess water does not meet the quality requirements set for the intended use, e.g. as process water, treatment techniques are used to promote recycling of excess water (see Sections 4.3.2.2.2 to 4.3.2.2.6).

Nevertheless, an environmentally sound treatment of the water to maintain the required water quality is not always possible.

From the data provided by operators on water management, it has been observed that in some cases 70 % of the EWIW collected is discharged, e.g. EWIW with a high salt content.

Higher re-use/recycling rates have been observed at sites where the EWIW can be returned to a water-using process such as froth flotation.

At the Kittilä Mine, for example, the internal water is recirculated between the concentration processes, the EWF, the leaching pond and the extraction site. Fresh water intake is pumped from a nearby river to the concentration plant. Part of the water is used for the concentration plant and for placing back extractive waste into excavation voids (see Figure 4.38). Part of the process water evaporates in autoclaves, the rest is discharged with extractive waste from mineral processing into a pond containing extractive waste produced by the flotation process and a pond containing extractive waste from the leaching process. The water from the leaching pond and part of the water from the flotation pond are pumped back to the process. Only the excess water from the EWF is pumped to natural peatlands and eventually discharged to a receiving surface water body.

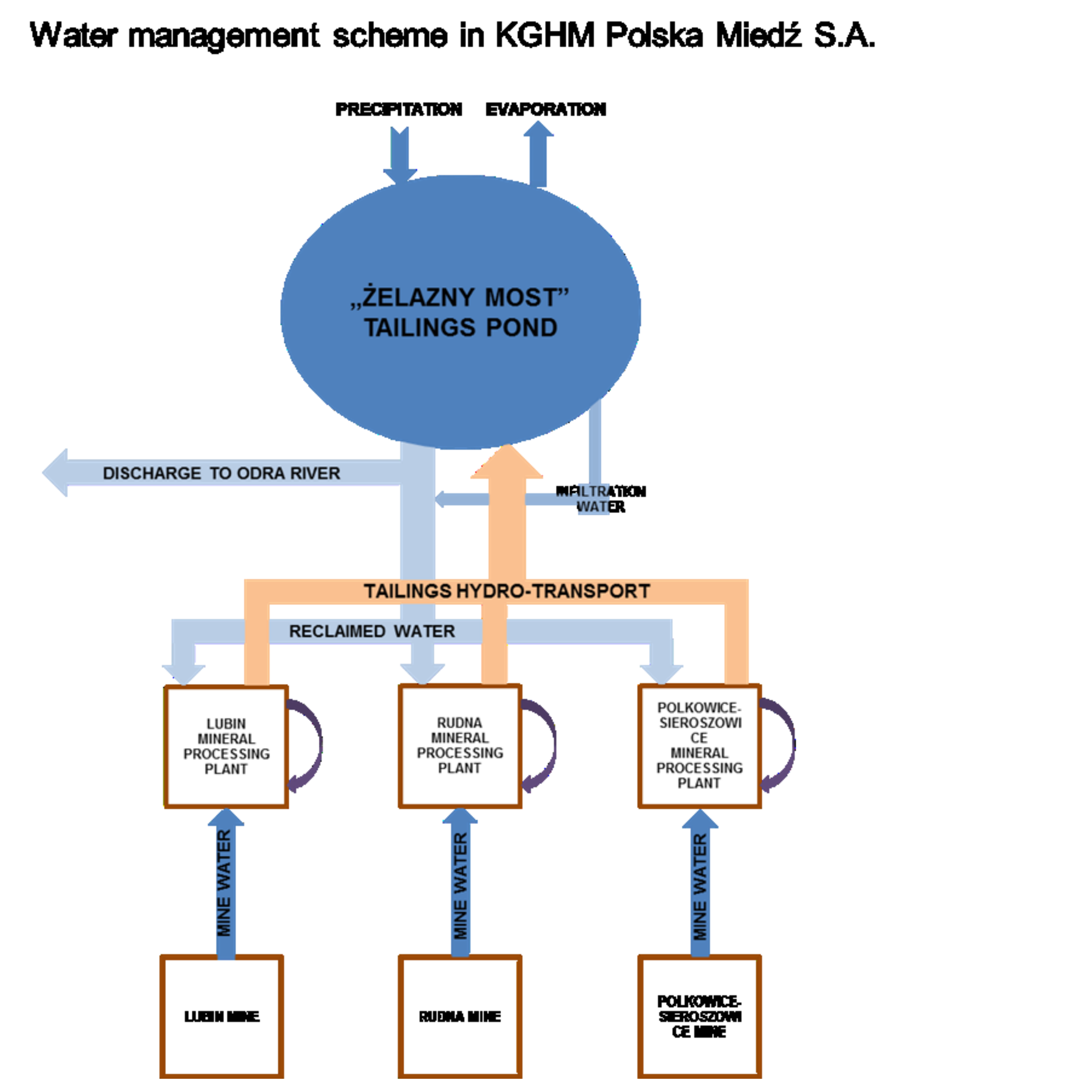


Source: Kittilä Mine questionnaire

Figure 4.38: Flowsheet of the water recirculation process at the Kittilä Mine

Another example is provided by the KGHM Polska Miedź S.A Żelazny Most site, where the decant water and drainage water from the pond are returned to the mineral processing plants (flotation processes) (see Figure 4.39). KGHM Polska Miedź S.A. owns three underground copper mines, in the Legnica-Głogów copper basin. A concentration plant is operating at each of the extraction sites, Lubin, Polkowice-Sieroszowice and Rudna. Each concentration plant is composed of a crushing station, a grinding station, a flotation station, a concentrate dewatering station and a pumping station. About 60 000 m^3 of salty mine water is pumped to the surface per day. Depending on the depth of the extracted ore, the water contains from 0.2 g/l to 140 g/l of Cl^- and ~ 2.8 g/l of SO_4^{2-}.

On the surface at each mining and mineral processing site, a water collection system is in place and rainwater, cooling water overflows and mine water pumped to the surface are collected in retention tanks. From the tanks the water is pumped to flotation circuits (in some cases the mine water is pumped directly to the flotation circuits). The water is kept in closed systems and used for hydro-transporting the extractive waste from mineral processing to the pond. As the water system is continuously supplied with mine and rainwater, excess water needs to be removed. The discharge into the Oder river is done using a 20 km long pipeline. The water flows gravitationally and is discharged into the Oder river through a perforated pipe located on the river bed, which allows relatively quick mixing. The amount of water discharged is strictly controlled.



Source: KGHM Polska Miedź S.A., Żelazny Most tailings pond questionnaire

Figure 4.39: Flowsheet of the water recirculation process at KGHM Polska Miedź S.A.

5. Cross-media effects

- Consumption of energy (e.g. treatment and pumping) and reagents for water treatment, if recycling is required.

6. Technical considerations relevant to applicability

- The applicability of re-use and recycling of excess water depends on both the water quality and technical requirements.
- It is applicable to the extent that the re-use of water or the environmentally sound treatment in the case of recycled water can maintain the accumulation of reagents/components below a level where any negative interference with the process remains acceptable.
- Re-use/recycling of excess EWIW in hot or arid climates, where free water from ponds mainly evaporates, may be limited.

7. Economics

- According to the MTWR BREF (EC-JRC 2009), the main operational cost of the circulation of process water is the pumping cost. Pumping water back varies from EUR 0.04 to EUR 0.33 per tonne of extractive waste from mineral processing.

- At Minas de Aguas Teñidas:
  The CAPEX for the water treatment plants and the distribution system was EUR 20.8 million for a treatment capacity of 4.4 Mt/year. The reported OPEX was EUR 1.8/m^3.

8. Driving force for implementation
- Compliance with the waste hierarchy principles; to prevent, re-use, recycle and subsequently reduce the amount of waste produced.
- Efficient use of materials.
- Legal and environmental requirements, according to the Water Framework Directive and, in some cases, to local legislation.
- Economic benefits: reduction of costs and optimisation of the integrated water management.

9. Example sites
- LKAB Malmberget Iron ore Mine (SE)
- Minas de Aguas Teñidas (ES). Integrated water management system (two water treatment plants, a water distribution system and three regulatory ponds)
- Yerakini Mine (EL)
- Somincor Neves Corvo Mine (PT), subaerial thickened extractive waste deposition.
- KGHM Polska Miedź S.A., Żelazny Most tailings pond (PL)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Kevitsa Mine (FI)
- Kemi Mine (FI)

10. Reference literature
(EC-JRC 2009)
(Kinnunen *et al.* 2015)
(Kyllönen *et al.* 2015)
(Pöyry 2011a, b)

4.3.2.1.2 Diversion of water run-off systems during operation

1. Description
This technique consists of including diversionary structures in the perimeter of the pond or heap to prevent clean natural water run-off from coming into contact with extractive waste. These structures range from simple run-off diversions to highly complex engineered surface and subsurface structures.

2. Technical description
This BAT candidate is relevant for ponds, dams and heaps.

Contact between natural water run-off and extractive waste is limited as far as possible. Construction of diversionary structures and isolation of waste from water by using a covering structure, as described in Section 4.3.1.3, can considerably reduce the amount of water whose quality and chemistry might be influenced by contact with extractive waste (EWIW).

Ponds and dams
Diversion of natural water run-off is critical to the safety of a dam retaining extractive waste and has to be designed in order:
- to maintain the necessary freeboard; failure of any part of the dam can lead to the pond receiving floods for which it was not designed, possibly causing overtopping with a risk of total failure of the dam;
- to avoid contamination of the natural water run-off with process liquids or chemicals;
- to reduce the volume of water in those ponds relying on evaporation, to remove excess water rather than to treat and discharge it;

- to ensure dry deposit conditions in the case of paste or thickened extractive waste deposition methods.

According to the MTWR BREF (EC-JRC 2009), there are several types of *diversionary structures*:
- *engineered channels* above and around the dam, conduits underneath the dam, tunnels through the side of the dam or other structures to divert natural external run-off;
- *engineered slurry walls*, *sheet pile walls*, *grouting or other subsurface structures* to divert or contain groundwater.

Surface water run-off retention systems are usually included above the upstream dam. If it contains a large amount of fines, the collected natural surface run-off is diverted into segmented pond(s) for clarification before discharge.

<u>Heaps</u>
The MTWR BREF (EC-JRC 2009) reports the following:
- Water is by far the most likely cause of instability in an extractive waste heap and its foundations since it may lead to increased pore pressure and a reduction in shear strength. Therefore, anything that tends to increase the amount of water or pore pressure in a heap and its foundations is a potential source of instability. Particular attention is given to drainage around the heap in order to divert the natural water run-off, to prevent the flow of groundwater into the heap and to prevent ponding of water at the heap toe. On sloping ground, drains are usually constructed near the uphill side of the facility.
- For calculating the capacity, the following factors are taken into account: the catchment area uphill of the drain, the existence of springs, the agricultural drains and natural surface water flows which may come into contact with the heap.
- At "potash heaps", the brine (saline water) draining from the heap is kept separated from surface water run-off.

The technique is applied in the life cycle phases of the extractive waste management listed below:
- <u>*Planning and design phase*</u>
  Diversion of water run-off is designed and planned in the design phase of the extractive waste management.
- <u>*Operational (construction, management and maintenance) phase*</u>
  During the operational phase, diversion of water run-off is carried out. Monitoring and maintenance are also carried out.

3. Achieved environmental benefits
- Helping to ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF) by:
  - preventing water erosion, which would negatively affect the structural stability of the extractive waste deposition area (including the EWF);
  - preventing an anomalous presence of phreatic surface or infiltrated water within dams or heaps, which would negatively affect the structural stability of the extractive waste deposition area (including the EWF).
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate water collection.
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the generation of EWIW to be discharged.

4. Environmental performance and operational data
- At the <u>Dunka mine</u>, shallow ditches (2 m) and one deep channel (18 m deep excavated through the bedrock) have been constructed to divert water run-off from the extractive waste. This reduced the watershed influencing the heaps by up to 54 % (ITRC 2010l).

- At the Copper Hill mine, a settling pond has been designed to collect surface run-off sometimes overflowing during high-precipitation events. Surface water run-off was collected and diverted away from the EWF using a concrete trench. This diversion resulted in a 90 % decrease in spillage from the pond when compared to the previous year (ITRC 2010l).

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- Diversion of water run-off is applicable in combination with water balance analysis (see Section 4.2.1.3.4.1) and a water management plan (see Section 4.2.1.3.4.2).
- Diversionary structures can be applied over a wide range of sites, ranging from simple run-off diversions to highly complex engineered surface and subsurface structures.
- They are applicable to a wide range of flow rates. Their choice depends on site topography and expected flow rates.
- In some cases, they cannot be used as a stand-alone remediation technique, particularly where interaction between water and extractive waste cannot be completely avoided through the diversion of the upstream clean water. In this case, diversionary structures are commonly applied in combination with other treatment technologies (ITRC 2010l).

7. Economics
- Costs are primarily associated with capital costs for system design and construction and periodic maintenance.
- At the Bingham Canyon Mine, the large-scale system, including construction of the concrete cut-off walls, the capital costs were more than EUR 37 million (USD 50 million, year 2010) (ITRC 2010l).
- At the Dunka Mine, the costs for construction of a large ditch (18 m deep in the bedrock) amounted to more than EUR 0.45 million (USD 0.6 million, year 2010).
- Diversionary structures can reduce the generation of EWIW that requires treatment; therefore remedial costs may be substantially reduced over time (ITRC 2010l).

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements.
- Economic benefits from diverting water from the pond containing extractive waste.
- Avoiding costs from catastrophic events.

9. Example sites
- Kemi Mine (FI)
- Leviathan Mine, Dunka Mine, Copper Hill, Mine Bingham Canyon Mine (US)

10. Reference literature
(EC-JRC 2009)
(ITRC 2010l)

4.3.2.1.3 Covering techniques

See Section 4.3.1.3.2 on temporary covers.
See Section 4.3.1.3.3 on vegetative covers.
See Section 4.3.1.3.4.1 on permanent dry covers.

4.3.2.1.4 Landscaping and geomorphic reclamation

1. Description

Landscaping and geomorphic reclamation are techniques used to recreate the shapes and functionality of the natural landscapes. They are used to reduce the visual impact and emissions to surface water and groundwater, but also to control wind erosion and noise emissions, as the slopes of the extractive waste deposition areas (including EWFs) are reshaped to simulate natural heaps while optimising the extent of re-engineering works.

2. Technical description

This BAT candidate is relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back.

The landscaping technique may consist of constructing heaps by first creating their outer slope and then transfer ramps and working benches into the heap's inner area. The EWF slopes are then reshaped to simulate a natural landform while optimising the extent of re-engineering works. It may also serve for wind erosion prevention and noise reduction (see Section 4.4.1).

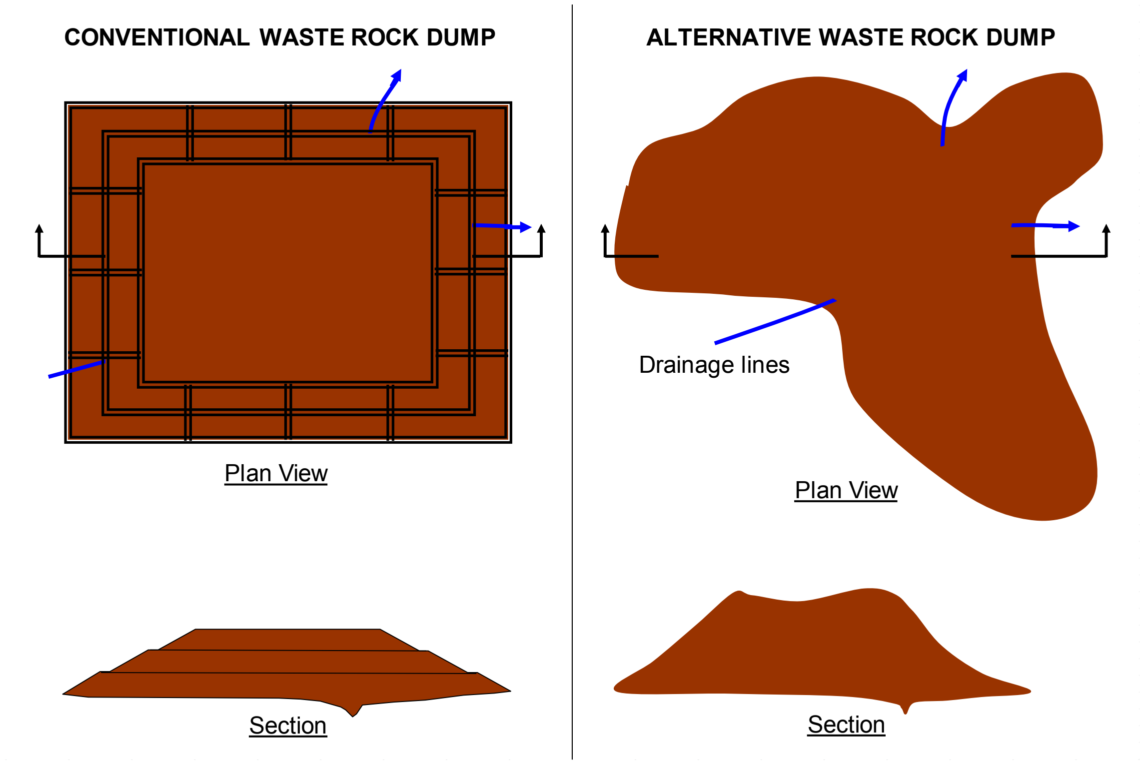
Any landscaping and geomorphic reclamation is designed in such a way that any confining function is not impaired and that short- and long-term geotechnical stability is not reduced (see Section 4.2.1.3.6.1 and Section 4.2.1.3.6.2).

For geomorphic reclamation, excavation and rehabilitation processes are integrated, which offers maximum earth movement savings. Thus, placement of the generated extractive waste is planned to coincide with the geomorphic reclamation landforms, i.e. valleys or ridges, according to the geomorphic design and following progressive rehabilitation. Therefore, a general reclamation landform shape emerges as the excavation process progresses.

Landscaping and geomorphic reclamation are used to reduce the visual impact, but furthermore they increase the physical stability, provide a natural hydrological function, minimise erosion from storm water and snowmelt run-off, provide a natural landform variety that promotes ecological diversity for vegetation and wildlife communities, and minimise construction and short- and long-term maintenance and repair costs.

Landscaping and geomorphic reclamation of a waste-rock deposit is aimed at reconstructing a similar distribution of slope angles and lengths, drainage patterns and density, surface textures and vegetation patterns to those that either existed before the EWF construction or that replicate a suitable shape similar to the local environment. Outside their upper convex shapes, most of the length of natural slope profiles is typically concave, as this is the profile for long slopes with less erosion. If the waste-rock has been deposited in layers with benches between lifts, a concave slope can be readily constructed in the after-closure phase. Final deposit landforms can better match natural landforms if this consideration has been included in the design since the planning phase.

Natural landscapes are a 3D arrangement of drainage networks and convex/concave slopes.
Figure 4.40 shows schematically the contrast between a conventional waste-rock deposit layout and an alternative layout that takes into account the pre-existing drainage lines and natural shapes (Williams 2014).

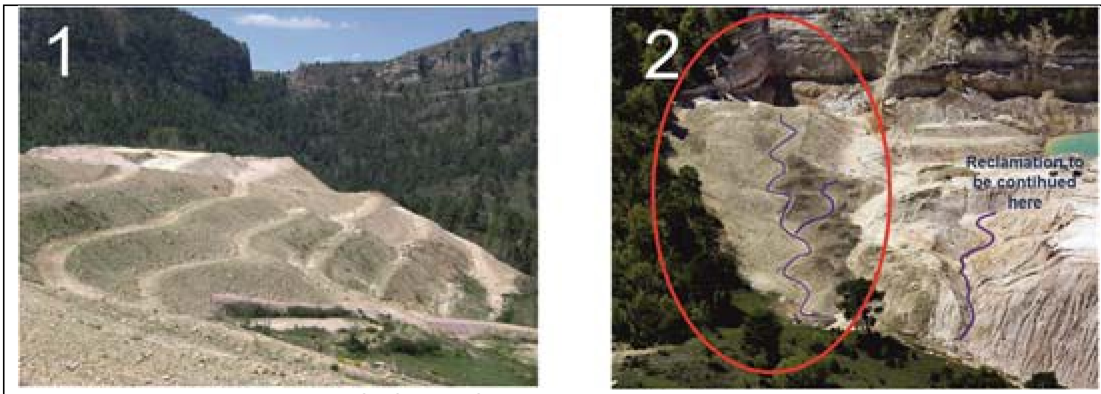


Source: (Williams 2014) with permission of Prof. Williams

Figure 4.40: Scheme of a conventional layout and example of an alternative layout for waste-rock deposit rehabilitation

Specific patented methods of landform design based on fluvial geomorphic concepts as well as soil erosion and landscape evolution models are available worldwide for obtaining an optimum and stable landform design.

Extractive waste heaps reclaimed with this technique can become functional watershed systems like the ones that develop spontaneously in nature. The drainage patterns of undisturbed lands are reproduced. Instead of the uniform terraces and linear slopes, geomorphic landforms provide complex surfaces, with ridges and valleys, and S-shaped slopes. Small drainage paths are created and they converge to natural-looking meandering channels.

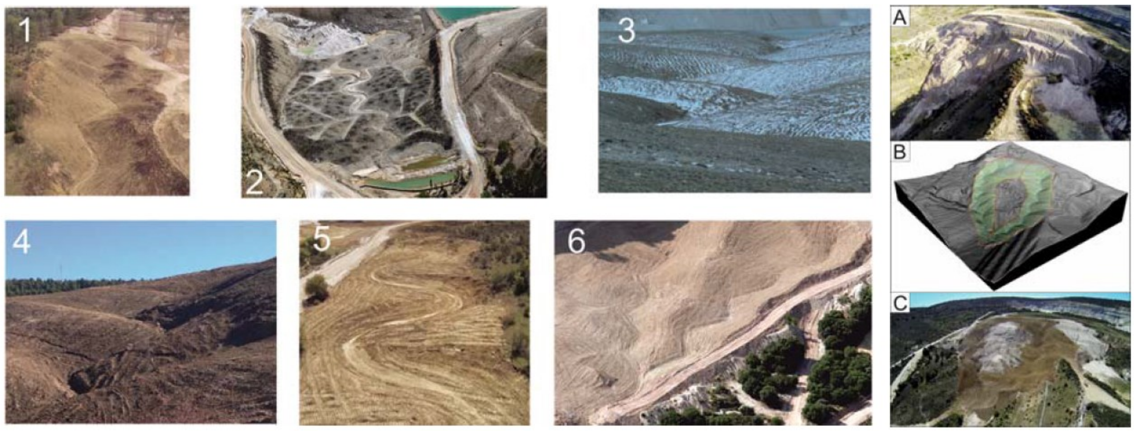


NB: 1 and 2 El Machorro mine, CAOBAR (Spain)
Source: Provided by the TWG

Figure 4.41: (1) Conventional terraced reclamation; (2) Geomorphic reclamation tying into the existing topography of the surroundings

A typical geomorphic reclamation project for stabilising and rehabilitating an EWF includes the following phases:

- locating stable natural landforms in earth materials similar to the extractive waste as field input;
- designing the area with the help of computer tools such as computer-aided design (CAD) software;
- making a geomorphic reclamation model of the site;
- validating the stability and the performance;
- building the designed landforms;
- monitoring the hydrological and erosive-sedimentary production of the geomorphic reclamation.



NB: Left: 1, El Machorro active mine; 2 and 3, María José active mine; 4 and 5, Nuria abandoned mine; 6, Somolinos abandoned mine. Right: Nuria abandoned mine (A, active landslide; B, landform design; C, built reclamation.
Source: Provided by the TWG

Figure 4.42: Geomorphic reclamation carried out by CAOBAR in Spain

Landscaping and geomorphic reclamation are planned in the design phase and are usually implemented in the closure phase.

- *Planning and design phase*
  Planning and design of the landscaping or geomorphic reclamation.
- *Operational (construction, management and maintenance) phase*
  Landscaping and geomorphic reclamation is implemented, while applying management systems.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the EWIW generation.
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing the formation of polluted seepage due to inappropriate water collection.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising the self-ignition of extractive waste.

- Helping to ensure the long-term and short-term physical stability of the extractive waste deposition area (including the EWF) by:
    - minimising soil erosion.
- Prevention or minimisation of air pollution by:
    - preventing or reducing wind erosion and dusting from exposed surfaces of the extractive waste.
- Prevention or minimisation of noise and vibration emissions from the management of extractive waste.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
    - providing a natural channel morphology that conveys water and sediment discharge in hydrological balance;
    - improving vegetation and habitat values; the landscape designs provide a broader range of post-extraction land use alternatives.

4. Environmental performance and operational data

- At the El Machorro mine, landscaping has been incorporated into the operation plans since 2012. The geomorphic reclamation is carried out as a progressive rehabilitation process in slope or contour mines. After four years, the surfaces are stable in geomorphic terms and maintenance is not needed. The concave shape of the base of the watershed slopes plays a key role in terms of geomorphic stability and promotion of ecosystems development.

An example of the management of the active slag heaps in the Ruhr area is reported in Annex 4.

5. Cross-media effects

- Land availability for extractive waste placement, associated with lowering the average slope angles. Compared with traditional steep slopes, geomorphic reclaimed landscapes may need a larger area (footprint) than cone-shaped heaps.

6. Technical considerations relevant to applicability

- The characteristics of the waste material and specific local conditions, amongst others, have to be taken into account.
- The applicability may be restricted by land availability on existing operational sites.
- The technique is applicable in combination with BAT on structural stability (see Section 4.2.1.3.6.1, Section 4.2.1.3.6.2 and Section 4.2.1.3.6.4), ARD prevention or minimisation (see Section 4.2.2.2.2) and self-ignition prevention or minimisation (see Section 4.2.2.2.3).
- This technique cannot be applied to slurried extractive waste from mineral processing and extractive waste from mineral processing accumulated upstream in dams. It is applicable to dry extractive waste encapsulated with inert materials, provided that the landform regrade does not affect the core of the encapsulated extractive waste.
- Geomorphic reclamation provides physical stabilisation of the extractive waste heaps.
- Geomorphic reclamation needs to be carried out either with GPS-guided machines or by survey stakeout (with differential GPS), whereas conventional approaches do not usually require this.

7. Economics

- High capital costs (CAPEX) are related to the relevant amount of land available. These can be later compensated by savings in maintenance.

- At the El Machorro mine, economic savings of EUR 55 000 per year by applying geomorphic restoration compared to the costs of cleaning and maintaining a settling pond have been estimated.
- According to the information provided in the questionnaire by users of the geomorphic restoration method, cost savings range from revenue-neutral up to 37 % when compared to traditional rehabilitation methods. Most of the economic benefits are derived from the absence of containment structures and the reduction of maintenance operations.

- However, geomorphic reclamation operations can also be more expensive than traditional ones, particularly when the rehabilitation is not carried out progressively.

The use of landscaping and geomorphic reclamation methods, as described in this section, can be much more cost-effective and efficient when considered in the design process.

8. Driving force for implementation
- National legal and environmental requirements (such as Natura 2000 requirements).
- Local requirements.
- Presence of protected areas.

9. Example sites
- Schöttelheide (DE)
- Haniel (DE)
- El Machorro Kaolin Mine, Maria José Kaolin Mine (ES)
- Aurora Clay Quarry, Somolinos and Nuria abandoned mines (ES)
- La Plata Mine, San Juan Mine, Navajo Mine, McKinley Mine (New Mexico); Log Creek Church abandoned mine lands (Indiana) (US)
- Mangoola, Tasman, Ravensworth, Mt Arthur Colliery, among others (Australia)
- Mina Bijao (Colombia)

10. Reference literature
(ASA 1982)
(Balaguer *et al.* 2014)
(Bugosh and Epp 2014)
(DePriest *et al.* 2015)
(Martín Duque and Bugosh 2014; Martín Duque *et al.* 2015)
(Martín-Moreno *et al.* 2016)
(NM MMD 2010)
(Orman *et al.* 2011)
(Roth 2014)
(Williams 2014)
(Zapico *et al.* 2018)

4.3.2.1.5 Use of reagents or chemicals with a low environmental impact

Not enough information and data were provided to develop a 10-heading description. However, operators have reported the use of reagents or chemicals for the management of extractive waste with a low environmental impact, which are biodegradable or non-toxic or have no or demonstrated limited adverse effects on the environment and human health.

The technique is applied in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  The use of reagents with a low environmental impact is planned in the design phase.
- *Operational (construction, management and maintenance) phase*
  The use of reagents with a low environmental impact is implemented during the operational phase. Existing reagents or chemicals are replaced by alternatives with a lower environmental impact that continue to ensure a sufficient level of technical performance.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

Examples of reagents and chemicals with a low environmental impact used for the treatment of EWIW are given in Section 4.3.2.2.2.3 presenting some reagents used for the coagulation and flocculation of EWIW.

4.3.2.2 Techniques to prevent or minimise emissions to surface water

In order to prevent or minimise emissions to surface water, operators collect the EWIW and, when necessary, treat it before discharge to meet the water quality requirements.

Water treatment techniques can be divided into two types of techniques:

- Passive treatment techniques which do not require energy and nutrients addition. These techniques are usually designed to be self-sustaining over a longer period of time, e.g. 10-30 years, and therefore do not require significant maintenance. Passive techniques are generally suitable for closed extractive waste management sites with lower flow rates (e.g. < 50 l/s) and lower pollutant loads (e.g. acid load < 150 kg/day, acidity < 800 mg/l) (Taylor *et al.* 2005; Turunen 2015b). In some cases, passive techniques are used during the operational phase of the extractive waste management site as polishing techniques in addition to active water treatment techniques.
- Active treatment techniques, as opposed to passive treatment techniques, require energy, chemicals or reagents and maintenance. Active treatment techniques are designed to accommodate and treat site-specific EWIW. Therefore, at each site, active techniques will be adapted to the site-specific conditions: e.g. input water quality, output water requirements, input and output flows and climatic conditions. Active techniques are usually implemented during the operational phase of the extractive waste management site.

In addition, treatment techniques can be divided into different categories reflecting the main type of contaminant to be removed. For the purpose of this document, four main categories have been identified:

- suspended particles, including solid and liquid particles such as oil and grease;
- dissolved substances, including nutrients such as phosphates, nitrates, nitrites, and ammonia, dissolved metals, salts such as sulphates, chlorides, nitrates and organic contaminants such as BOD, COD and dissolved hydrocarbons;
- alkalinity or acidity;
- other extraction process contaminants, including flocculants.

Table 4.34 summarises the different techniques that are presented in this subsection.

Table 4.34: Extractive waste influenced water treatment techniques overview

Contaminants category	Examples of targeted contaminants / parameters	Examples of Passive treatment	Examples of Active treatment
Suspended particles	TSS, TSP, turbidity	Settling ponds (including ponds containing extractive waste from mineral processing) Wetlands	Clarification in tanks Coagulation and flocculation Air flotation Media filtration Membrane filtration
Dissolved substances	TDS, phosphates, nitrates, nitrites, ammonia, sulphates, chlorides, fluorides, metals, BOD, COD, dissolved hydrocarbons	Settling ponds (including ponds containing extractive waste from mineral processing) Aerobic and anaerobic wetlands	Aeration and active chemical oxidation Active aerobic biological oxidation Anoxic BCRs Co-precipitation Adsorption Ion exchange Nanofiltration Reverse osmosis
Alkalinity or acidity	Basic or acid load, acidity or alkalinity, pH	OLDs/OLCs SAPS Anaerobic wetlands	Active neutralisation
Process contaminants	Flocculants, cyanides	Aerobic wetland ponds	Aeration and active chemical oxidation, Cyanide destruction using SO_2/air or hydrogen peroxide

4.3.2.2.1 Drainage of EWIW

4.3.2.2.1.1 Drained EWIW collection and handling

1. Description
This technique consists of collecting the EWIW by means of drainage systems and handling the drained EWIW by means of return systems such as pumping stations (to pump it back to the extractive waste deposition area) or collection systems such as water retention basins.

2. Technical description
This BAT candidate is relevant for non-inert EWIW.

The collection of EWIW is carried out by means of drainage systems for ponds and dams (see Section 4.2.1.3.5.1) or drainage systems for heaps (see Section 4.2.1.3.5.2), including a composite basal structure system (see Sections 4.2.1.3.3.1.3.1 and 4.2.1.3.3.2.3.1).

The handling of EWIW is carried out by means of the following:

- *Return systems*, which may consist of the following:
    - *Collector ditches*. They are suitable for any kind of dam and constitute low-cost solutions.
    - *Wells*. They can reach greater depths and are useful as a remedial measure; However, they are expensive and their effectiveness depends on local aquifer characteristics.
    - *Pumping stations* to pump the drainage water back to the extractive waste deposition area).

- *Collection systems*, such as *water retention basins*.

According to the MTWR BREF (EC-JRC 2009), return systems handle the collected EWIW, which can then be treated, mixed with other EWIW or pumped back into the extractive waste deposition area (including the EWF).

In some cases, it may be more appropriate to install return systems instead of seepage barriers.

The collection and handling of drained EWIW is carried out in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  The collection and handling of drained EWIW are planned and designed.
- *Operational (construction, management and maintenance) phase*
  The collection and handling of drained EWIW are carried out, monitored and maintained.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the uncontrolled release of EWIW to surface water.
- Prevention or minimisation of groundwater status deterioration and soil pollution by:
  - preventing or reducing pollution due to the infiltration of polluted seepage into the ground.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.
- In cold climates an anti-freezing system has to be installed in the pipelines and return systems.

7. Economics

- No information provided.

8. Driving force for implementation

- Safety requirements.
- Legal and environmental requirements and local legislation.

9. Example sites

- Collection of drainage water is applied at many sites in Europe.

10. Reference literature

(EC-JRC 2009)

4.3.2.2.1.2 Collection and off-site treatment of EWIW

This BAT candidate is relevant for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.

Not enough information and data were provided to develop a 10-heading description; however, operators responsible for the management of drilling muds and other extractive wastes from oil and gas exploration and production did report in some cases that they do not manage the EWIW on site, but rather transfer it to a dedicated off-site water treatment facility.

In the United States this has particularly been the case with the development of the extraction of oil and gas from unconventional geologies. Specialised companies provide services to extractive waste operators in order to treat the EWIW prior to discharge or to partially recycle the EWIW generated by the drilling and extracting activities in order to enable its use in subsequent oil and gas drilling and extraction activities.

The main cross-media effect reported by such a practice is the increased need for transport by trucks.

The collection and off-site treatment of EWIW is carried out in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  The collection and off-site treatment of EWIW are planned and designed.
- *Operational (construction, management and maintenance) phase*
  The collection and off-site treatment of EWIW are carried out.

4.3.2.2.2 Removal of suspended solids or suspended liquid particles

4.3.2.2.2.1 Gravity separation in settling ponds

1. Description
The removal of suspended solids or liquid particles is performed by settling finely grained material into the ponds by gravity.

2. Technical description
This BAT candidate is relevant for EWIW containing TSS and TSP.

Ponds used for gravity settlement of solid particles are usually called settling, sediment, sedimentation, lagoon or polishing ponds. Sedimentation is also performed in ponds containing extractive waste from mineral processing. The characteristics of settling ponds can be summarised as follows:

- The size of the ponds may vary considerably from a few hundred cubic metres to hundreds of thousands of cubic metres depending on the need. The gradient of the pond will enable water to flow through the pond.
- In a settling pond, solid particles are separated from the liquid phase by means of gravity and time. Smaller particles require a longer settling time and thus a larger pond.
- Sedimentation may be implemented after neutralisation/precipitation in order to separate the precipitates from the EWIW.
- One or more ponds may be used in series or in parallel to achieve the targeted removal efficiency.

Seepage from the pond is reduced and controlled with the construction of a basal structure (e.g. an impermeable natural soil basal structure or an impermeable artificial basal structure, see Sections 4.3.1.1.1 and 4.3.1.1.2 respectively), a drainage systems for ponds and dams (see Section 4.2.1.3.5.1), a spillway system to avoid overflows (see Section 4.2.1.3.4.4) and a water level control system.

The technique is planned in the design phase and is implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Settling ponds are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Settling ponds are used to treat EWIW contaminated with suspended particles.
- *Closure and after-closure phase*
  Settling ponds are adapted to the specifics of the closure phase and implemented.
  Settling ponds are adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body.
- Enhanced management of excess water, enabling potential re-use/recycling of water.

4. Environmental performance and operational data

The design and sizing of settling ponds depends on the design flood, the topography, the flow rate and the granulometry of the extractive waste, according to the MTWR BREF (EC-JRC 2009).

The achievable performance level of the settling pond is difficult to estimate as gravity separation is usually implemented in combination with additional techniques such as filtration, use of flocculants and coagulants.

In the questionnaires, the following data have been reported:

- The TSS in the inflow water generally varies from ~ 2 mg/l to ~ 2 000 mg/l with a median/average value of ~ 40 mg/l.
- The TSS in the discharged water varies from less than 1 mg/l to ~ 100 mg/l with a median/average value ~ 10 mg/l.
- Only 5 operators have reported TSS concentrations in both the inflow and the outflow, enabling the calculation of the removal efficiency. Those data suggest that up to 90 % of the TSS can be removed before discharge when using a settling pond in combination with other techniques assisting solid/liquid separation.

An important parameter for the sedimentation performance and hence removal of suspended solids is the particle size of the solids. Unfortunately, not enough data have been provided to suggest a correlation between the particle removal efficiency and the particle size.

Particles smaller than one micron are usually not removed by sedimentation (Pearce 2014).

During operation, settling ponds require maintenance, i.e. dredging, in order to collect the settled waste which requires proper management.

5. Cross-media effects

- Accumulation of sludge and sediments in the settling ponds that will require proper management.

6. Technical considerations relevant to applicability

- Gravity separation is not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
- The applicability may be restricted by the location (nature protection, hydrogeology, soil characteristics, etc.) and the availability of land.

7. Economics

- For the Aguas Teñidas Mine the CAPEX amounted to ~ EUR 4 400 000.
- Gravity settlement is a cost-effective solution with reasonable operational costs (OPEX). However, no specific data on OPEX were provided in the questionnaires.

8. Driving force for implementation

- Legal and environmental requirements.
- Reduction of EWIW.

9. Example sites

- Minas de Aguas Teñidas (ES). Three regulation ponds built at different heights with a front-closure dam of ungraded materials and a core composed of well-graded aggregates.
- Leziate quarry (UK)

10. Reference literature

(UK EA 2011)
(EC-JRC 2009)
(Kauppila *et al.* 2013)

4.3.2.2.2.2 Clarification in tanks

1. Description

The removal of suspended solid or liquid particles can be achieved by means of mechanically forced gravity settling in tanks where the settling time or specific area is controlled.

2. Technical description

This BAT candidate is relevant for EWIW containing TSS and TSP.

It is a treatment technology used for the removal of solid and liquid particles suspended in the EWIW. A technical description of settling tanks and lamella clarifiers is provided in the CWW BREF (Brinkmann *et al.* 2016).

It can be combined with the use of reagents (coagulation/flocculation) (see Section 4.3.2.2.2.3).

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Clarification tanks are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Clarification tanks are used to treat EWIW contaminated with suspended particles.
  The technique may be implemented after a primary gravity sedimentation.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body.

4. Environmental performance and operational data

Treatment flow rates can vary widely from a few tens of cubic metres per hour to several thousand.

At KGHM Polska Miedź S.A. Żelazny Most tailings pond, the concentration of suspended solids in water leaving the pond varies depending on the weather conditions and the total volume of excess water. To keep it under control, the turbidity of the discharged water is continuously measured, which indicates the concentration of TSS. When the TSS temporarily (10 days in 2013) tend to reach the level of 35 mg/l, the water treatment plant is put into operation. The technology of the plant is based on coagulation (with ~ 300 mg/l ferric chloride) supported by flocculation with a polyelectrolyte (1 mg/dm^3), followed by sedimentation in a lamella settling tank.

A TSS level lower than 15 mg/l is obtained through optimal design and operation of the clarification tanks (MEND 2014).

Reported abatement efficiencies in the chemical sector vary from 60 % to 99 % for TSS, according to the CWW BREF (Brinkmann *et al.* 2016).

5. Cross-media effects

- Energy consumption.
- Sludge generation.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- Equipment costs (CAPEX) can vary from a few tens of thousands of euros to several million (MEND 2014) depending on the installed treatment capacity.
- A good cost indicator is provided in the CWW BREF (Brinkmann *et al.* 2016).

8. Driving force for implementation

The same as for sedimentation:

- Legal and environmental requirements.
- Reduction of EWIW.

9. Example sites

- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature

(Brinkmann *et al.* 2016)
(MEND 2014)

4.3.2.2.2.3 Coagulation and flocculation

1. Description

The settling properties of suspended solids in the EWIW are enhanced with the use of coagulating/flocculating agents that promote sedimentation by increasing the agglomeration of particles into settleable flocs and have a low environmental impact.

2. Technical description

This BAT candidate is relevant for EWIW containing TSS and TSP.

Coagulation refers to the technique in which colloids (particles in the size range of 0.01 microns to 0.1 microns (Pearce 2014)) are destabilised by neutralising the forces that keep them separated and particles are aggregated into much larger forms to facilitate the separation of the liquid and the solid phases.

Flocculation is the second step of the process and aims at assisting the coagulation process. The flocculation process refers to gentle/slow mixing of coagulated particles to form bigger settleable particles/flocs.

Settling of particles is promoted by the growth in the size of precipitate particles, which speeds up the sedimentation in the ponds. The produced precipitates settle on the bottom of the pond.

Coagulants and flocculants generally reported via the questionnaires are listed below:
- inorganic coagulant agents such as aluminium or ferric sulphate, aluminium or ferric chloride and sodium aluminate;
- organic coagulants such as polyamines (GE 2016a);
- anionic and cationic flocculants, so-called polyelectrolytes.

Low-toxicity flocculants have to be selected in order to minimise the risk of flocculant-induced toxicity in the EWIW discharge from the pond (Clark 2010).

Biodegradable or non-toxic flocculants can be used when there is a risk of adverse effects on the environment or human health or when there is a risk of water status deterioration (see Section 4.3.2.1.5).

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:
- *Planning and design phase*
  Coagulation and flocculation technology are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  EWIW containing suspended particles is mixed with coagulants/flocculants. Flocs are then removed by sedimentation, clarification or filtration.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body;
  - higher settling rate;

  - enhanced separation of fine particles from the liquid phase;
  - increase of the efficiency of the downstream treatments.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - having a lower footprint as a higher settling efficiency implies a smaller pond size.
- Decrease of the general environmental risks related to EWIW management.

4. Environmental performance and operational data

TSS concentrations of 250 mg/l can be reduced to less than 20-50 mg/l (as reported at the Cobre Las Cruces site, Kittilä Mine and the Żelazny Most tailings pond).

Consumption of reagents varies from site to site depending obviously on the type of reagents and treated volumes. Specific consumption levels have been reported in Table 4.35.

Table 4.35: Specific consumption levels of reagents based on site-specific data reported by operators via the questionnaires or collected from additional literature

Reagent	Units	Typical dosage	Reference
Ferric chloride	mg/l	~ 300	Żelazny Most (questionnaire)
Ferric sulphate	mg/l	10-30	Kittilä, Galmoy (questionnaire)
Ferric sulphate	mg-Fe/l	15	(MEND 2014)
Commercial name flocculants	mg/l	~ 1	(MEND 2014)

Natural biodegradable flocculants (such as chitosan, gums and mucilage, sodium alginate) have been used in recent years. They are based on polysaccharides or natural polymers. Due to their moderate flocculating efficiency and shorter shelf life, a large dosage is needed (Lee *et al.* 2014). New polymeric flocculants, produced by grafting polymers onto the backbone of natural polymers, are under study (Lee *et al.* 2014).

5. Cross-media effects

- Potential toxicity for aquatic and human life.
- Presence of residual metal concentration in the treated water.
- Lack of biodegradability and dispersion of potentially toxic monomers (such as acrylamide) into surface waters (Lee *et al.* 2014).
- Use of coagulating/flocculating agents.
- Power consumption.
- Generation of sludge to be dredged and managed properly.

6. Technical considerations relevant to applicability

- No information provided.

7. Economics

- At the Cobre Las Cruces site, the cost estimation based on the water treatment capacity is:
  - CAPEX: EUR 3 000-5 000 per m^3/h of water treatment capacity;
  - OPEX (only chemicals and power consumption considered): EUR 0.15-0.25/m^3.
- At the Kittilä Mine:
  - the annual cost for the use of ferric sulphate is approximately EUR 10 000;
  - the dredging is performed four times per year and the cost is up to EUR 20 000.
- From the VTT report (Kinnunen *et al.* 2015):
  - CAPEX: ~ EUR 500 per m^3/day of water treatment capacity, including the microfiltration costs;
  - OPEX: EUR 0.02-0.45/m^3, including the microfiltration costs.

8. Driving force for implementation
- Water quality.
- Legal and environmental requirements.
- Re-use/recycling of water.

9. Example sites
- LKAB Malmberget Iron ore Mine (SE) sedimentation pond with a clarification pond combined with a high ratio of recycling of process water.
- Minas de Aguas Teñidas (ES)
- Proyecto Cobre Las Cruces (ES)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)

10. Reference literature
(Clark 2010)
(EC-JRC 2009)
(GE 2016a)
(Kauppila *et al.* 2013)
(Kinnunen *et al.* 2015)
(Lee *et al.* 2014)
(MEND 2014)

4.3.2.2.2.4 Air flotation

1. Description
The air flotation process relates to the separation of solid and liquid particles by attaching them to air bubbles.

2. Technical description
This BAT candidate is relevant for EWIW containing TSS and TSP.

A good general description of the flotation process as a water treatment technique is provided in the CWW BREF (Brinkmann *et al.* 2016).

Air flotation can be applied in the mineral processing itself, which is not within the scope of this document, or as a water treatment technique to improve the re-use of EWIW in extractive operations.

The flotation process is usually assisted by the addition of coagulants.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:
- *Planning and design phase*
  Air flotation techniques are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  EWIW containing suspended particles are treated with air flotation.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
    - preventing or minimising the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body;
    - preventing or reducing the level of dissolved substances in the EWIW to be discharged into the receiving surface water body;
    - increasing the concentration of DO in EWIW (COD reduction);
    - removal of heavy metals;
    - removal of ARD.
- Reduction of reagent consumption compared to the coagulation/flocculation process.

4. Environmental performance and operational data

The TSS removal efficiency can be as high as 97 % (Watermark 2016).

In AMD treatment from coal mines, the following metal removal efficiencies have been reported (Ross *et al.* 2003):

- iron: 88.9 %;
- manganese: 87.5 %;
- aluminium: 86.7 %.

In the management of extractive waste resulting from oil and gas extraction, the following removal efficiencies have been reported (CSM 2009):

- oil: 93 %;
- COD: 75 %;
- H_2S: 90 %.

Pretreatment with flocculants may be required prior to air flotation treatment.

Post-treatment of the float is required in order to dewater the float, which usually contains only 2 % to 10 % solids. The following techniques may be used for this purpose: filter presses, belt filter presses, centrifuges, drying beds or vacuum filters.

The water recovery rate is 100 %.

5. Cross-media effects

- Energy consumption.
- Possible reagents consumption

6. Technical considerations relevant to applicability

- It is only applicable to particles that can naturally, or by means of flotation reagents, attach to air bubbles.
- Flotation is sensitive to foaming agents, which need to be excluded prior to treatment.

7. Economics

- The CAPEX and OPEX vary depending on the installed treatment capacity.

- For treatment capacities varying from 10 m^3/h to 10 000 m^3/h, the CWW BREF (Brinkmann *et al.* 2016) provides some indicative ranges:
    - CAPEX: EUR 75 000 to EUR 750 000;
    - OPEX: EUR 7 500 to EUR 500 000 per year.

- The Colorado School of Mines reported a treatment cost of ~ EUR 0.55/m^3 (CSM 2009).

8. Driving force for implementation

- Compliance with legal and environmental requirements.

- Improved water recycling capacity.
- High processing rates (up to 10 000-20 000 m^3/h).
- Improved product recovery when applied at the processing stage.
- Metallic ions removal.

9. Example sites
- Compañía Minera Doña de Collahuasi (Chile)

10. Reference literature
(CSM 2009)
(Brinkmann *et al.* 2016)
(Kinnunen *et al.* 2015)
(Ramírez *et al.* 2015)
(Rodrigues and Rubio 2007)
(Ross *et al.* 2003)
(Watermark 2016)

4.3.2.2.2.5 Media filtration

1. Description
Media filtration enables the removal of solid particles via size exclusion and/or adsorption on a medium that acts as a filter.

2. Technical description
This BAT candidate is relevant for EWIW containing TSS and TSP. It is particularly relevant for non-inert EWIW.

Media filtration is driven by gravity or a pressure gradient. By passing through the media, solids are retained by means of size exclusion (particles cannot pass through) or are adsorbed on the surface of the media.

One or more filters can be used to remove solids from EWIW using one or more filtering media (e.g. sand, peat, anthracite and magnetite). The filter is usually composed of:
- a *filter shell* (usually an open vessel made of concrete or steel for gravity-driven systems and a closed vessel for pressure-driven ones);
- a *particle bed support* (to support the media and avoid loss of particles);
- an *underdrain system* combined with a container for backwash water collection;
- a *control device* to monitor and control the filtering operation.

The media thickness is ~ 0.3-0.7 m. The particles size range is ~ 0.3-1.7 mm.

Multiple layers of media may be used. In that case, coarse and less dense particles are at the top of the filter bed whereas finer and denser ones are at the bottom.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:
- *Planning and design phase*
  Media filtration techniques are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  EWIW containing suspended particles are filtered to remove the particles.
- *Closure and after-closure phase*

The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
    - o preventing or minimising the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body.

4. Environmental performance and operational data

Depending on the load and operating conditions, best performances of TSS reduction below 5 mg/l have been reported at the industrial scale, according to MEND (MEND 2014).

Media are cleaned regularly (backwashing).

5. Cross-media effects

- Water consumption for media cleaning and energy consumption.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- The CAPEX is usually below EUR 1 million and depends on the designed filtration flow rate (MEND 2014).

8. Driving force for implementation

- No information provided.

9. Example sites

- No information provided.

10. Reference literature

(GE 2016b)
(MEND 2014)

4.3.2.2.2.6 Membrane filtration for suspended particles

1. Description

The removal of suspended solid particles is performed by transporting a liquid stream, driven by a pressure gradient, through a membrane that retains particles based on the membrane pore size.

2. Technical description

This BAT candidate is relevant for EWIW containing TSS and TSP. It is particularly relevant for non-inert EWIW.

<u>Pressure-driven membrane separation</u> (PDMS) processes use semipermeable membranes to reduce the concentration of the suspended solids in a feed solution, thus producing a permeate stream, which contains materials that pass through the membrane, and a concentrate (or waste stream), which contains the materials filtered out of the feed solution. Passage through the membrane matrix is controlled by the application of a "driving force". The membrane is essentially a thin barrier that permits the selective mass transport of solutes and solvents across the barrier.

Four main types of membrane filtration can be differentiated:

- *microfiltration* for the removal of suspended solids including colloids as a secondary treatment;
- *ultrafiltration* for the removal of suspended solids including colloids as a secondary treatment;
- *nanofiltration* for the removal of dissolved substances (see Section 4.3.2.2.3.7);
- *reverse osmosis* for the removal of dissolved substances (see Section 4.3.2.2.3.8).

<u>Microfiltration</u>
Microfiltration is a PDMS process that removes contaminants from a fluid by passage through a microporous membrane. It has been shown to remove major pathogens, bacteria and other contaminants. Microfiltration is typically used to separate suspended solids and can be applied to waters that are easy to treat. Due to the low pressures and high porosity, the membranes are unable to remove smaller compounds (ITRC 2010m).

<u>Ultrafiltration</u>
During the ultrafiltration process, suspended solids are retained in the concentrate, while water with solutes passes through as permeates. The size of the pores is submicroscopic. Therefore the molecular size of the solutes removed is the primary fundamental difference between this separation technique and microfiltration. Ultrafiltration membranes have proven to be effective at recovering flotation agents, surfactants and organometallic complexes (ITRC 2010m).

The technique is planned in the design phase and implemented in the operational phase:

- <u>*Planning and design phase*</u>
  Membrane filtration techniques is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- <u>*Operational (construction, management and maintenance) phase*</u>
  EWIW containing suspended particles is filtered to remove the particles.
- <u>*Closure and after-closure phase*</u>
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - o preventing or minimising the discharge of EWIW, containing suspended solids or liquid particles, into the receiving surface water body.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - o being a flexible application with a relatively small footprint.
- Implementation of the waste hierarchy principles by:
  - o minimising the volume of extractive waste.
- Reduction of contaminants migration.

4. Environmental performance and operational data
Microfiltration and ultrafiltration are used as polishing techniques (secondary treatment) to remove the residual suspended particles present in the EWIW after a primary filtration.

- Microfiltration membrane pore size ranges usually from 0.1 microns to 10 microns (Gusek and Figueroa 2009; MEND 2014). The operating pressure for microfiltration ranges from 0.04 MPa to 0.35 MPa (Gusek and Figueroa 2009).
- Ultrafiltration pore size ranges usually from 0.0025 microns to 0.1 microns and the operating pressure for nanofiltration ranges from 0.35 MPa to 1.4 MPa (Gusek and Figueroa 2009).

Membranes require regular cleaning and backwashing to remain efficient.

The use of anti-scaling agents to prevent scale build-up is usually considered for membranes or discharge pipes due to the possibility of generating concentrations of calcium sulphate, magnesium carbonate and iron sulphate compounds above their solubility levels.

Constant inflow quality is usually required in order to achieve better results; therefore equalisation may be required prior to treatment.

Concentrations of less than 1 mg/l of TSS can be achieved.

5. Cross-media effects

- Energy consumption.
- Potential difficulty of concentrate disposal.

6. Technical considerations relevant to applicability

- The characteristics of the feed solution and the desired permeate quality dictate the choice of membrane process, the membrane type, module design and configuration.
- The applicability of PDMS processes may be restricted in the case of:
    - varying quality of the feed water to be treated (e.g. non-constant inflow quality);
    - high TSS;
- PDMS processes can be implemented to treat EWIW:
    - if less stringent standards have to be attained, ultrafiltration and microfiltration may be more cost-effective;
    - if legal requirements prohibit the reintroduction of treated water to the environment or if treated water is to be provided to the public for consumptive or irrigational use, then nanofiltration or reverse osmosis are the best options.
- Pretreatment/removal of suspended solids may be necessary to avoid clogging.
- Microfiltration or ultrafiltration are sometimes used as pretreatment options for feed solutions intended to be treated by nanofiltration or reverse osmosis, respectively.

7. Economics

- This technique implies high capital and operation and maintenance costs.

- From the VTT report (Kinnunen *et al.* 2015):
    - CAPEX: ~ EUR 450-3 500 per m^3/day of treatment capacity;
    - OPEX: ~ EUR 0.010-0.35 per m^3.

8. Driving force for implementation

- More stringent environmental regulations.
- Incentives created by the potential capture and re-use or sale of extracted metals.

9. Example sites

- Proyecto Cobre Las Cruces (ES)

10. Reference literature

(ITRC 2010m)
(MEND 2008, 2014)
(Merta 2015c)
(Kinnunen *et al.* 2015)

4.3.2.2.3 Removal of dissolved substances

4.3.2.2.3.1 Oxidation-based systems

4.3.2.2.3.1.1 Aeration and active chemical oxidation

1. Description
Metal oxidation is an active water treatment process used to oxidise dissolved metals in EWIW in order to transform them into less soluble forms and eventually into settleable precipitates.

2. Technical description
This BAT candidate is relevant for EWIW containing TDS.

Two main types of metal oxidation can be applied:
- *aeration of EWIW* using air;
- *chemical oxidation* using strong oxidants such as chlorine, peroxides (e.g. Fenton), ozone or permanganate.

Aeration means the mechanical introduction and dissolution of air and thus oxygen into the EWIW stream through gravity (e.g. water-fall) and/or mechanical devices (e.g. agitation, air blowing, or jet pumps). It is essentially applied to convert some dissolved metals into a less soluble form to be precipitated by a neutralisation precipitation process: e.g. ferrous iron (Fe^{2+}) into ferric iron (Fe^{3+}) that can then precipitate as $Fe(OH)_3$ and so be removed.

Chemical oxidation with strong oxidants refers to the introduction of strong oxidants into the EWIW stream in agitated reaction tanks or ponds in order to promote the oxidation of dissolved metals into less soluble forms. The selection of the appropriate oxidising agent will depend on the EWIW's pH and the targeted metals. It is commonly applied to oxidise manganese (Mn^{2+}) in order to precipitate it as MnO_2 (less soluble).

An example of such a process is the Fenton process. EWIW is treated using hydrogen peroxide in combination with a ferrous iron as a catalyst in order to oxidise contaminants in EWIW.

Both techniques are commonly applied prior to solid/liquid separation (e.g. filtration, coagulation/flocculation, settling ponds) and/or in combination with precipitation (see Section 4.3.2.2.3.3) and neutralisation (see Section 4.3.2.2.4) techniques.

The technique is planned in the design phase and implemented in the operational phase:
- *Planning and design phase*
  Aeration or active chemical oxidation is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  EWIW is treated by oxidation in order to precipitate part of the dissolved substances.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body;
  - increasing the concentration of DO in EWIW;

  - promoting the oxidation of iron, manganese, arsenic, and other metals into less soluble forms;
  - increasing the pH by reduction of the dissolved CO_2 content.
- The use of air as an oxidant will avoid the permitting, management, handling and disposal issues that may apply to other chemical reagents.

4. Environmental performance and operational data
Aeration and oxidation performance levels are reported in Table 4.36.

Table 4.36: Aeration and oxidation performance levels

Parameter	Treatment	Achievable performance	Reference
Fe (total)	Aeration	< 0.3 mg/l at pH 7.5-8.0	(MEND 2014)
Mn (total)	Chemical oxidation	< 0.5 mg/l	(MEND 2014)

Usual oxidising reagents are (Gusek and Figueroa 2009):
- hydrogen peroxide; or
- sodium hypochlorite; or
- potassium permanganate.

5. Cross-media effects
- Energy consumption for agitation and pumping.
- Reagents consumption for chemical oxidation.

6. Technical considerations relevant to applicability
- Neither process can be used as a stand-alone technique; each has to be combined with precipitation, solid/liquid control and pH adjustment techniques.
- Aeration is not suitable for manganese removal at pH < 9.5.

7. Economics
- The cost will depend on flow rates and initial inflow quality.

- For chemical oxidation, costs will be similar to hydroxide precipitation (see Section 4.3.2.2.3.3.1).

8. Driving force for implementation
- More stringent environmental regulation.

9. Example sites
- Garpenberg Mine (SE)
- Leviathan Mine (Canada)

10. Reference literature
(INAP 2014d)
(ITRC 2010n)
(MEND 2014)

4.3.2.2.3.1.2 Active aerobic biological oxidation

1. Description
Active aerobic biological oxidation is a biological process using oxidation of carbonaceous and nitrogenous matter by means of aerobic bacterial activity.

2. Technical description
This BAT candidate is relevant for EWIW containing biologically oxidisable TDS.

Active aerobic biological oxidation encompasses a wide range of technologies used for the treatment of EWIW such as:
- activated sludge process;
- aerated lagoons;
- sequencing batch reactors;
- membrane bioreactors;
- Biological Aerated Filters (BAF);
- trickling filters;
- rotating contactors;
- Moving Bed Biofilm Reactors (MBBR).

Two main configurations can be distinguished:
- *suspended growth*: microorganisms are maintained in suspension via stirring/mixing;
- *attached growth*: microorganisms develop on an immobile support through which the EWIW flows.

Actually, a third category exists and is as a combination of the two main ones:
- *combining both systems* in a single reactor: media with a high specific surface are dispersed in a reactor and act as a support for biofilms, i.e. microorganism growth.

The main process occurring in an aerobic biological reactor is the oxidation of nitrogenous and carbonaceous matter.

The technique is planned in the design phase and implemented in the operational phase:
- *Planning and design phase*
  Active aerobic biological oxidation is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  EWIW is treated by active aerobic biological oxidation in order to remove part of the dissolved substances.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Prevention or minimisation of surface water status deterioration:
    - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body;
    - removing the following dissolved substances from the EWIW before the discharge into the receiving surface water body:
        - carbonaceous matter (oil, grease);
        - nitrogenous matter (ammonia, cyanates, cyanides);
        - COD and BOD;
        - metals.

4. Environmental performance and operational data
Environmental performance data are summarised as follows:
- The optimal pH for nitrification is between 7.0 and 9.0.

- The reaction consumes alkalinity, therefore alkaline addition may be required.
- The temperature is kept in a 10-30 °C range. Preheating will be required for inflow temperatures below 5 °C.
- Aerobic conditions are maintained by aeration of the tank/reactor.
- Dissolved oxygen (DO) has to be > 2 mg/l; aeration will be required if it is lower.
- Since cyanide is toxic for bacterial activity, prior oxidation of cyanide to cyanate is necessary.
- Calcium concentration in the inflow has to be monitored and regulated in a range of 50 mg/l to 200 mg/l in order to achieve the best nitrification rates (MEND 2014).
- The outflow will require additional solid/liquid separation, usually by the use of clarifiers (see Section 4.3.2.2.2.2).
- Operating conditions have to be adapted to the specific bacteria involved in the treatment.

Some achievable performance levels using aerobic biological reactors are provided in Table 4.37.

Table 4.37: Active aerobic biological oxidation performance levels reported by operators via the questionnaires and gathered from additional literature

Parameter	Implemented technique [a]	Achievable performance	Reference
COD removal	BAF	30-60 %	(CSM 2009)
BOD removal	BAF	85-95 %	(US EPA 2000a, b)
Oil removal	BAF	70-80 %	(US EPA 2014)
TSS removal	BAF	75-85 %	(US EPA 2014)
Total nitrogen removal	BAF	50-60 %	(US EPA 2014)
Total nitrogen removal	MBBR	95-98 %	Garpenberg (SE)
Total nitrogen content	MBBR	1.5-1.6 N-mg/l	Garpenberg (SE)
NH_3 content	MBBR	< 2.0 N-mg/l	(MEND 2014)
Cyanide content	MBBR	< 8.0 mg/l	(MEND 2014)
Cyanate content	MBBR	< 1.0 N-mg/l	(MEND 2014)
Thiocyanate content	MBBR	< 2.0 N-mg/l	(MEND 2014)

[a] *BAF = Biological aerated filter, MBBR = Moving bed biofilm reactor.*

5. Cross-media effects
- Generation of sludge.

6. Technical considerations relevant to applicability
- The contaminant removal efficiency depends on the inflow water quality.
- The applicability may be restricted in the case of:
    - COD > 400 mg/l (CSM 2009);
    - BOD > 50 mg/l (CSM 2009);
    - oil content > 60 mg/l (CSM 2009);
    - high levels of salt which would prevent proper microbial oxidation (e.g. > 120 g Cl/l).

7. Economics
- The reported construction costs depend on the installed treatment capacity and range from ~ EUR 100 million for a 100 m^3/h treatment capacity to EUR 4-5 million for a 500 m^3/h flow rate treatment capacity.
- The OPEX of MBBR excluding the sludge management cost was reported to be in the range of ~ EUR 0.06/m^3, and ~ EUR 5.40/m^3 when including the sludge management cost (MEND 2014).

8. Driving force for implementation

- Legal and environmental requirements.

9. Example sites

- Garpenberg Mine (SE)
- Ojamaa Kaevandus (EE)

10. Reference literature

(CSM 2009)
(MEND 2014)
(US EPA 2000a, b, 2014)

4.3.2.2.3.1.3 Aerobic wetlands

1. Description

Constructed aerobic wetlands are man-made shallow ponds containing vegetation used as a passive water treatment technique in order to increase the retention time and aeration.

2. Technical description

This BAT candidate is relevant for EWIW containing TDS.

Constructed aerobic wetlands are shallow ponds, less than 1 m deep, constructed and designed to provide a longer retention time and passive aeration of EWIW.

Two main categories of wetlands can be distinguished:

- *free water surface flow wetlands*: water flows over a vegetated soil surface from the inlet to the outlet point, and the water surface is exposed to atmosphere;
- *subsurface flow wetlands*: water flows within an appropriate substrate (porous solid media), and the water level is maintained below the surface of the substrate bed.

Natural overland-flow wetlands (*peatlands*) containing vegetation can also be used as a passive water treatment technique for the treatment of EWIW in peat extraction. Natural overland-flow wetlands are abundant in the boreal zone. They are formed by accumulation of peat soil which is created by inhibited decomposition and oxidation of organic plant material by microorganisms in waterlogged conditions.

Aerobic wetlands can work by means of:

- vertical flow: EWIW enters the wetland from the top and moves vertically down through the substrate and out, and the system operates under water-unsaturated conditions;
- horizontal flow: EWIW moves horizontally, parallel to the surface, and the system operates under water-saturated conditions.

According to the US Environmental Protection Agency (US EPA 2000a, b), an aerobic wetland is composed of:

- a basal impervious structure to prevent seepage (synthetic liners such as PVC or HDPE membrane, or natural liners such as clay or compacted soil);
- a drainage structure to control flow direction and water retention time and water level (gravel and crushed rocks and pipes);
- a layer of organic matter (wetland soil) to support the vegetation and microbial activity; and
- vegetation (e.g. cattail, bulrush, reeds) that provides oxygen through the roots.

Aerobic wetlands utilise soil- and water-based microbes associated with wetland plants to remove suspended solids and dissolved metals from EWIW over a long period, in general 1 to 5 days depending on the permit (Taylor *et al.* 2005).

According to the MTWR BREF (EC-JRC 2009), metals are removed through ion exchange, adsorption, absorption, and precipitation with geochemical and microbial oxidation and reduction. Ion exchange occurs as metals in the water come into contact with humic or other organic substances in the wetland. Wetlands constructed for this purpose often have little or no soil, instead being made of straw, manure or compost. Oxidation and reduction reactions catalysed by bacteria that occur in the aerobic zone play a major role in precipitating metals as hydroxides. Precipitated and adsorbed metals settle in quiescent ponds or are filtered out as water percolates through the medium or the plants.

The precipitation of iron or aluminium hydroxides may enhance the co-precipitation of other metals such as arsenic or molybdenum, according to the Closedure project (Turunen 2015a).

Natural overland-flow wetlands (peatlands) are constructed on large pristine or ditched peatlands, with a peat layer with a minimum thickness of 0.5 m. They can be used for both subsurface and free water surface flow processes in which the horizontal flow dominates.

The EWIW directed to the natural overland-flow wetlands runs at the surface and subsurface layers of the peat. The pollutant removal mechanism in natural overland-flow wetlands (peatlands) and aerobic wetlands are similar.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Aerobic wetlands are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Aerobic wetlands are usually used as a polishing step (final step).
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body;
  - removing the following substances from the EWIW before the discharge into the receiving surface water body:
    - suspended solids (TSS);
    - BOD;
    - dissolved metals and metalloids;
    - nutrients (e.g. phosphorus, nitrogen).
- Helping to ensure the short-term and long-term physical stability of the extractive waste deposition area (including the EWF) by:
  - minimising soil erosion.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting resulting from the management of extractive waste.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - habitat creation and/or restoration.

4. Environmental performance and operational data

The greatest utility of wetlands appears to be in the treatment of small flows in the order of tens of litres per minute, according to the MTWR BREF (EC-JRC 2009).

The design of a constructed wetland varies based on site characteristics. The most important design considerations are biochemical processes, loading rate, retention time, slope, substrate, vegetation, sediment control, morphometry and seasonality.

Aerobic wetlands are generally used to remove iron and aluminium more than manganese, according to ITRC (ITRC 2010a; Taylor *et al.* 2005) and the Closedure project (Turunen 2015a).

Removal of nutrients such as nitrogen or phosphorus has been reported too. However, the removal efficiency may vary considerably depending on the climate and precipitation. Usually in the winter period, lower removal efficiencies are observed and in some cases leaching of nutrients can occur (e.g. nitrates, nitrites). Nevertheless, an overall removal efficiency of ~ 50 % has been reported in Finland for both nitrogen and phosphorus removal.

Typical removal efficiencies observed in wetlands are provided in Table 4.38.

Table 4.38: Aerobic wetland performance levels from literature

Parameter	Achievable performance	Reference
TSS removal	> 80 %	(US EPA 2000a, b)
BOD removal	> 70 %	(US EPA 2000a, b)
Sulphate removal	10-30 %	(US EPA 2014)
Aluminium removal	> 90 %	(US EPA 2014)
Cadmium removal	75-90 %	(US EPA 2014)
Copper removal	80-90 %	(US EPA 2014)
Iron (total) removal	60-95 % 10-20 $g/d/m^2$	(Taylor *et al.* 2005; Turunen 2015a; US EPA 2014)
Lead removal	80-90 %	(US EPA 2014)
Manganese (total) removal	< 10 % 0.5-1.0 $g/d/m^2$	(Taylor *et al.* 2005; Turunen 2015a)
Zinc removal	75-90 %	(US EPA 2014)

The lifetime of wetlands or natural overland-flow wetlands varies from site to site and depends on the size of the wetland and the EWIW composition. However, it is usually estimated to be 20-30 years.

The general design principles of natural overland-flow wetlands are the following:

- the surface area in pristine peatland is at least 4.5 % of the run-off area and in ditched peatlands 5.0 % of the run-off area;
- the depth of peat layer is at least 0.5 m;
- the hydraulic load is 340 m^3/ha/day;
- the humification degree of the peat layer is H1 – H3;
- the recommended inclination throughout the field is 1 %;
- the surface contour lines are vertical to the direction of water flow;
- the ratio 0.5:1 can be used between the width and length of the surface area.

Monitoring for saturation, spillover and sedimentation is needed. Periodic dredging of sediments may be necessary (US EPA 2014).

5. Cross-media effects

- Large remedial footprint per unit treated.
- Disposal of accumulated material.
- Potential to become a permanent feature of the ecosystem, requiring long-term maintenance.

6. Technical considerations relevant to applicability

- Aerobic wetlands are not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
- Aerobic wetlands are not applicable for treating acidic EWIW; the inflow pH is higher than 5.5-6, according to the Closedure project (Turunen 2015a) and Taylor and co-authors (Taylor *et al.* 2005), and the average acidity < 500 mg $CaCO_3$/l (Taylor *et al.* 2005).
- Neutralisation of acidic water may be required prior to treatment (US EPA 2014).
- This technology is not applicable as a permanent solution as the wetlands will eventually be filled with metal-laden sediment that will require ultimate removal or capping.
- The technique performs relatively slowly in comparison to other treatment technologies.
- Wetlands are better suited for moderate or low water flows (< 50 l/s (Taylor *et al.* 2005)).
- It is not suitable for treatment of EWIW with high salinity, e.g. > 120 g Cl/l, which would prevent proper microbial oxidation.
- Additionally, the applicability and effectiveness of the process may be restricted in the case of the following:
    - Limited land availability.
    - Long-term applications, as the long-term effectiveness of constructed wetlands is not well known. Wetland ageing may be a problem which may contribute to a decrease in contaminant removal rates over time, according to the MTWR BREF (EC-JRC 2009).
    - High temperature and flow fluctuations affecting the wetland function and potentially causing a wetland to display inconsistent contaminant removal rates, according to the MTWR BREF (EC-JRC 2009);
    - Adverse local climatic conditions, as in cold climates the bacterial activity might be reduced and the removal performance of contaminants reduced, especially removal of BOD, NH_3 and NO_3 (US EPA 2000b).
    - A heavy flow of incoming water, which can overload the removal mechanisms in a wetland.
    - A dry spell, which can damage plants and severely limit wetland function, according to the MTWR BREF (EC-JRC 2009).
    - Sensitivity to high throughput excursions.
- Therefore, aerobic wetlands may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase.
- It is not applicable as a stand-alone technique.
- Maintenance may be required.
- Overland-flow wetlands are applicable to EWIW from peat extraction.
- Overland-flow wetlands are not applicable to treat large volumes of EWIW.
- The use of the method may be restricted by the unavailability of materials, e.g. suitable bog areas.

7. Economics

- The construction costs and operating costs depend greatly on the performance requirements, i.e. on the dimensions of the wetland.

- (Skousen and Ziemkiewicz 2005) reported construction costs from ~ EUR 3/m^2 up to EUR 30/m^2 with a median cost of ~ EUR 8-9/m^2.
- The U.S. Naval Facilities Engineering Service Center's Remediation Technology Online Help Program lists the costs of constructed wetlands treatment at between ~ EUR 0.03/m^3 and ~ EUR 0.30/m^3 (ITRC 2010a).

- Overland-flow wetlands are frequently used as a passive treatment in Finland due to their cost-effectiveness (e.g. Heikkinen et al., 1995): the CAPEX is EUR 300-1 400/ha (depending on whether they function based on gravitation or pumping) and the OPEX EUR 14-35/ha/year (depending on whether they function based on gravitation or pumping).

8. Driving force for implementation
- National and/or local legal requirements.
- Favourable public perception and improved aesthetics.

9. Example sites
- Enonkoski mine, Vihanti mine, Luikonlahti Mine (FI)
- Verkaneva site, Kompsasuo site and other Vapo's peat extraction sites (~ 400) for the natural overland-flow wetlands (FI)
- Burleigh Tunnel wetland Colorado; Asarco's West Fork site, Missouri; Somerset wetland, Somerset County, Pennsylvania; Latrobe wetland, Westmoreland County, Pennsylvania; Friendship Hill wetland, Fayette County, Pennsylvania; Commerce/Mayer site, Oklahoma; Copper Basin site, Tennessee; Keystone site, California; Hartshorne/Whitlock site, Oklahoma (US) (US EPA 2014)

10. Reference literature
(EC-JRC 2009)
(ITRC 2010a)
(Skousen and Ziemkiewicz 2005)
(Taylor *et al.* 2005)
(Turunen 2015a)
(US EPA 2000a, b, 2014)
(Räisänen 2015a, b, c)

4.3.2.2.3.2 Reduction-based systems using bacterial activity

4.3.2.2.3.2.1 Anaerobic wetlands

1. Description
Constructed anaerobic wetlands are similar to aerobic wetlands. However, anaerobic conditions are maintained thanks to the microbial activity of sulphate-reducing bacteria.

2. Technical description
This BAT candidate is relevant for EWIW containing TDS. It is particularly relevant for treating ARD.

In comparison with aerobic wetlands, anaerobic wetlands are constructed in a very similar way but contain an additional bottom layer of limestone beneath a much thicker organic substrate layer and sulphate-reducing bacteria.

The main processes of anaerobic wetlands are chemical and microbial reductions which lead to anoxic conditions in the substrate and water flows as a subsurface flow.

Because water flows through porous substrate, physical filtration also occurs with removal of precipitated particles. The flow direction can be horizontal or vertical depending on the design.

The sulphate-reducing bacteria activity generates bicarbonate alkalinity through the sulphate reduction:

$$2\ H_2O + SO_4^{2-} + C_{(organic\ matter)} \leftrightarrows H_2S + 2\ HCO_3^- \qquad (1)$$

Limestone dissolution also adds alkalinity to the system:

$$CaCO_3 + H^+ \leftrightarrows Ca_2^+ + HCO_3^- \qquad (2)$$

In such conditions, the H_2S produced through sulphate reduction combines with metal cations to form metal sulphides according to the following reaction:

$$2\ Me^{n+} + n\ S^{2-} \leftrightarrows Me_2S_n\ (s) \qquad (3)$$

Infiltration fields are a type of constructed wetlands, where water to be treated is infiltrated to the area. The flow direction is more vertical than horizontal as infiltration of water is a hydrological process, in which water is transported vertically to the wetland structure. In some infiltration fields there is no single outlet as all water is infiltrated to the area.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Anaerobic wetlands are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Anaerobic wetlands are usually used as a polishing step (final step).
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body;
  - removing dissolved metals and metalloids (such as iron, manganese, arsenic, dissolved aluminium, copper, zinc, cadmium, nickel, lead, selenium) and dissolved sulphate from the EWIW before the discharge into the receiving surface water body;
  - preventing or minimising the discharge of acidic EWIW into the receiving surface water body.
- Helping to ensure the chemical stability of extractive waste by:
  - preventing or minimising ARD.
- Helping to ensure the long-term and short-term physical stability of the extractive waste deposition area (including the EWF) by:
  - minimising soil erosion.
- Prevention or minimisation of air pollution by:
  - preventing or reducing wind erosion and dusting resulting from the management of extractive waste.
- Prevention or minimisation of visual and footprint impacts from the management of extractive waste by:
  - habitat creation and/or restoration.

4. Environmental performance and operational data

The size of the wetland is defined according to the acidity load: a recommended loading rate is 2 000 mg to 7 000 mg $CaCO_3/m^2/day$ according to Taylor and co-authors (Taylor *et al.* 2005) and the Closedure project (Turunen 2015d).

After treatment, the outflow can reach a pH of 6.0 to 8.0 (Taylor *et al.* 2005).

Skousen and co-authors calculated an average acidity removal of 16.4 g $CaCO_3/m^2/day$ (Skousen and Ziemkiewicz 2005).

5. Cross-media effects
- The cross-media effects are the same as for aerobic wetlands.
- Limestone consumption.
- Generation of odours (H_2S).

6. Technical considerations relevant to applicability
- Anaerobic wetlands are not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
- Anaerobic wetlands are applicable for treating:
  - net acidic EWIW, pH > 2.5 (Taylor *et al.* 2005), with a low oxygen concentration (DO 2-5 mg/l) (Ford 2003; Taylor *et al.* 2005);
  - acidity loads up to 500 mg $CaCO_3$/l (Taylor *et al.* 2005), however a high acidity load (> 300 mg/l) will start to hinder the bacterial activity, according to the Closedure project (Turunen 2015d).
- The same limiting factors as for aerobic wetlands apply, according to the MTWR BREF (EC-JRC 2009).
- Wetlands are better suited to moderate or low water flows (< 50 l/s (Taylor *et al.* 2005)).
- Wetlands are suitable for closure and after-closure EWIW treatment.
- The technique is not suitable for treatment of EWIW with high salinity, e.g. > 120 g Cl/l, which would prevent proper microbial reduction.
- The technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase.
- It is not applicable as a stand-alone technique.
- Maintenance may be required.

7. Economics
- The construction costs vary from ~ EUR 20 to EUR 350 per m^2 (Skousen and Ziemkiewicz 2005) with a median value of ~ EUR 100 per m^2.
- The U.S. Naval Facilities Engineering Service Center's Remediation Technology Online Help Program lists the costs of constructed wetlands treatment at between ~ EUR 35 and EUR 250 per m^3 (ITRC 2010a). EPA reported OPEX of ~ EUR 5 500 per year for a 15.8 m^3/h wetland (~ 100 000 gallons/day).

8. Driving force for implementation
- National and/or local legal requirements.
- Favourable public perception and improved aesthetics.

9. Example sites
- Burleigh Tunnel wetland, Colorado; Asarco's West Fork site, Missouri; Somerset wetland, Somerset County, Pennsylvania; Latrobe wetland, Westmoreland County, Pennsylvania; Friendship Hill wetland, Fayette County, Pennsylvania; Commerce/Mayer site, Oklahoma; Copper Basin site, Tennessee; Keystone site, California; Hartshorne/Whitlock site, Oklahoma (US) (US EPA 2014)

10. Reference literature
(EC-JRC 2009)
(ITRC 2010a)
(Ford 2003)
(Skousen and Ziemkiewicz 2005)
(Taylor *et al.* 2005)
(Turunen 2015d)
(US EPA 2014)

4.3.2.2.3.2.2 Anoxic Bio Chemical Reactors

1. Description

Anoxic BioChemical Reactors (BCRs) treat EWIW using biochemical reduction of contaminants to remove them.

2. Technical description

This BAT candidate is relevant for EWIW containing TDS. It is particularly relevant for treating ARD.

Anoxic BCRs are similar to anaerobic wetlands but without vegetation. They remove dissolved contaminants using microbial respiration as a catalyst for precipitation of dissolved metals, consumption of sulphates and increasing the alkalinity.

Anoxic BCRs operate in anaerobic conditions using sulphate-reducing bacteria activity like anaerobic wetlands (ITRC 2010b). Hence, these systems are also known as "Sulphate-Reducing" Bioreactors (SRBs), according to VTT (Kinnunen *et al.* 2015).

BCRs can be divided into the following:

- *Active BCRs:* those that require energy and/or reagent input. In that case, carbon is provided into the system through an external liquid source of organic substrate and separate tanks are used for the biological, chemical and physical (solids separation) processes consuming energy. Active BCRs are usually proprietary systems based on anoxic biological reduction principles using biofilms for example. Some of these systems are developed to target specific contaminants such as selenite.
- *Passive BCRs:* the organic carbon is provided in a pond or a tank within a mixture consisting of an organic carbon source (e.g. ethanol, manure, woodchips), a bacterial source or inoculant, a solid granular medium, nutrients (e.g. nitrogen, phosphorus) and a neutralising agent (usually limestone). Filtration is performed by means of natural gravity flow through the solid porous medium.

The BCR is typically divided into four zones (ITRC 2010b):

- *free water* evenly distributed on the top (< 20 cm);
- an *oxidative zone* where biodegradation of organic matter takes place;
- a *transitional zone* where dissolved metals form temporary carbonate precipitates (metallic cations react with limestone);
- a *sulphate reduction zone* where sulphates are first reduced by bacterial activity into sulphide ions and bicarbonates and then sulphide ions react with metals to form sulphide precipitates.

The technique is implemented in all the life cycle phases of the extractive waste management listed below:

- Planning and design phase
  Anoxic BCRs are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- Operational (construction, management and maintenance) phase
  EWIW is treated in order to remove part of the dissolved substances.
- Closure and after-closure phase
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
    - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body;
    - removing the following dissolved substances from the EWIW before the discharge into the receiving surface water body:
        - dissolved metals and metalloids such as arsenic, cadmium, chromium, cobalt, copper, lead, nickel, selenium, thallium, uranium and zinc from EWIW;
    - sulphate reduction;
    - neutralisation of EWIW.

4. Environmental performance and operational data

Operational data are reported as follows:

- The optimal reduction rate occurs in a pH range of 6.5 to 7.5 and a temperature range of 25 °C to 45 °C (MEND 2014), but the systems can tolerate temperature ranges from -5 °C to 75 °C, according to the VTT report (Kinnunen *et al.* 2015).
- With a pH > 7.5, sulphide tolerance can be over 1 000 mg/l, decreasing to less than 500 mg/l when moving to acidic conditions (Celis-García *et al.* 2007; Greben *et al.* 2004).
- The SRB systems have the following characteristics:
    - according to the review of (Papirio *et al.* 2013), they can tolerate heavy metal (Fe, Cu, Ni, Zn, Pb, Cd) concentrations from just a few milligrams to hundreds of milligrams per litre, according to the Closedure project (Mäkinen 2015a);
    - minimum contact times generally range from 8 to 48 hours (ITRC 2010b) with an optimum between 20 and 30 hours (Kinnunen *et al.* 2015);
    - they are built to last several years.

With reference to the performance levels:

- specific site data indicate a removal efficiency of 95 % for most metals (ITRC 2010b); additional studies confirmed these results (Reisman *et al.* 2008; Reisman *et al.* 2009);
- various types of systems can result in 98 % removal of selenium and achieve final concentrations of less than 5 µg/l of selenium (MEND 2014; US EPA 2014).

Performance levels are indicated in Table 4.39.

Table 4.39: Performance levels for the removal of suspended and dissolved substances according to literature

Parameter	Achievable performance	Reference
Selenium removal	98 %	(US EPA 2014)
Selenium content	< 0.005-0.020 mg/l	(MEND 2014)
Other metals removal*	> 98 %	(ITRC 2010b)
Other metals content*	< 0.010 mg/l	(US EPA 2014)
NO_3^- content	< 0.100 N-mg/l	(MEND 2014)
Sulphate	30-75 %	(ITRC 2010b)
TSS	< 30-35 mg/l	(MEND 2014)
BOD	< 30 mg/l	(MEND 2014)

** Other = aluminium, arsenic, cadmium, cobalt, chromium, copper, nickel, lead, zinc.*

BCRs do not usually require extensive maintenance. Nevertheless, regular maintenance might be required to avoid clogging of the substrate. This is done by means of the following activities:

- adding inert gravel to the mixture to provide structure to offset compaction;
- using recycling systems in compost-based BCRs and flushing circuits in rock-based BCRs to remove any build-up (ITRC 2010b).

5. Cross-media effects

- Release of organics and nutrients from the BCR.
- Land availability (footprint).
- Generation of odours.

6. Technical considerations relevant to applicability

- Anoxic BCRs are not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
- The main sulphate-reducing bacteria require water conditions of pH > 5.5 (García *et al.* 2001), but microbe activity is also observed with a pH < 3.0 (Johnson 2003).
- Compared to other SO_4^- reduction methods (e.g. reactive barriers, bioreactors), BCRs need special equipment, maintenance, electricity, monitoring and skilled personnel, increasing the costs and maintenance of infrastructure. For these reasons, the technology is most suitable for sites with little available space or very strict emission limits, according to the Closedure project (Mäkinen 2015a).
- The climate can limit passive BCR treatment applicability. In this case, active systems might be preferred (ITRC 2010b).
- The technique is not applicable for treatment of EWIW with high salinity, e.g. > 120 g Cl/l, which would prevent proper microbial reduction.

7. Economics

- Bioreactors can be costly to construct since generally the systems are lined and often contain additional components, such as settling ponds and/or aerobic polishing cells.
- The CAPEX varies between ~ EUR 360 000 and ~ EUR 1 000 000 depending on the treatment capacity and location.
- The OPEX is ~ EUR 5/m^3 for an average treatment capacity flow rate of 3-4 m^3/day (US EPA 2014).

8. Driving force for implementation

- Legal requirements.

9. Example sites

- West Fork mine, Missouri; Leviathan mine, California; Golinsky mine, Shasta Lake City, California; Stowell mine, Shasta Lake City, California; Copper Basin, Tennessee; Central City/Clear Creek, Superfund Site (US) (US EPA 2014)

10. Reference literature

(Celis-García *et al.* 2007)
(García *et al.* 2001)
(Greben *et al.* 2004)
(ITRC 2010b)
(Johnson 2003)
(Kinnunen *et al.* 2015)
(Mäkinen 2015a)
(Papirio *et al.* 2013)
(Reisman *et al.* 2008; Reisman *et al.* 2009)
(US EPA 2014)

4.3.2.2.3.3 Chemical precipitation

4.3.2.2.3.3.1 Hydroxide and carbonate precipitation

1. Description

Active treatment of EWIW aiming at removing dissolved metals by precipitation as metal hydroxides and/or carbonates by means of pH control, based on addition of acid or basic reagents.

2. Technical description

This BAT candidate is relevant for EWIW containing TDS. It is particularly relevant for EWIW containing dissolved metals.

Addition of alkaline, basic reagents controls the pH and causes precipitation of metallic cations Me^{n+} (typically divalent cations) at a specific pH to form metal hydroxide precipitates following the generic reaction (1):

$$Me^{n+} + n\,OH^{-} \leftrightarrows Me(OH)_n\,(s) \qquad (1)$$

In some cases, such as alumina refining, basic EWIW will require addition of acidic reagents to lower the pH to an optimum pH, ~ 4-7 for $Al(OH)_3$, in order to promote precipitation of aluminium cations.

In other cases, such as in base metal mines, acid EWIW will be treated with basic reagents in order to increase the pH to an optimum, usually ~ 8-10, depending on the targeted metal (see Table 4.40).

Indeed, the kinetics and efficiency of the reaction are the highest at a specific pH which depends on the targeted metals to be precipitated. As the solubility of the metal hydroxides depends on the pH, the precipitation is higher at a lower metal hydroxide solubility. Some theoretical pH values corresponding to the minimum metal hydroxide solubility are presented in Table 4.40.

Table 4.40: pH of minimum metal hydroxide solubility

Metallic cation	Approximate pH value corresponding to the minimum metal hydroxide solubility[a]
Fe^{3+}	3.5
Sb^{2+}	4.2
Al^{3+}	4.5
Pb^{2+}	6.5
Cu^{2+}	7.0
Fe^{2+}	8.0
Zn^{2+}	8.5
Ni^{2+}	9.3
Cd^{2+}	10.0
Mn^{2+}	10.6

[a] *(INAP 2014a)*

Therefore, the removal of multiple metals from the EWIW has to be carried out at different pH values. The reaction is usually carried out in a series of stages to enable the selective precipitation:

- To reach the targeted pH and "feed" the solution with hydroxide or carbonate anions, various reagents can be used such as:
    - quicklime (CaO) and sodium hydroxide (NaOH), which are the most common ones; nevertheless, limestone ($CaCO_3$), hydrated lime ($Ca(OH)_2$), soda ash (Na_2CO_3) and magnesium oxides (MgO) and carbonates ($MgCO_3$) are typical agents used for precipitation of metal hydroxides;

  - quicklime, which is slaked on site to produce hydrated lime; in some cases, it costs less to purchase directly hydrated lime;
  - limestone as precipitation reagent, which is limited to dissolved aluminium (Al^{3+}) and ferric iron (Fe^{3+}).

- Simultaneously to the hydroxide precipitation, the carbonate anions CO_3^{2-} precipitate with metallic cations following the generic reaction (2):

$$2\ Me^{n+} + n\ CO_3^{2-} \leftrightarrows Me_2(CO_3)_n\ (s) \qquad (2)$$

  The kinetics of the precipitation depends on the pH. Primarily, lead, nickel and zinc will be removed by means of carbonate precipitation.

- If limestone or lime is added, the calcium will promote removal of:
  - sulphate via precipitation as gypsum following equation (3):
  $$SO_4^{2-} + Ca^{2+} \leftrightarrows CaSO_4\ (s) \qquad (3)$$
  - arsenic (pentavalent) via precipitation as calcium arsenate following equation (4):
  $$2\ AsO_4^{3-} + 3\ Ca^{2+} \leftrightarrows Ca_3(AsO_4)_2\ (s) \qquad (4)$$
  - phosphorus (as phosphate) via precipitation as hydroxylapatite (5):
  $$6\ PO_4^{3-} + 10\ Ca^{2+} + 2\ OH^- \leftrightarrows Ca_{10}(OH)_2(PO_4)_6\ (s) \qquad (5)$$

- To adjust the pH in basic EWIW, acid reagent can be added. Typically, sulphuric acid is used.

Precipitation with, for example, lime in combination with a coagulation/flocculation step and a clarification step is also known as a High-Density Sludge process.

In bauxite/alumina extraction, seawater is used to lower the pH and act as a neutralisation/precipitation agent.

After precipitation, a solid/liquid separation technology, such as the one described in Section 4.3.2.2.2, is necessary to meet the legal requirements and more specifically to remove the suspended solids.

The overall precipitation efficiency can be improved by implementing along with hydroxide precipitation, aeration techniques (see Section 4.3.2.2.3.1.1), co-precipitation of iron and/or arsenic (see Section 4.3.2.2.3.4) and/or techniques to remove scaling and improve agitation, mixing and dissolution of reagents such as rotating cylinder systems (US EPA 2014).

Finally, after precipitation and solid/liquid separation, a final pH adjustment (re-acidification in metal mining) of the outflow prior to re-use/recycling or discharge will be required.

The technique is planned in the design phase and implemented in the operational phase:

- *Planning and design phase*
  Hydroxide or carbonate precipitation is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Hydroxide and/or carbonate precipitation are implemented to treat EWIW in order to remove part of the dissolved substances, especially dissolved metals.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.

The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - o preventing or reducing the level of solid and liquid dissolved substances, particularly dissolved metals, in the EWIW to be discharged into the receiving surface water body;
  - o neutralisation of EWIW.

4. Environmental performance and operational data

Both the selection of precipitation reagents and the consumption of different reagents are site-specific, depending on the reagent availability on site, the initial quality of EWIW to be treated and the final targeted quality.

Limestone addition can result in difficulties in treating ARD with a high ferrous-ferric ratio and ineffectiveness at removing manganese. Furthermore, loss of efficiency of the system has been reported, due to coating of the limestone particles with iron precipitates.

Soda ash briquettes are especially effective for treating small ARD flows in remote areas. The major disadvantage is the poor settling properties of the sludge.

Caustic soda is especially effective for treating low flows in remote locations and for treating ARD with a high manganese content. Major disadvantages are dangers involved with handling the chemical, poor sludge properties, and freezing problems in cold weather.

Typical achievable concentrations of metals after hydroxide and carbonate precipitation and solid/liquid separation are provided in Table 4.41.

Table 4.41: Hydroxide precipitation performance indicators

Parameter	Max. value or Min. – Max. ranges in discharged EWIW after treatment (mg/l) (from questionnaires[a])	Achievable concentration or concentration ranges (mg/l) (from literature[b])
Al	**0.200-0.423**	0.070-0.500
As (total)	**< 0.014**	< 0.030-~ 5.000
Cd	< 0.001	**0.0002-0.0005**
Cr (total)	**0.011-0.110**	NI
Cu	< 0.450	**0.002-0.070**
Fe (total)	0.200-2.100	**< 0.050-0.100**
Hg	**0.0001-0.0002**	NI
Mn	**0.100-0.200**	0.410-0.580
Ni	**0.026-0.061**	< 0.200
Pb	< 0.054	**< 0.050**
P (total)	0.049-1.100	**1.000**
Sulphate	1 585-43 850	**1 800-2 410**
W	**0.914-2.100**	NI
Zn	< 0.630	**< 0.400**

[a] *Data collected from site-specific questionnaires where hydroxide neutralisation/precipitation is implemented along with solid/liquid separation.*
[b] *(MEND 2014; US EPA 2014)*
NB: The best performance indicators are in bold.

5. Cross-media effects

- Reagents consumption.

- Sludge generation (typically 3-15 % w/w solids) and management.

6. Technical considerations relevant to applicability

- This treatment technique is generally applicable to the treatment of acidic EWIW and/or EWIW containing high levels of dissolved metals such as ARD or neutral mine drainage (NMD) in the management of extractive waste resulting from metal extraction or coal extraction.
- The implementation of the technique requires additional solid/liquid separation techniques to be implemented and final pH adjustment.
- The technique is not suitable for the removal of chromium, selenium and uranium.
- The applicability may be restricted in the presence of chelates, such as ammonia, and metal-complexing agents, such as cyanides, which will negatively influence the precipitation process.

7. Economics

- The reported CAPEX in literature (INAP 2014a) ranges from EUR 216 (USD 300, year 2009) per m^3/day to EUR 900 (USD 1 250, year 2009) per m^3/day of treatment capacity.
- The OPEX varies from EUR 0.15/m^3 (USD 0.2/m^3, year 2009) to EUR 1.1/m^3 (USD 1.5/m^3, year 2009) (INAP 2014a).
- From data collected via the questionnaire, the OPEX varies from less than EUR 0.02/m^3 to ~ EUR 1.3/m^3.
- Some indicative cost ranges of reagents are presented in Table 4.42 based on the ranges reported in (MEND 2014).

Table 4.42: Hydroxide precipitation reagent cost ranges

Reagent	Format	Cost (EUR/t)[a, b]
Limestone	Dry	~ 7-35
Quicklime	Dry	~ 60-180
Hydrated lime	Dry	~ 45-200
Sodium hydroxide	50 % w/w solution	~ 315-1 300
Soda ash	Dry	~ 115-260

[a] *Based on data taken from literature (MEND 2014; Pearce 2014).*
[b] *The costs provided are indicative and may vary significantly depending on quantities, location and market.*

8. Driving force for implementation

- Neutralisation of acid EWIW (see Section 4.3.2.2.4).
- AMD/ARD treatment.

9. Example sites

- Minas de Aguas Teñidas (ES)
- Aughinish Alumina Ltd (IE)
- Galmoy Mines (IE)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Kevitsa Mine (FI)
- Pyhäsalmi Mine Oy (FI)
- Aitik Mine (SE)
- Imerys Refractory Minerals Glomel (FR)
- Kisladag Gold Mine (TR)

10. Reference literature

(EC-JRC 2009)
(INAP 2014a)
(MEND 2014)
(Pöyry 2011a)

(US EPA 2014)

4.3.2.2.3.3.2 Sulphide precipitation of dissolved metals

1. Description

Active treatment used to remove dissolved metals from EWIW streams by means of precipitation of dissolved metals as metal sulphides by adding sulphide reagents.

2. Technical description

This BAT candidate is relevant for EWIW containing TDS. It is particularly relevant for EWIW containing dissolved metals.

The addition of sulphide reagents causes precipitation of metallic cations Me^{n+} (typically zinc, cadmium and arsenic) at a specific pH to form metal sulphide precipitates following the generic reaction (1):

$$2\ Me^{n+} + n\ S^{2-} \leftrightarrows Me_2S_n\ (s) \qquad (1)$$

Sulphide precipitation can be used to remove lead, copper, chromium (VI), silver, mercury, nickel, thallium, antimony and vanadium from EWIW.

Sulphide reagents usually used are:
- sodium sulphide (Na_2S);
- sodium hydrosulphide (NaHS);
- hydrogen sulphide (H_2S);
- ferrous sulphide (FeS);
- calcium sulphide (CaS);
- polymeric organo-sulphide chemicals.

The kinetics of sulphide precipitation are higher than those of hydroxide precipitation.

As for hydroxide precipitation, the technique has to be coupled with solid/liquid separation (see Section 4.3.2.2.2).

The technique is planned in the design phase and implemented in the operational phase:
- *Planning and design phase*
  Sulphide precipitation is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Sulphide precipitation is implemented to treat EWIW in order to remove part of the dissolved substances, especially dissolved metals.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits
- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances, particularly dissolved metals, in the EWIW to be discharged into the receiving surface water body.

4. Environmental performance and operational data
The precipitation occurs in a pH range typically in between 7 and 9 (INAP 2014a).

Typical achievable concentrations of metals after sulphide precipitation and solid/liquid separation are provided in Table 4.43.

Table 4.43: Sulphide precipitation performance indicators

Parameter	Achievable concentration from literature (mg/l)[a]
As^{3+}	< 0.050
Cd	< 0.004
Cu	< 0.030
Fe^{2+}	< 0.300
Mn^{2+}	< 0.050
Ni	< 0.050
Pb	< 0.050
Se	< 0.050
Zn	< 0.020-0.225

[a] *(ITRC 2010c; MEND 2014)*

Removal efficiencies of 90 % for cadmium and 99 % for zinc were reported in the US (ITRC 2010c).

5. Cross-media effects
- Metal sulphide sludge generation.
- Management of sludge requires reducing conditions.
- H_2S gas generation.
- Possible odour problems.

6. Technical considerations relevant to applicability
- As for hydroxide precipitation, the technique requires solid/liquid separation to remove precipitates.
- The recovery of metals is concentrated in the sludge; therefore the technique is generally applied to recover valuable metals from the EWIW. Nevertheless, the technique can be implemented after hydroxide precipitation as a polishing step even if it is not possible to obtain any financial benefit from metal recovery.

7. Economics
- Costs can be 10 times higher than for hydroxide precipitation due to higher reagent costs and sludge management costs.
- The reported OPEX vary from site to site in a wide range from ~ EUR 0.20/m^3 up to EUR 6.00/m^3.
- The average cost of planning, according to the MEND report, is ~ EUR 0.60-0.70/m^3.
- Some indicative cost ranges of reagents are presented in the following table based on the ranges reported in (MEND 2014).

Table 4.44: Sulphide precipitation reagent cost ranges

Reagent	Format	Cost (EUR/t)[a]
NaHS	44-46 % w/w solution 70-72 % w/w flake	~ 420-600
Na_2S	60-52 % w/w flake	~ 210
S	Dry	~ 320

[a] *(MEND 2014)*

8. Driving force for implementation
- Legal requirements.
- Metals recovery.

9. Example sites
- No information provided.

10. Reference literature
(INAP 2014a)
(ITRC 2010c)
(MEND 2014)

4.3.2.2.3.4 Co-precipitation with chloride or sulphate metal salts

1. Description
It is a process that consists of adding metal chloride or sulphate salts to remove trace metals such as As, P or Se or ^{226}Rafrom EWIW by co-precipitation of contaminants at acid pH.

2. Technical description
This BAT candidate is relevant for EWIW containing TDS. It is particularly relevant for EWIW containing radium-226.

Dissolved metals are removed from the EWIW using ferric iron or aluminium salts as coagulants in a two-step process to co-precipitate the metals.

Salts are added to co-precipitate and adsorb certain metals onto ferric hydroxide precipitates. In detail, the addition of a ferric iron or aluminium salt to the water generates a ferric hydroxide and ferrihydrite precipitate, the formation of which results in concurrent adsorption of metals at the surface. The precipitates are then removed by means of solid/liquid separation. According to the US Environmental Protection Agency (US EPA 2014), this method is widely implemented at full scale.

According to the MTWR BREF (EC-JRC 2009), a typical example is the removal of arsenic either as calcium or as ferric arsenate by precipitation.

- Arsenites can also be precipitated, but they are generally more soluble and less stable than arsenates. Arsenite-containing EWIW is generally oxidised prior to precipitation to ensure that the arsenate predominates. Process water from the processing of arsenic-bearing ores may contain varying amounts of arsenic (III) and (V) oxyanions, arsenite and arsenate. The presence of metal ions such as copper, lead, nickel and zinc limit the solubility of arsenic due to the formation of barely soluble metal arsenates.
- The stability and solubility of these arsenates depends on the ratio of iron to arsenic. The larger the ratio, the more insoluble and stable the precipitate. Thus, where ferric arsenate is relatively soluble, the basic arsenates with an iron-to-arsenic molar ratio of eight or more are orders of magnitude less soluble in the pH range of approximately 2 to 8.
- The precipitation of insoluble ferric arsenates is very likely to be accompanied by the co-precipitation of other metals such as selenium. This involves interactions between the various metal species and the ferric hydroxide precipitate. This makes ferric salts a very effective scavenger for the removal of trace contaminants. The process normally involves the addition of a soluble ferric salt to the process water, followed by the addition of sufficient base to induce the formation of insoluble ferric hydroxide. In many situations, the process water contains adequate iron, thus only the addition of a base is required to induce the precipitation of ferric hydroxide.
- The co-precipitation process of pentavalent arsenic follows the reaction below:

$$2\ H_3AsO_4^{3-} + 2\ H_2O + Fe_2(SO_4)_3 \leftrightarrows 2\ FeAsO_4 \cdot H_2O(s) + 3\ H_2SO_4 \quad (1)$$

Barium chloride is used to remove radium-226 from EWIW. The barium co-precipitates with radium in a barium-radium sulphate.

A background concentration of sulphate is therefore necessary to enable the reaction. Ferric or aluminium sulphates can be used to achieve the necessary concentration.

The technique is planned in the design phase and implemented in the operational phase:

- *Planning and design phase*
  Co-precipitation with metal salts is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Co-precipitation is implemented to treat EWIW in order to remove part of the dissolved substances, especially dissolved metals.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances, such as arsenic, phosphorus and radium, in the EWIW to be discharged into the receiving surface water body.

4. Environmental performance and operational data

Ferric chloride ($FeCl_3$), ferric sulphate ($Fe_2(SO_4)_3$) or aluminium salts such as aluminium chloride ($AlCl_3$) and aluminium sulphate ($Al_2(SO_4)_3$) can be used to co-precipitate for example As, P or Se.

Barium or strontium chlorides or sulphates are usually employed to co-precipitate ^{226}Ra.

The precipitation of stable ferric arsenate occurs at a controlled pH and ferric iron to arsenic stoichiometric ratio. With a pH in the range of 4-6 and a Fe/As ratio > 4, dissolved arsenic concentrations of 0.5 mg/l or less can be obtained by precipitation with ferric iron. According to (MEND 2014), concentrations of less than 0.1 mg/l of arsenic can even be achieved.

Concentrations of other dissolved elements such as antimony and molybdenum of < 0.5 mg/l can be achieved by contact with ferric hydroxide.

Concentrations of selenium of ~ 0.090 mg/l are reported to be achievable (MEND 2014; US EPA 2014).

The removal of radium with barium chloride can effectively reduce the radium content in EWIW below 0.37 mg/l (MEND 2014).

5. Cross-media effects

- Consumption of ferric salts, aluminium salts or barium chloride.

6. Technical considerations relevant to applicability

- Solid/liquid separation such as gravity sedimentation is required to separate iron solids and adsorbed metals from the outflow.
- The applicability may be restricted in the case of sensitiveness to higher variations in EWIW quality and therefore an equalisation step prior to treatment is usually required.

7. Economics
- Costs are similar to those reported for hydroxide precipitation (see Section 4.3.2.2.3.3.1).

8. Driving force for implementation
- Synergies with other treatment processes such as coagulation/flocculation.

9. Example sites
- Some sites in Finland, as reported in the Closedure project (Merta 2015a)
- Several precious metal, diamond and metal ore extraction sites in Canada (MEND 2014)
- Kennecott Utah Copper Corporation Garfield Wetlands-Kessler Springs, Utah (US) as reported in the Closedure project (Merta 2015a)

10. Reference literature
(EC-JRC 2009)
(MEND 2014)
(Merta 2015a)
(US EPA 2014)

4.3.2.2.3.5 Adsorption

4.3.2.2.3.5.1 Removal of dissolved solids

1. Description
The adsorption of dissolved metals and other pollutants from the EWIW is based on the surface properties of a medium, which is selected in order to attract and adsorb pollutants.

2. Technical description
This BAT candidate is relevant for EWIW containing TDS.

A very wide variety of materials can be used to perform adsorption. Materials used for the management of extractive waste also encompass waste materials or by-products from other industries. Therefore, it is not possible to exhaustively address them in this document. According to the Closedure project (Merta 2015b), the most common ones for the management of extractive waste are:
- zeolites;
- activated carbon;
- natural materials: clays such as bentonite, kaolinite;
- non-hazardous industrial mineral wastes or by-products such as red mud, fly ash, iron slag, extractive waste from mineral processing containing hydroxides or silicates;
- natural biological materials such as plants (see phytotechnologies), algae or bacteria;
- non-hazardous biological waste such as sawdust, agricultural waste;
- iron oxides and hydroxides.

Materials used as adsorbers are usually finely grinded to enhance the adsorption performance as finer particles will have a higher specific surface.

The technique can be applied by directly mixing absorbers with EWIW, in which case a solid/liquid separation process will be required to remove the solid particles after adsorption, or by passing the EWIW through a column containing the adsorbing materials, in which case the adsorbing media will require backwashing or renewal.

The technique is planned in the design phase and implemented in the operational phase:

- *Planning and design phase*
  Adsorption systems are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Adsorption is usually applied as a polishing step (secondary treatment).
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances, such as iron, manganese, organic carbon, BTEX, heavy metals and oil, in the EWIW to be discharged into the receiving surface water body.

4. Environmental performance and operational data

The pH needs to be controlled in order to achieve the best performance.

Depending on the targeted pollutants and adsorbing media used, the optimum operating pH can vary from ~ 4 to 10. A pH adjustment after treatment might be required.

The process can work by gravity without requiring energy consumption except during maintenance to regenerate the media.

5. Cross-media effects

- Where media are not regenerated, disposal of solid waste has to be planned.

6. Technical considerations relevant to applicability

- The applicability may be restricted in the case of high levels of salt, whichwould prevent proper adsorption.

7. Economics

- No information provided.

8. Driving force for implementation

- The presence of extractive waste from mineral processing and/or other extraction materials present on site that can be used as absorbers.

9. Example sites

- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)

10. Reference literature

(EC-JRC 2009)
(Merta 2015b)

4.3.2.2.3.5.2 Removal and recovery of water-soluble hydrocarbons from flowback and produced water resulting from oil and gas exploration and production, using Regenerable Polymeric Adsorbents

1. Description

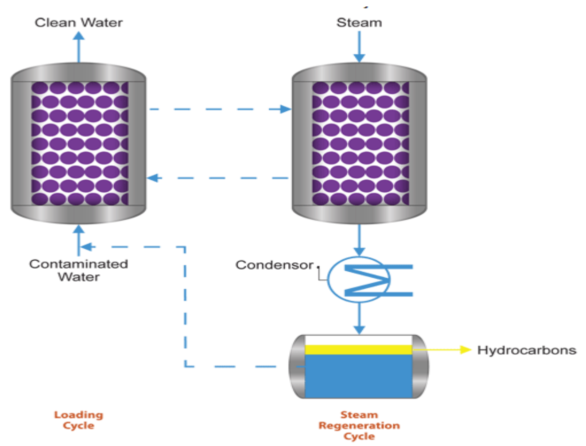
This technique involves the use of regenerable polymeric adsorbent media to remove and recover water-soluble petroleum hydrocarbons (e.g. BTEX) in flowback and produced water resulting from oil and gas exploration and production.

2. Technical description

This BAT candidate is relevant for EWIW containing water-soluble hydrocarbons.

The process uses synthetic methylene-bridged polymeric media to absorb and remove soluble organics and residual oil from water. The polymeric adsorbents are supplied in the form of hard spherical beads possessing both a large surface area within micro-pores and a high pore volume in the meso-pore and macro-pore structures. This results in both a high loading capacity and rapid mass transport (kinetics). Due to the engineered pore structure of the product, adsorbents can be thermally regenerated on site and quickly put back into service. This allows minimisation of system size and reduces overall treatment costs.

A simple block diagram of regenerable adsorbent operation is depicted in Figure 4.43.



Source: provided by the TWG

Figure 4.43: Block diagram of Regenerable Adsorbent Operation

Loading cycle: During the loading cycle, the process works as an ion exchange system (see Section 4.3.2.2.3.6). The raw water is run through the media beds either downstream or upstream at a spatial velocity of 20-100 Bed Volumes per hour (BV/h) until breakthrough of the target contaminant is observed in the EWIW. At this point, the resin has reached its effective loading capacity. The loading capacity of organics in the resin is generally 10-40 % w/w.

Regeneration cycle: Once the useful adsorption capacity is exhausted, the fully loaded bed of media is taken out of service, drained and regenerated. The steam regeneration procedure consists of the following steps:

- The residual water between the media particles is blown down by introduction of air, nitrogen or steam.
- The outlet for the media column is closed and steam is introduced to the media column at the supply pressure of 1-10 bars. Steam is applied for 4-6 hours. Higher steam pressure, with higher temperature, results in faster and more efficient regeneration.

- Once the media column reaches a steady temperature and pressure, a valve is opened between the outlet of the media column and inlet to the steam condenser.
- The steam used for regeneration is condensed and collected in a separate vessel. The hydrocarbons are skimmed from the collection vessel and the condensed steam, which may be saturated with soluble hydrocarbons, is sent back to the beginning of the process.

The technique is planned in the design phase and implemented in the operational phase:

- <u>*Planning and design phase*</u>
  Adsorption systems are planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- <u>*Operational (construction, management and maintenance) phase*</u>
  The technique is usually applied to remove dissolved hydrocarbons from EWIW.
- <u>*Closure and after-closure phase*</u>
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body, such as:
    - Water-Soluble Organics (WSO) removal;
    - removal of semi-soluble petroleum hydrocarbons including: (poly)aromatic compounds and their derivatives (e.g. BTEX, phenols, NPD).
- As part of an integrated system for the treatment of flowback and water produced by reverse osmosis and thermal desalination, the technique may use less energy than contained in the recovered hydrocarbons.
- The technology is able to reduce VOC emissions to the atmosphere associated with air stripping and degasification of produced waters, and significantly reduces passive VOC emissions resulting from ambient produced water storage.
- Being *regenerable* media, the engineered adsorbents eliminate the need to consume, transport and dispose of *single-use* media such as activated carbon.

4. Environmental performance and operational data

Generally, the steam requirement is 1-3 kg per kg of Water-Soluble Organics (WSO) recovered. Performance levels are reported in Table 4.45.

Table 4.45: Field data - Residual oil measurements

Residual oil measurements	Total oil and grease [a]	GRO [b]	DRO [c]
Raw water to media filter pretreatment (ppm)	11	150	38
Pre-treatment outflow, Polymeric absorbent inflow (ppm)	2.2	46	6.6
Polymeric absorbent outflow (ppm)	< 1	0.13	2.9
Removal by media filter	80 %	69 %	83 %
Removal by the polymeric adsorbents	-	99.9 %	92.4 %

[a] *Total oil and grease per EPA Method 1664.*
[b] *Gasoline Range Organics (GRO).*
[c] *Diesel range organics (DRO) per EPA 8015C.*
Source: Encana's Moneta Divide Project

5. Cross-media effects

- Possible transfer of contaminants to an alternate waste stream.
- Energy consumption for steam generation.

6. Technical considerations relevant to applicability

- The technique is applied as a tertiary treatment for discharge of produced waters or as a pretreatment step in an integrated water treatment system designed for re-use/recycle applications (e.g. produced water desalination).
- In oilfield waste water applications, regenerable adsorbent media requires protection from foulants. These include: some heavier and higher molecular weight oil, tars, some oil-wet solids (e.g. iron sulphide), and excessive concentrations of solids. These foulants have the potential to clog the resin bed and/or foul the matrix of the resin beads.
- The technique is not suitable for the treatment of EWIW with high salinity that would damage the membrane or limit its efficiency.
- Considerations are usually made with respect to availability of low-pressure steam or solvents on site for regeneration of the adsorbent media. Methanol regeneration is a possible alternative.

7. Economics

Two economic cases deserve consideration:

- Overall cost to treat vs. value of recovered hydrocarbons shows the value of saleable hydrocarbons captured assuming a price of EUR 506/m^3 of oil (EUR 80/bbl-oil) over a range of WSO concentration and treatment capacities (Goltz and Johnson 2014).
- Relative cost vs. next best alternative shows a simple cost comparison between activated carbon and regenerable adsorbent media presented to the American Filtration Society in March 2014 (Johnson and Goltz 2014).

Table 4.46: Value captured from recovered hydrocarbons

Concentration of Water-Soluble Organics (ppm)	Value captured (EUR/m^3) *(EUR/bbl-water)*
50	0.16 *(0.02)*
100	0.25 *(0.03)*
200	0.50 *(0.06)*

Table 4.47: Cost comparison of regenerable adsorbent vs. activated carbon

	Activated carbon	Regenerable adsorbent
Fate of exhausted media	Disposal / off-site regeneration	On site regeneration
Required rate of removal	4.53 kg/h (10 lbs/h)	
Media requirement	108 kg/day (240 lbs/day), 39 139 tonne per year (86 400 lbs per year)	24 hr regeneration cycles 2x108 kg (240 lbs media)
Cost of media replacement	EUR 161 990 (USD 216 000, year 2014) per year EUR 4.12/kg (USD 2.5/lb, year 2014) with local disposal	EUR 15 000 (USD 20 000, year 2014) replaced every 3-5 years
Recovered hydrocarbon	None	108 kg/day (240 lbs/day)

8. Driving force for implementation

The following forces are driving adoption of regenerable adsorbents in oil and gas applications:

- Environmental impact on water resources. Residual Water-Soluble Organics (WSO) in produced water are receiving increased attention due to the environmental impact on water discharges. Conventional de-oiling technologies do not effectively address their removal.
- Reclamation of saleable product from exploration and production wastes. The capability of the technology to recover saleable components is attractive to oil and gas producers.

- Reduction of emissions to air. Many soluble and semi-soluble components on the light oil spectrum are semi-volatile and have the potential to create issues with odour and emissions air. The toxicity of some of these components (e.g. benzene) is driving stricter monitoring requirements and more stringent specifications for discharge of produced waters.
- Adoption of advanced treatment technologies for re-use and recycling. Pretreatment for WSO is often required to enable use of desalination technologies. In the case of membrane (reverse osmosis) desalination, soluble residual petroleum hydrocarbons dissolve various materials of high-pressure element construction and irreversibly foul the membrane. When thermal methods are used for desalination, volatile components interfere with the distillation process and may cause unintentional emissions in the evaporator overheads.

9. Example sites
- Encana's Neptune desalination facility, Wyoming (US) (DOW 2014)

10. Reference literature
(DOW 2014, 2016)
(Goltz and Johnson 2014)
(Johnson and Goltz 2014)

4.3.2.2.3.6 Ion exchange

1. Description
Ion exchange consists of exchanging charged compounds/ions between an inflow stream and a solid medium (commercial resins or naturally occurring materials like peat and zeolites). A specific compound/ion is absorbed by the medium and replaced in the stream with an ion liberated from the medium.

2. Technical description
This BAT candidate is relevant for EWIW containing TDS.

Ion exchange is based on the exchange of charged compounds/ions between an inflow stream and a medium. A specific compound/ion is absorbed by the medium due to its high affinity with the medium and replaced in the stream by another ion released from the medium.

For that purpose, the EWIW is driven through a column containing the medium ("reactor tank"). The outflow is concentrate containing released cations and anions but cleared of the targeted compound.

The solid media used in ion exchange can be commercially produced (usually resins) or made from naturally occurring substances (e.g., peat, zeolites). Various resin forms are available to remove either cations or anions. Synthetic organic resins are the predominant type since their characteristics can be tailored to specific applications/compounds. The selectivity of the resin is controlled by selecting the appropriate functional group.
- *Resins* are usually designed to remove one or a few targeted groups. Therefore, several types of resins might be necessary to remove different compounds.
- *Synthetic materials* are polymers with functional groups associated initially to sodium (Na^+), hydrogen (H^+), chloride (Cl^-) and hydroxide (OH^-) ions.

The operating capacity of any media will depend on the number of available exchange sites, and the inflow water chemistry/quality.

Once the resin reaches the exchange capacity it has to be replaced or regenerated. Typical solutions used for regeneration are caustic soda, sulphuric acid, sodium chloride, or hydrochloric acid.

After acid or base regeneration, the medium is washed to recover the targeted substances from the medium and finally a neutralisation step is required before putting the resin back into service.

The technique is planned in the design phase and implemented in the operational phase:

- *Planning and design phase*
  Ion exchange treatment is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Ion exchange is usually applied as a secondary treatment.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of solid and liquid dissolved substances in the EWIW to be discharged into the receiving surface water body, such as:
    - calcium, magnesium;
    - barium, strontium;
    - radium and radionuclides;
    - nitrates, fluoride, arsenates, chromates, uranium complexes;
    - boron and heavy metals.

4. Environmental performance and operational data

During operation the pH is usually controlled in a range of 4 to 8.
The achievable performances of ion exchange are reported in Table 4.48 based on the data collected via the questionnaires and in literature (MEND 2014; US EPA 2014).

Table 4.48: Ion exchange performance levels

Parameter	Max. value or Min. – Max. ranges in discharged EWIW after treatment (mg/l) (from the questionnaires[a])	Achievable concentration or concentration ranges (mg/l) (from literature[b])
Al	NI	**< 0.050**
As	NI	**< 0.005**
B	**< 5.0**	NI
Cu	NI	**0.010-0.030**
Co	NI	**< 0.010**
Fe (total)	**0.004-0.055**	< 0.200
Mn	NI	**< 0.500**
Mo	**0.031-0.109**	NI
N (total)	**7.0-18.0**	NI
NH_4^+	NI	**9.0-11.6**
Ni	NI	**< 0.010**
Pb	NI	**< 0.020**
Se	NI	**0.005-0.010**
U	**0.035-0.145**	NI
Zn	NI	**< 0.020**

[a] Based on site-specific questionnaires where ion exchange technology is implemented.
[b] (MEND 2014; US EPA 2014)
NB: The best performance indicators are in bold.
NI stands for No Information.

5. Cross-media effects
- Chemical consumption.
- Generation of concentrated brines.

6. Technical considerations relevant to applicability
- The solid medium for the removal of targeted compounds will depend on the site-specific chemistry of the EWIW to be treated.
- Ion exchange is not applicable with a low pH (< 4.0).
- High concentrations of iron, aluminium or manganese considerably worsen the performance of the media.
- The more complex the mixture, the harder it is to remove all metals effectively.
- The removal efficiency will depend, among others, on the selectivity which depends on the medium.In fact, the targeted cations and their preference/affinity for a strong acid resin and a natural zeolite are considerably different:
  - according to ITRC (ITRC 2010d), a typical order of preference for cations on strong acid resins is:
    $Pb^{2+} > Ca^{2+} > Ni^{2+} > Cd^{2+} > Cu^{2+} > Zn^{2+} > Mg^{2+} > K^{+} > NH_4^{+} > Na^{+} > H^{+}$
  - according to MEND (MEND 2014), the selectivity of zeolites is as follows:
    $Cs^{+} > Rb^{+} > K^{+} > NH_4^{+} > Ba^{2+} > Sr^{2+} > Na^{+} > Ca^{2+} > Fe^{3+} > Al^{3+} > Mg^{2+}$
- Ion exchange media are sensitive to fouling/clogging by organic compounds such as oil and grease which are removed from the inflow stream as far as possible before treatment (oil and grease < 2 mg/l in some cases).
- Scale formation on resins can considerably worsen the performance of the treatment.
- This technique is usually implemented as a polishing step, in order to reach the final quality standard. A high content of suspended particles clogs the medium and hence worsens its performance (inflow TSS < 2 mg/l might be required). A pretreatment is needed (e.g. microfiltration or ultrafiltration) to remove suspended solids/particles.
- The applicability may be restricted in the case of high levels of salts that would prevent proper ion exchange.

7. Economics
- A CAPEX of ~ EUR 800 000 was reported for ~ 1 m^3/min treatment capacity.
- Reported annual OPEX in literature range from ~ EUR 150 000 per year to more than EUR 10 million per year depending on the flow rate of treated water (from ~ 0.23 m^3/min to ~ 2.66 m^3/min).
- Typical OPEX including equipment, resin and chemicals is expected to be ~ EUR 0.30/m^3 for ion exchange technology.
- In literature, reported OPEX for ion exchange alone fall in a range of ~ EUR 0.20-0.50/m^3.

8. Driving force for implementation
- Legal requirements.
- High water quality and beneficial water re-use/recycling.
- Water scarcity in some regions makes the technique profitable compared to the costs of fresh water withdrawal.
- Reduced costs for the management of EWIW.

9. Example sites
- Diamo s.e. branch plant GEAM Dolní Rožínka (CZ)
- Cetățuia II tailing pond (RO)
-

<u>From additional literature sources</u>
- The Anticline Disposal LLC facility in Boulder, WY (US) using a boron-selective ion exchange resin as the final step in a reverse osmosis-produced water desalination facility since 2011 ((Shafer 2011) from questionnaire); Soudan State Park, MN (US) (ITRC 2010d)

10. Reference literature
(ITRC 2010d)
(Hansen *et al.* 2008)
(MEND 2014)
(Merta 2015d)
(Shafer 2011)
(US EPA 2014)

4.3.2.2.3.7 Nanofiltration

1. Description
Nanofiltration is a pressure-driven separation technique using a semi-permeable membrane rejecting contaminants by means of size and/or charge exclusion.

2. Technical description
This BAT candidate is relevant for EWIW containing TDS.

In nanofiltration, multivalent dissolved solids are removed from the EWIW by driving the EWIW under pressure through a semi-permeable and selective membrane that will allow water molecules and monovalent ions to pass through but will reject multivalent ions by means of size and charge exclusion.

The dissolved ions are retained in a concentrated solution.

The technique is planned in the design phase and implemented in the operational phase:

- *Planning and design phase*
  Nanofiltration is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Nanofiltration is usually applied as a secondary treatment.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of multivalent solid dissolved substances in the EWIW to be discharged into the receiving surface water body.
- Prevention or minimisation of visual and footprint impacts resulting from the management of extractive waste by:
  - being a flexible application with a relatively small footprint.

4. Environmental performance and operational data
Nanofiltration membranes are engineered to selectively reject as much as 95-99 % of divalent ions while letting through as much as 90 % of monovalent ions (e.g. Na^+ and Cl^-) (CSM 2009).

However, for feed solutions containing 2 000 mg/l of TDS and an applied pressure of 5 bar typical rejection levels of 60 % for sodium chloride, 80 % for calcium carbonate, and 98 % for magnesium sulphate are referenced in literature (MEND 2008) (ITRC 2010m).

Water recovery is in between 75-90 % (CSM 2009).

Nanofiltration is most often used for water with low TDS for the purpose of removing cations (softening). Nanofiltration is generally applied when the nominal TDS ranges between 500 mg/l and 15 000 mg/l (CSM 2009).

Multivalent dissolved metals removal efficiency varies from 84 % to 95 % depending on the metals (MEND 2008) (see Table 4.49).

Table 4.49: Nanofiltration performance levels

Parameter	Removal efficiency [a]
Al	> 95 %
As (V)	> 90 %
Cu	> 90 %
Fe	> 95 %
Pb	> 84 %
Mn	> 95 %
Ni	> 95 %
Se	> 90 %
Zn	> 95 %

[a] *(MEND 2008)*

The usual pore size of nanofiltration membranes is ~ 0.0015 µm to 0.0025 µm (Gusek and Figueroa 2009). The operating pressure ranges from 1 MPa to 2.7 MPa (Gusek and Figueroa 2009; ITRC 2010m).

TSS has to be removed prior to nanofiltration, which is used as a polishing step (secondary treatment) and generally associated with reverse osmosis (see Section 4.3.2.2.3.8).

The brine produced is typically 20 % to 30 % of the influent flow in a single system, depending on influent water quality.

The treated stream may also require pH and TDS buffering prior to discharge to receiving waters to meet regulatory requirements (US EPA 2014).

5. Cross-media effects
- Energy consumption (~ 0.5 kWh/m^3).
- High capital and operation and maintenance costs.
- Fouling of membranes and scale production.
- Potential difficulty for concentrate disposal.

6. Technical considerations relevant to applicability
- Depending on the membrane, pH and temperature control might be required in order to assure efficient removal and avoid membrane deterioration.
- Nanofiltration is not applicable to monovalent ions.
- The technique is usually not applicable to EWIW with a TSS content higher than 100 mg/l.
- The applicability may be restricted by requirements for disposal of brine solution.
- The applicability may be restricted in the case of high levels of salts that would prevent proper nanofiltration.

7. Economics
- CAPEX: EUR 5 000-30 000 per m^3/h of treatment capacity.
- OPEX: EUR 0.2-0.6/m^3.

8. Driving force for implementation
- Environmental and legal requirements.
- Protection of downstream equipment.

- Protection of water resources and water availability.
- Can also be used to treat mine water.

9. Example sites

- Proyecto Cobre Las Cruces (ES)
- Bingham Canyon Water Treatment Plant, Kennecott site, Utah (US) (MEND 2008)

10. Reference literature

(CSM 2009)
(ITRC 2010m)
(MEND 2008)
(US EPA 2014)

4.3.2.2.3.8 Reverse osmosis

1. Description

Reverse osmosis is a water purification technology based on a semi-permeable membrane filtration where pressure is applied to overcome osmotic pressure and separate solutes from the solvent.

2. Technical description

This BAT candidate is relevant for EWIW containing TDS.

<u>Reverse osmosis</u> uses a semi-permeable membrane through which EWIW flows by applying pressure. The membrane is the primary component of a reverse osmosis system. Molecules and ions are rejected by means of size and charge by controlling the pore size of the membrane and the chemistry. The typical pore size in reverse osmosis is < 0.002 µm, according to ITRC and the CWW BREF (Brinkmann *et al.* 2016; ITRC 2010m). As a result of the treatment, almost pure water (called "permeate") will flow out whereas a more highly concentrated brine solution will remain upstream as the rejected part (called "concentrate" or "reject stream").

This high-grade purity filtration process is therefore used to remove ionic solutes, dissolved metals (mono or multivalent), and macromolecules or bacteria from feed solution.

<u>Membranes</u> are usually made of cellulose acetate, or polymers such as polyamide, polyimide, polycarbonate, polyvinylchloride, polysulphone, polyacetal, polyacrylates, etc., according to the CWW BREF (Brinkmann *et al.* 2016).

The development of a new generation of membranes, such as thin-film composite membranes, has enabled reverse osmosis to be suitable for water treatment in a wide range of operating conditions (wide pH ranges, high temperatures, oxidising EWIW) (ITRC 2010m).

The purification of EWIW by reverse osmosis requires a pretreatment, typically clarification and ultrafiltration, prior to reverse osmosis filtration, in order to remove suspended solids that might clog the membrane.

The technique is planned in the design phase and implemented in the operational phase:

- <u>*Planning and design phase*</u>
  Reverse osmosis is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- <u>*Operational (construction, management and maintenance) phase*</u>
  Reverse osmosis is usually applied as a secondary treatment.
- <u>*Closure and after-closure phase*</u>

The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the level of dissolved solid and biological matter in the EWIW to be discharged into the receiving surface water body, such as:
    - salts;
    - metals;
    - macromolecules.

4. Environmental performance and operational data

Solutions with higher TDS concentrations have greater osmotic pressures, and therefore require more hydraulic pressure to produce permeate.

The usual pore size of reverse osmosis membranes is below 1.5 nanometres. The required operating pressure ranges from 2.7 MPa to 10.3 MPa (Gusek and Figueroa 2009).

According to MEND (MEND 2014), the removal efficiencies reported in Table 4.50 can be achieved.

Table 4.50: Reverse osmosis performance levels

Parameter	Removal efficiency [a]
Al	95-99 %
As (V)	91-99 %
Cl	> 98 %
Cu	> 95 %
Fe	> 95 %
Mn	> 95 %
NH_4^+	> 85 %
Ni	> 95 %
P	> 80 %
Se	91-99 %
Zn	> 95 %

[a] *(MEND 2014)*

5. Cross-media effects

- Energy consumption (< 0.15 kWh/m^3 to ~ 0.80 kWh/m^3) (CSM 2009; MEND 2014).
- Brine generation.

6. Technical considerations relevant to applicability

- The introduction of oxidising chemicals like peroxide, chlorine, and chromic acid can cause polymer membranes to degrade.
- Reverse osmosis is not applicable with high temperatures (> 45 °C) as membranes do not tolerate elevated temperatures (CSM 2009).
- Pretreatment is necessary to prevent membrane fouling due to organic matter and particularly if the water contains elevated levels of hardness (i.e. calcium or magnesium) or TSS. With pretreatment and routine maintenance, membranes typically last 2 to 7 years (CSM 2009; US EPA 2014).
- Reverse osmosis membrane processes are typically applied for treatment of saline streams with TDS concentrations ranging from 500 mg/l to 20 000-40 000 mg/l.
- The system limitations are (US EPA 2014):

  - o requirements for disposal of brine solution;
  - o reverse osmosis permeate steam will require treatment prior to discharge to receiving waters to meet aquatic toxicity test limits;
  - o frequent membrane monitoring and maintenance;
  - o need for temperature control at low and high temperatures to minimise viscosity effects.
- The applicability may be restricted in the case of very high levels of salts (~ 200 g/l or higher) which would prevent proper reverse osmosis.

7. Economics

- Reverse osmosis capital costs range from ~ EUR 200 to EUR 1 700 per m^3/day of treatment capacity depending on various factors including treatment capacity, complexity of the design, construction materials and control system.
- Operating costs are highly dependent upon energy price, feed water TDS, and choice of chemistry. Baseline operating costs for a conventional two-pass or two-stage reverse osmosis may be approximately EUR 0.45/m^3. Using high-pH feeds (pH > 10) and unconventional chemistry to mitigate membrane fouling can add as much as EUR 2.25/m^3 (Johnson 2014).
- For oilfield applications, it is often the cost of pretreatment and brine disposal that determines the economic viability of the reverse osmosis/nano-filtration processes. In 2004, CDM Engineering published a review of economics and economic factors impacting membrane processes in oilfield applications for the Petroleum Association of Wyoming, Section 3 (CDM 2004).
- From the site-specific questionnaires, the overall cost for water treatment with reverse osmosis technology including filtration, sedimentation and evaporation in some cases was between EUR 0.16/m^3 and EUR 4.33/m^3.

8. Driving force for implementation

- Driving forces for desalination of produced water tend to be local and closely related to specific extractive waste management (e.g. management of extractive waste resulting from oil and gas or uranium extraction) and the applied extraction methods. For example:
  - o limited water availability or limited disposal options;
  - o in oil and gas: aging fields generating more water than is required for secondary recovery thus limiting the possibility to re-use or recycle flowback and/or produced water, resulting in the need to discharge properly treated excess water;
  - o possibility to recycle water into processes that require a high quality water input.

9. Example sites

- Feldioara, Brasov (RO)
- Dolní Rožínka (CZ)
- Efemçukuru Gold Mine (TR)
- Moneta Divide Field, Wyoming; Pinedale, Wyoming; San Ardo, California; San Luis Obispo, California; Eagle Ford Shale and Permian Basin, Texas; Rubiales Field, Columbia (US)

10. Reference literature

(Brinkmann *et al.* 2016)
(CDM 2004)
(CSM 2009)
(DOW 2014)
(ITRC 2010m)
(Johnson 2014)
(MEND 2014)
(Shafer 2011)
(Simard 2013)
(Smith 2013)
(Tao *et al.* 1993)

(Webb *et al.* 2009)

4.3.2.2.4 Neutralisation of EWIW prior to discharge

4.3.2.2.4.1 Active neutralisation

1. Description
Active treatment of EWIW based on addition of acidic or basic reagents in a pond or a tank in order to control the pH and reduce the acidity or alkalinity of EWIW.

2. Technical description
This BAT candidate is relevant for acidic or alkaline EWIW.

<u>The neutralisation process</u> is based on the principle of acid-base reaction. In the case of alkaline EWIW, e.g. from a bauxite-alumina refining process or from hydroxide precipitation, an acid reagent is added to the EWIW in order to adjust the pH as far as possible to a neutral value and to reduce the total alkalinity of the EWIW.

Generally the pH is adjusted in a range required by the permit (varying in most cases from 6-7 to 9-10) or by the downstream process if water is intended for re-use/recycling.

The system can be designed to operate continuously or in batches.

The process will require:

- *a neutralisation pond or tank*;
- *a neutralisation reagent* such as:
    - o sulphuric acid solution, carbon dioxide gas or seawater to neutralise alkaline EWIW;
    - o sodium hydroxide, magnesium hydroxide, lime or ammonia to neutralise acidic EWIW;
- *a reagent feeding system*;
- *a mixing device*.

The technique is planned in the design phase and implemented in the operational phase:

- *<u>Planning and design phase</u>*
  Active neutralisation is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *<u>Operational (construction, management and maintenance) phase</u>*
  Active neutralisation is usually applied as the final step to adjust the pH.
- *<u>Closure and after-closure phase</u>*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
    - o preventing or minimising the discharge of acidic or alkaline EWIW into the receiving surface water body.

4. Environmental performance and operational data
Collected data with the questionnaire indicate that the pH is adjusted:

- to, on average, between 7.2 and 8.2 prior to discharge;

- with peak minimum and maximum values of 5.6 and 11.0 respectively.

Consumption of reagents is site-specific depending on EWIW quality and chemistry.

The neutralisation potential of some common reagents (alkali materials) used for neutralisation of acidic EWIW is presented in Table 4.51.

Table 4.51: Alkali materials used for neutralisation

Alkali material	Theoretical material requirement to neutralise 1 tonne of acidity (expressed as t of $CaCO_3$)
Limestone ($CaCO_3$)	1.0
Magnesite ($MgCO_3$)	1.19
Dolomite ($CaMg(CO_3)_2$)	1.08
Soda ash (Na_2CO_3)	1.06
Caustic soda (NaOH)	0.8
Hydrated lime ($Ca(OH)_2$)	0.74
Lime (CaO)	0.56
Magnesium oxide (MgO)	0.4

Based on data collected from literature (Gusek and Figueroa 2009; INAP 2014a)

5. Cross-media effects
- Sulphuric acid consumption.
- Alkali reagents consumption.

6. Technical considerations relevant to applicability
- The neutralisation and clarification system is provided with the capacity to handle seasonal loads taking into account the design storm rainfall and the available buffer storage capacity.
- Active treatments do not have technical limitations other than the design characteristics.

7. Economics
- The cost of the treatment of EWIW with lime is ~ EUR 0.1 per tonne of extractive waste from mineral processing of metal ores, according to the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation
- Dissolved metal removal by the precipitation process.
- Legal requirements.

9. Example sites
- LKAB Kiruna Iron ore Mine (SE)
- Aughinish Alumina Ltd (IE)
- Sardinian Alumina refinery (IT)
- Galician Alumina refinery (ES)

10. Reference literature
(EC-JRC 2009)

4.3.2.2.4.2 Passive neutralisation

4.3.2.2.4.2.1 Oxic Limestone Drains/Open Limestone Channels

1. Description
This technique consists of filling uncovered open trenches with an impermeable bottom and walls with limestone pebbles/cobbles that will dissolve with water and act as a carbonate agent,

generating alkalinity, raising the pH and promoting precipitation of the dissolved metals in oxic conditions.

2. Technical description
This BAT candidate is relevant for acidic EWIW.

An Oxic Limestone Drain (OLD), also called Open Limestone Channel (OLC), is the most simply constructed passive treatment method consisting of the following:

- *An uncovered open trench filled with limestone pebbles/cobbles*. The limestone will dissolve with water and act as a carbonate agent, generating alkalinity, raising the pH and promoting precipitation of the dissolved metals in oxic conditions.
- *A lining system* (with natural or synthetic materials) on the bottom and the walls of the trench/ditch in order to avoid seepage, soil and groundwater contamination.

The main reactions occurring in an OLD/OLC are:

- the *dissolution* of calcium or magnesium carbonates (e.g. limestone, dolomite, magnesite) and production of carbonates;
- *pH raise* (production of hydroxide ions);
- and the *hydroxide precipitation* of less soluble metals at pH 6.0-8.0, mainly ferric iron (Fe^{3+}) and aluminium (Al^{3+}).

Strong or aggressive dissolution of limestone (high increase of pH) promotes sorption of metallic ions on the limestone. This results in a coating of limestone pebbles with carbonate and hydroxide precipitates and is known as the armouring reaction.

OLD/OLC outflow has to be collected in a settling pond prior to being discharged or re-used/recycled.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Passive neutralisation using OLDs/OLCs is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Passive neutralisation is applied as the final step to adjust the pH.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or reducing the discharge of acidic EWIW into the receiving surface water body;
  - removing metals (such as manganese, aluminium, iron, copper, lead, zinc, selenium) from the EWIW before the discharge into the receiving surface water body.

4. Environmental performance and operational data
The performance of the treatment will depend to a large extent on the retention time or contact time of the EWIW. This obviously depends on the water flow which is controlled by designing the dimensions and the slope of the channel properly.

Typically, the limestone content, the length and the flow rate have to be adapted to the chemistry of the influents in order to provide sufficient time and reagent to successfully remove the dissolved metals and increase the pH to as close as possible to neutral.

High-grade limestone with a $CaCO_3$ content greater than 90 % is usually used. At this percentage, the limestone dissolves quickly and high alkalinity levels in the water can be obtained (near 300 mg/l as $CaCO_3$).

OLDs/OLCs are designed to have a retention time of several hours (Taylor *et al.* 2005; Ziemkiewicz *et al.* 2003).

The armouring negatively affects the OLD/OLC performance as it reduces the limestone dissolution process. To overcome this issue, channels are usually designed with a steep slope. The best performances of OLDs/OLCs have been observed with slopes of up to 45-60 % (US EPA 2014). A minimum slope of 20 % is usually suggested (Green *et al.* 2008; Zipper *et al.* 2011) in order to promote flow velocity and turbulence which will keep sediments in suspension and therefore promote surface abrasion of limestone and reduce armouring. A minimum slope of 10 % is also reported by (Ziemkiewicz *et al.* 2003).

Combining both steep channels and long retention times might result in long channels (greater than 900 m) with thousands of tonnes of limestone, according to the Closedure project (Turunen and Hämäläinen 2015).

Typical performance rates and operational data are reported in Table 4.52.

Table 4.52: Oxic Limestone Drain/Open Limestone Channel performance levels from literature

Parameter	Operating range or performance level	Reference
Achievable outflow pH	~ 6	(US EPA 2014; Ziemkiewicz *et al.* 2003)
Alkalinity generation	< 150 mg/l	(Skousen and Ziemkiewicz 2005)
Acidity removal: On average:	66-69 % ~ 30 g $CaCO_3/t_{limestone}$/day	(Skousen and Ziemkiewicz 2005; Ziemkiewicz *et al.* 2003)
Fe removal	~ 70 %	(Skousen and Ziemkiewicz 2005; Taylor *et al.* 2005)
Al removal	40-50 %	(Skousen and Ziemkiewicz 2005; Taylor *et al.* 2005)
Mn removal	10-20 %	(Skousen and Ziemkiewicz 2005; Taylor *et al.* 2005)

OLDs/OLCs are properly designed to enable optimum efficiency and avoid armouring and clogging. Preliminary removal of dissolved metals might be necessary. Ongoing inspection and maintenance is required to ensure good performance.

5. Cross-media effects

- Greater space required compared to chemical treatments.
- Limestone consumption.

6. Technical considerations relevant to applicability

- The system is not suitable to treat high levels of metal content and/or acidity. The typical average acidity load to be treated is < 150 kg $CaCO_3$/day (Taylor *et al.* 2005), usually ~ 20-30 kg $CaCO_3$/day according to the Closedure project (Turunen and Hämäläinen 2015).
- It is not applicable when the EWIW to be treated presents the following characteristics:
    - o iron (Fe) concentration > 20 mg/l (Cała *et al.* 2013);
    - o aluminium (Al) concentration > 20 mg/l (Cała *et al.* 2013);
    - o average acidity range > 150 mg $CaCO_3$/l (Taylor *et al.* 2005);

  - flow rate > 20 l/s (Taylor *et al.* 2005).
- Therefore, the technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase.
- It is not applicable as a stand-alone technique.
- Maintenance may be required.
- OLD/OLC is not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
- System applicability might depend on land availability and site topography (in some cases, construction of long and steep channels might not be possible).

7. Economics
- Costs can vary from site to site, depending on location, local availability of limestone and cover materials, the potential need for insulation to address conditions of extreme cold, and the possible need for pretreatment to reduce oxygen, aluminium, or iron levels in the EWIW.

- An average construction cost is typically ~ EUR 25 000, according to the Closedure project (Turunen and Hämäläinen 2015).
- The cost of treatment varies between ~ EUR 20 and EUR 7 000 per tonne of acid removed per year (US EPA 2014). On average, the cost is ~ EUR 125 per tonne per year, according to the Closedure project (Turunen and Hämäläinen 2015).

8. Driving force for implementation
- Legal and environmental requirements.
- Lower maintenance costs.

9. Example sites
- Luikonlahti Cu-Zn-Co-Ni mine in Kaavi (FI). The Luikonlahti site was evaluated as a case study site in the Closedure project (Turunen and Hämäläinen 2015). A detailed description of the OLD/OLC and the wetland applied in this site is also provided in the Closedure project (Räisänen 2015a).
- Many sites in north-west Virginia: Brownton, Dola, Florence, Webster and Airport sites; Brandy Camp site, Pennsylvania; Big Bear Lake near Hazelton in north-east Preston County, West Virginia; Lick Creek in south-west Indiana; McCarty Highwall site in Preston County, West Virginia (US) (US EPA 2014)

10. Reference literature
(Cała *et al.* 2013)
(EC-JRC 2009)
(ITRC 2010h)
(Skousen and Ziemkiewicz 2005)
(Taylor *et al.* 2005)
(Turunen and Hämäläinen 2015)
(US EPA 2014)
(Watzlaf *et al.* 2000)
(Ziemkiewicz *et al.* 2003)
(Zipper *et al.* 2011)

4.3.2.2.4.2.2 Anoxic Limestone Drains

1. Description
Drainage and treatment of acidic EWIW is performed within impermeable trenches filled with limestone pebbles/cobbles and covered with capping that will dissolve with water and act as a

carbonate agent, generating alkalinity, raising the pH and promoting precipitation of the dissolved metals in anoxic conditions.

2. Technical description
This BAT candidate is relevant for acidic EWIW.

The anoxic limestone drain (ALD) consists of a trench containing limestone similar to an OLD/OLC, but with a capping preventing the dissolution of oxygen in the EWIW. The encapsulation on the top is done with clay or compacted soil to maintain anoxic conditions. An additional capping layer of topsoil and vegetation may be required to control erosion (ITRC 2010h; US EPA 2014).

Capping the drain also prevents water infiltration and helps to prevent emissions of carbon dioxide produced by the reaction of calcium carbonate and protons present in the acid stream.

The anoxic conditions prevent the oxidation of metallic ions such as the precipitation of ferrous iron to its ferric state, while the pH is raised in the EWIW stream to 6-8 by the dissolution of limestone.

At this pH, the dissolved metals contained in the outflow of an ALD can precipitate upon encountering aerobic conditions. For this reason, ALD are associated with aerobic ponds or wetlands to precipitate and remove the metals.

Finally, once the water exits the drain, sufficient area is provided to slow the water flow to allow oxidation, hydrolysis and precipitation of metals.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Passive neutralisation using ALD is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Passive neutralisation is applied as the final step to adjust the pH.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the discharge of acidic EWIW into the receiving surface water body.
- Prevention or minimisation of visual impacts or footprint impacts resulting from the management of extractive waste.

4. Environmental performance and operational data
As for OLDs/OLCs, the performance of ALD systems will depend to a large extent on the retention time or contact time of the EWIW.

High-grade limestone with a $CaCO_3$ content of greater than 90 % is usually used. At this percentage, the limestone dissolves quickly and high alkalinity levels in the water can be obtained (near 300 mg $CaCO_3$/l).

The usual retention time required for such systems is ~ 10-15 hours (Taylor *et al.* 2005; US EPA 2014).

The quantity of limestone to be used varies from site to site depending on the EWIW characteristics.

Nevertheless, a commonly accepted design rule is expressed in the following equation (Zipper *et al.* 2011):

$$M = (Q \times \rho \times t/V) + (Q \times C \times T/x) \quad (1)$$

where M represents the mass of limestone to be used for the construction;
Q the water flow rate (l/h);
ρ the limestone bulk density (kg/m^3);
t is the retention time in hours;
V is the bulk void volume of limestone gravels/pebbles (V ranges from 0 to 1);
C is the targeted/predicted rate of alkalinity generation in mg $CaCO_3$/l;
T represents the targeted lifetime of the system (in hours);
x is the $CaCO_3$ content (the limestone purity).

ALD systems can achieve the performance levels reported in Table 4.53.

Table 4.53: Anoxic limestone drain performance levels from literature

Parameter	Operating range or Performance level	Reference
Achievable outflow pH	6-8	(Taylor *et al.* 2005; US EPA 2014)
Acidity removal: On average:	50-80 % ~ 86 g $CaCO_3/t_{limestone}$/day	(Skousen and Ziemkiewicz 2005)
Alkalinity outflow	150-300 mg/l	(Skousen and Ziemkiewicz 2005; US EPA 2014)

Although ALD is reported as a successful method in raising pH, most ALD systems exhibit a reduced effectiveness over time and eventually require replacement (US EPA 2014).

Proper ongoing maintenance is required to avoid clogging of the system and loss of performance.

The typical service lifetime of such a system is expected to be 25-30 years.

5. Cross-media effects

- Longer retention times will require greater space.
- Limestone consumption.

6. Technical considerations relevant to applicability

- ALDs have some technical restrictions regarding the inflow chemistry. Indeed, ALDs are not applicable to treat EWIW with the following characteristics:
  - DO > 1 mg/l (Cała *et al.* 2013; Taylor *et al.* 2005);
  - Al^{3+} > 1 mg/l (Cała *et al.* 2013);
  - Fe^{3+} > 1 mg/l (Cała *et al.* 2013);
  - pH < 2 (Taylor *et al.* 2005).
- Best performance is achieved within:
  - a 150-300 mg $CaCO_3$/l range (Skousen and Ziemkiewicz 2005);
  - a flow rate in a 10-40 l/s range (Skousen and Ziemkiewicz 2005).
- Coating of the limestone, by iron and aluminium precipitates, affects the performance of this treatment method (EC-JRC 2009).

- The technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase.
- It is not applicable as a stand-alone technique.
- Maintenance may be required.
- ALD is not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.

7. Economics

- Costs can vary from site to site, depending on location, local availability of limestone and cover materials, the potential need for insulation to address conditions of extreme cold, and the possible need for pretreatment to reduce oxygen, aluminium, or iron levels in the EWIW.

- A typical ALD construction cost at most locations in Canada (not including remote sites) ranges from ~ EUR 4 400 to ~ EUR 27 000 (US EPA 2014).
- OPEX of ~ EUR 0.03/m^3 of treated water have been reported (ITRC 2010h).

8. Driving force for implementation

- Legal and environmental requirements.

9. Example sites

- Copper Basin mining site, TN; Hartshorne/Whitlock-Jones: Hartshorne, OK; Ohio abandoned bituminous coal, OH; Tecumseh - AML Site 262, IN; Tennessee Valley Authority, AL; Valzinco mine, VA (US) (ITRC 2010h)

10. Reference literature

(Cała *et al.* 2013)
(EC-JRC 2009)
(ITRC 2010h)
(Skousen and Ziemkiewicz 2005)
(Taylor *et al.* 2005)
(US EPA 2014)
(Watzlaf *et al.* 2000)
(Zipper *et al.* 2011)

4.3.2.2.4.2.3 Successive alkalinity-producing systems

1. Description

Successive alkalinity-producing systems (SAPS) combine the use of an ALD and a permeable organic substrate into one system that creates anaerobic conditions prior to water coming into contact with the limestone.

2. Technical description

This BAT candidate is relevant for acidic EWIW.

SAPS are systems built with a succession of reducing and alkalinity-producing systems. The latter are watertight basins/cells/ponds containing limestone and organic matter (e.g. compost or peat) covered by several metres of water.

A drainage system is constructed in the bottom with a standpipe to control the water flow and ensure that the organic layer and the limestone are always submerged.

The system is based on a vertical flow driven by gravity pressure. The EWIW to be treated flows through organic matter where oxygen is removed by aerobic bacteria.

Simultaneously, sulphate-reducing bacteria present in the organic layer generate alkalinity and partially remove dissolved metals such as aluminium by hydroxide precipitation processes, but not iron, as under these conditions ferrous iron is present in higher quantities and ferric iron is reduced by bacterial activity.

By means of a pressure gradient, EWIW flows through the limestone where the dissolution of the limestone increases the alkalinity like in an ALD.

Finally, drainage pipes below the limestone convey the outflow into an aerobic pond for the precipitation of iron and settling of solid particles (flocs).

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  Passive neutralisation using SAPS is planned and designed during the planning and design of the extractive waste management. Site-specific conditions, e.g. planned input water quality, output water requirements, planned input and output flows and climatic conditions, are taken into consideration.
- *Operational (construction, management and maintenance) phase*
  Passive neutralisation is applied as the final step to adjust the pH.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - preventing or minimising the discharge of acidic EWIW into the receiving surface water body;
  - reducing metals concentration (such as aluminium, copper, iron, manganese, zinc) in the EWIW before the discharge into the receiving surface water body.

4. Environmental performance and operational data

A typical system will consist of a 1- to 3-metre water layer over a compost layer ranging from 0.1 m to 0.3 m thick and a high calcium carbonate content limestone (> 90 %) layer of 0.5-1.0 m thick (Turunen 2015c; US EPA 2014; Zipper *et al.* 2011).

A freeboard of 1 m is recommended by the Closedure project (Turunen 2015c).

The retention time has to be designed to reach at least 15 hours in limestone. It can reach several days in some cases (four days in Summitville mine, US (US EPA 2014)).

SAPS can achieve the performance levels reported in Table 4.54.

Table 4.54: Successive alkalinity-producing systems' performance levels from literature

Parameter	Operating range or performance level	Reference
Achievable outflow pH	6-8	(Taylor *et al.* 2005; US EPA 2014)
Acidity removal on average	~ 88 g $CaCO_3/m^2$/day	(Skousen and Ziemkiewicz 2005)
Aluminium removal	Up to 97 %	(US EPA 2014)
Copper removal	Up to 90 %	(US EPA 2014)
Iron removal	Up to 64 %	(US EPA 2014)
Manganese removal	Up to 11 %	(US EPA 2014)
Zinc removal	Up to 57 %	(US EPA 2014)

The bed permeability and the system effectiveness will decrease over time, as the SAPS will become clogged. The decreases in permeability are a function of the water flow rates, substrate porosity, potential clogging and influent metal concentrations. With high flows and high metal contents, some sites may require more complex designs that incorporate more treatment cells and settling ponds constructed in series (Demchak *et al.* 2001).

Some types of organic material can have problems with plugging (US EPA 2014).

Regular maintenance is required to prevent clogging with gypsum or metallic precipitates. Replacement of the compost with new compost has to be carried out every 2-3 years (Demchak *et al.* 2001; US EPA 2014).

5. Cross-media effects
- Consumption of limestone and organic matter.

6. Technical considerations relevant to applicability
- The DO concentration of the EWIW is often a design limitation for SAPS.
- SAPS have some technical restrictions regarding the inflow chemistry. SAPS are not applicable if the EWIW characteristics exhibit the following:
    - DO > 1-3 mg/l (Taylor *et al.* 2005);
    - pH < 2.5 (Taylor *et al.* 2005);
    - flow rate > 15 l/s (Taylor *et al.* 2005);
    - inflow average acidity > 300 mg $CaCO_3$/l (Taylor *et al.* 2005).
- The technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase.
- It is not applicable as a stand-alone technique.
- An aerobic pond is required after treatment in order to precipitate dissolved metals.
- Maintenance may be required.
- SAPS are not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.

7. Economics
- For treatment capacities varying from 0.3 l/s to 6.3 l/s, the construction costs for a SAPS based on a 15-year life range from ~ EUR 50 000 to EUR 100 000.
- The operating costs are less than EUR 0.01 per treated m^3.

8. Driving force for implementation
- Legal and environmental requirements.

9. Example sites

- Summitville mine, Colorado; Howe Bridge, REM, Schnepp Road, Filson sites, Jefferson County, Pennsylvania (US) (US EPA 2014)

10. Reference literature

(Demchak *et al.* 2001)
(Skousen 2000; Skousen and Ziemkiewicz 2005)
(Taylor *et al.* 2005)
(Turunen 2015c)
(US EPA 2014)
(Zipper *et al.* 2011)

4.3.2.2.4.2.4 Anaerobic wetlands

Passive neutralisation by applying this BAT candidate (described in Section 4.3.2.2.3.2.1) is relevant for acidic or alkaline EWIW.

4.3.2.2.5 Summary of exemplary achieved and reported performances for EWIW treatment

The summary of exemplary achieved and reported performances for EWIW treatment is reported in Table 4.55.

Table 4.55: Summary of exemplary achieved and reported performances using techniques for the removal of suspended solids or suspended liquid particles, techniques for the removal of dissolved substances and techniques for the neutralisation of EWIW prior to discharge, from a wide range of extractive waste management operations

Parameter		Concentration range (except for pH) (yearly average)*[a, b]
pH		6-9 ([1])
Chemical Oxygen Demand (COD)		< 15-100 mg/l ([2])
Total Suspended Solids (TSS)		5-35 mg/l ([2])
Total Nitrogen (TN)		5-25 mg/l ([2])
Sulphates (SO_4^{2-})		50-2 000 mg/l ([2])
Metals and metalloids	Arsenic (expressed as As)	10-50 µg/l ([2])
	Cadmium (expressed as Cd)	2-10 µg/l ([2])
	Chromium (expressed as Cr)	2-15 µg/l ([2])
	Copper (expressed as Cu)	2-100 µg/l ([2])
	Lead (expressed as Pb)	10-50 µg/l ([2])
	Mercury (expressed as Hg)	0.3-2 µg/l ([2])
	Nickel (expressed as Ni)	10-100 µg/l ([2])
	Zinc (expressed as Zn)	5-500 µg/l ([2])
Total cyanides (CN)		< 2-100 µg/l ([2])

a) Concentration ranges presented in this table are based on the information exchange exercise.
b) The local conditions and type of operations affect the concentration and are taken into account when setting the site-specific performance objectives.
([1]) Or ± 1 of the pH of the water receiving body, in cases where the latter is below 6 or above 9.
([2]) The lower end of the range has been defined taking the performance of plants achieved under normal operating conditions by the techniques described in Sections 4.3.2.2.2, 4.3.2.2.3 and 4.3.2.2.4 obtaining the best environmental performances as provided in the information exchange and in literature data. The upper end of the range has been derived by considering the range of performances associated with the application of the techniques described in Sections 4.3.2.2.2, 4.3.2.2.3 and 4.3.2.2.4 under normal operating conditions and literature data.

4.3.2.2.6 Removal/destruction of extraction process contaminants

4.3.2.2.6.1 Removal of flocculants

- No information provided.

4.3.2.2.6.2 Removal of cyanides

See Section 4.2.2.3.1.

4.3.2.2.7 Monitoring of emissions to surface water

4.3.2.2.7.1 Techniques to model emissions to surface water

1. Description

This technique consists of using numerical models as tools to forecast emissions and impacts in order to assist operators in their management strategies.

2. Technical description

Various hydrogeological models can be used to model emissions to water and forecast possible environmental effects of such emissions. Some commercial codes can be used to simulate the load on water bodies based on waste properties, leaching conditions and precipitation and infiltration rates. Some hydrogeological flow models are described in the VTT guidelines for mine water management (Punkkinen *et al.* 2016).

Models are calibrated and adjusted on the basis of on-site measurements.

Modelling of emissions can assist operators during the whole life cycle of the EWF:

- in the management of the EWF (e.g. selection of appropriate capping or liners) and in the treatment of extractive waste and/or EWIW stemming from the EWF;
- in providing an estimation of maximum discharge rates;
- in providing a forecast of the environmental impacts.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration.
- Selection and optimisation of the appropriate extractive waste management strategy.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- Environmental and economic benefits from the selection of the most appropriate extractive waste management strategy.

9. Example sites

- Preston New Road (UK)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)
- Agnico Eagle Finland Oy, Kittilä Mine (FI)
- Kevitsa Mine (FI)
- Cleveland Potash (UK)
- Aitik Mine (SE)
- Omya Hustadmarmor AS, Elnesvågen (NO). Liquid marble
- Efemçukuru Gold Mine (TR)

10. Reference literature
(Punkkinen *et al.* 2016)

4.3.2.2.7.2 Techniques to monitor emissions to surface water

1. Description
This technique consists of monitoring emissions to surface water, including the EWIW treatment efficiency and the water quality in the surroundings of the extractive waste management site (including the EWF).

2. Technical description
This BAT candidate is relevant for non-inert extractive waste. For inert extractive waste, only the TSS monitoring is relevant.

Monitoring of emissions to surface water can assist in:
- evaluating the efficiency of EWIW treatment, according to the permit and the monitoring goals;
- collecting sufficient data on emissions to surface water and their impacts;
- identifying possible process failures, such as leaks in the water collection system and from the EWF.

(Kauppila *et al.* 2013)

Sites have specific monitoring regimes set by the permit. In some cases, there is no EWIW discharge from the EWF to surface water. Climatic conditions influence the need to discharge excess water and therefore for monitoring.

A monitoring plan for emissions to surface waters is developed.

Monitoring parameters and frequencies are properly selected according to the site-specific conditions (particularly geological, hydrological and hydrogeological conditions), with particular regard to the potential risk of surface water status deterioration, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions.

If the emissions to surface water from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed.

Monitoring is planned in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.

The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.

Monitoring of emissions to water can be carried out on a continuous or batch basis.

The monitoring point for EWIW is usually located just before the discharge point.

The technique is planned in the design phase and implemented in the operational and closure and after-closure phases:

- *Planning and design phase*
  A surface water monitoring plan is set up for the bodies of surface water that may be impacted by the extractive waste management. Usually, downstream and upstream monitoring is planned.
- *Operational (construction, management and maintenance) phase*
  Monitoring is carried out and the information collected is used as feedback for possible corrective measures in the extractive waste management.
  The monitoring plan is adapted based on the monitoring findings over time.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of surface water status deterioration by:
  - o determining whether the implemented measures are effective or if additional corrective measures are necessary to prevent or minimise surface water status deterioration.
- Prevention and reduction of negative environmental impacts from the management of extractive waste. Optimisation of the extractive waste management and treatment strategies.
- Mitigation of accidents.
- Ensuring a high level of protection of the environment as a whole.
- Maintaining the appropriate operation, closure and after-closure of the extractive waste management site.

4. Environmental performance and operational data

Depending on the extractive waste and the site, different parameters are usually monitored.

Typical monitoring frequencies of different parameters during the operational phase are presented in Table 4.56 along with the monitoring standards usually applied, according to the information provided in the questionnaires. Several test methods for the eluate and leachate analysis are reported in Annexes B.3.8, 3.9 and 3.10 to CEN/TR 16376 (see Section 4.1.2.1.1).

During the after-closure phase, it is suggested that the monitoring of emissions to water be performed at least yearly (IRMA 2016).

Table 4.56: Reported monitoring parameters and frequencies of point source emissions to surface water (based on information exchanged via the questionnaires)

Reported parameter*	Reported unit*	Number of sites*	Reported annual frequency range (min.-max., unless only one value reported)*	Reported EN/ISO standard*
pH	-	37	1-365	EN ISO 10523
Electrical conductivity	S/cm	24	1-365	EN 27888
Hardness	°dH $CaCO_3$-mg/l	4	10	NI**
TDS	mg/l	7	9-365	EN 15216
Colour	Pt/Co Pt-mg/l	5	4-11	EN ISO 7887-6
Temperature	°C	15	4-365	NI**
Density	mg/l	1	10	NI**
TSS	mg/l	32	1-365	EN 872
Turbidity	FTU	2	NI*	NI**
Settleable Solids	ml/l	1	36-36	NI**
COD****	mg/l	26	4-365	EN 1484 EN ISO 6060 ISO 15705
BOD_5	mg/l	7	4-52	EN ISO 1899-1
BOD_7	mg/l	7	25-50	NI**
PAHs	mg/l	1	1	NI**
Phenols	mg/l	3	1-36	ISO 6439
C_{10}-C_{40}	mg/l	1	52	EN ISO 9377-2
THC	mg/l	3	1	NI**
TOC	mg/l	5	1-52	EN 1484
VOCs	mg/l	1	2	NI**
Alkalinity	mmol/l	10	52	EN ISO 9963-1
S^{2-}	mg/l	1	1	NI**
$S_2O_3^{2-}$	mg/l	1	25-52	EN ISO 10304-3
SO_3^{2-}	mg/l	1	1-1	NI**
SO_4^{2-}	mg/l	27	1-365	EN ISO 10304-1 ISO 9280
Total S	mg/l	2	10-11	EN ISO 17294-2
Ag	mg/l	1	36	EN ISO 11885
Al	mg/l	12	1-54	EN ISO 11885 EN ISO 17294-1 EN ISO 17294-2
As total	mg/l	21	1-52	
Ba	mg/l	7	11-52	EN ISO 11885 EN ISO 17294-2
Be	mg/l	1	11	EN ISO 17294-2
Ca	mg/l	10	4-52	EN ISO 17294-1 EN ISO 17294-2
Cd	mg/l	21	1-327	EN ISO 11885 EN ISO 17294-1 EN ISO 17294-2
Co	mg/l	9	10-52	EN ISO 11885 EN ISO 17294-2
Cr (VI)	mg/l	1	1	NI**
Cr total	mg/l	19	1-52	EN ISO 11885 EN ISO 17294-1 EN ISO 17294-2
Cu	mg/l	24	1-52	
Fe total	mg/l	22	1-54	
Hg	mg/l	19	1-327	EN 1483 EN ISO 11885 EN ISO 17852

Reported parameter*	Reported unit*	Number of sites*	Reported annual frequency range (min.-max., unless only one value reported)*	Reported EN/ISO standard*
K	mg/l	8	4-52	EN ISO 11885 EN ISO 17294-1 EN ISO 17294-2
Mg	mg/l	15	2-52	
Mn	mg/l	13	1-52	EN ISO 11885 EN ISO 17294-2
Mo	mg/l	4	9-12	
Na	mg/l	9	4-52	EN ISO 11885 EN ISO 17294-1 EN ISO 17294-2
Ni	mg/l	21	1-52	
Pb	mg/l	20	1-138	
Sb	mg/l	5	50-52	EN ISO 17294-2
Se	mg/l	3	1-32	
Sn	mg/l	2	1-11	
Sr	mg/l	1	NI*	NI**
Ti	mg/l	3	2-11	EN ISO 11885 EN ISO 17294-2
U	mg/l	2	36	NI**
V	mg/l	3	11-36	EN ISO 11885 EN ISO 17294-2
W	mg/l	1	4	EN ISO 11885
Zn	mg/l	24	1-138	EN ISO 11885 EN ISO 17294-1 EN ISO 17294-2
NH_4^+	mg/l	16	12-365	ISO 5664
NO_2^-	mg/l	5	36-136	EN 26777 EN ISO 13395
NO_3^-	mg/l	12	25-365	EN ISO 13395
NO_2^- + NO_3^-	mg/l	2	4-11	
Total Kjeldahl N	mg/l	15	4-50	EN 25663
Total N	mg/l	8	8-29	EN 12260 EN ISO 11905 EN ISO 13395
PO_4^{3-}	mg/l	7	12-136	NS only***
Total P	mg/l	22	3-54	EN 1189 EN ISO 11885 EN ISO 6878
WAD CN^-	mg/l	1	NI*	NI**
Total CN^-	mg/l	3	1-10	NI**
Br^-	mg/l	2	10-12	NI**
Cl^-	mg/l	20	10-327	EN ISO 10304-1 ISO 9297
F^-	mg/l	2	12-32	NI**
AOX	mg/l	3	12	NS only***
^{226}Ra	Bq/l	2	36	NS only***
Coliform bacteria	CFU/100ml	2	12	NS only***
Fish egg	NI	1	12	NI**
Toxicity	TU	1	2	NI**
	Dilution factor	1	10	NS only***

NB: Sampling programme and techniques are described in EN ISO 5667 on water quality – sampling. The sampling point is located where the emission leaves the extractive waste management installation.
** Parameters, information and data reported by operators via the questionnaire (in total 87 questionnaires).*
*** NI stands for No Information, meaning that operators did not provide information.*
**** NS only stands for National Standard provided only.*
***** EN ISO 6060 is not applicable for samples with a chloride content higher than 1 g/l.*

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- Legal and environmental requirements.
- Surveillance and early warning.

9. Example sites

- Monitoring of emissions to surface water is carried out in many sites participating in the questionnaire exercise, when there is discharge to receiving surface water bodies (monitoring reported in 35 questionnaires out of the 43 that reported emissions to water).

10. Reference literature

(Brinkmann *et al.* 2016; EC-JRC 2009)
(IRMA 2016)
(Kauppila *et al.* 2013)
(Punkkinen *et al.* 2016)

4.3.3 Techniques to prevent or minimise air pollution

4.3.3.1 Techniques to prevent and minimise dusting from exposed surfaces of extractive waste

4.3.3.1.1 Wet extractive waste

Keeping the potentially dusty extractive waste water-saturated or wet enables the prevention and minimisation of dusting.

Techniques to control the water content in the extractive waste are described in Section 4.2.2.1.1.

4.3.3.1.2 Water or water-based solutions spraying

1. Description

This technique consists of spraying water or water-based solutions such as lime water on the exposed surfaces of extractive waste (such as beaches) to increase the moisture in the extractive waste, in order to keep the extractive waste wet and to reduce dust emissions before, during and after loading, handling and transport.

2. Technical description

This BAT candidate is relevant for exposed surfaces of extractive waste.

<u>During operation</u>, according to the MTWR BREF (EC-JRC 2009), water sprinkling systems are used to maintain the exposed surface of extractive waste wet and to reduce the dust emissions:

- on the beach surfaces in combination with the continuous management of the discharge points; fully automated sprinkling systems with remote control are used for optimising the sprinkler use, for example during the night, when evaporation is minimised, or when dusty conditions are imminent;
- additional water curtains can be installed within the pond on the beach at a distance of ~ 150 m and are put into operation, for example, after removing the asphalt cover.

Sprinkling is often applied in thickened/paste extractive waste operations.

According to the MTWR BREF (EC-JRC 2009), water from the extractive waste management site (including the EWF) is usually used.

During loading, handling and transport, various methods of dust suppression are commonly used, according to the MTWR BREF (EC-JRC 2009), including:

- spraying the equipment such as conveyor belts;
- spraying the bucket and the tyres/tracks of the equipment (e.g. shovel, loader and excavator);
- spraying the dump truck and the tyres of the trucks;
- spraying roads, usually by means of water, but also with $MgCl_2$ (such as in the Malmberget site) or NaCl (such as in the Kiruna site);
- direct-spraying trucks by means of sprinkling devices along the road; in concentrate transportation, the trucks often have to pass water traps to clean the tyres, and in some cases the trucks are washed before leaving the site.

The technique is applied in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  Water spraying is planned and designed considering site-specific contextual information.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, the technique is implemented.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of air pollution by:
  - preventing or minimising wind erosion and dusting from exposed surfaces of the extractive waste;
  - preventing or minimising dusting from the handling and transport of the extractive waste.

4. Environmental performance and operational data

- At the Aughinish site, the entire BRDA (Bauxite Residue Disposal Area) surface is rewetted every four hours. With high temperatures and dry windy weather, continuous 24-hour sprinkling can be implemented. Recycled run-off from the BRDA surface is used. During the summer the quantity of sprinkling water can reach 10 000 m^3/day.
- At the KGHM Polska Miedź S.A. Żelazny Most tailings pond, water curtains, which are installed permanently on the dam crest, are used on windy days. Additionally, in periods of strong westerly winds, mobile curtains are put into operation on the beach at a distance of 120-150 m from the dam. The sprinkling system uses only circulating water; no additional water is needed.
- Modelling of the sprinkler throw at different wind speeds is required to determine the coverage per sprinkler (for example, at the Aughinish site, 40 m between sprinklers provides appropriate coverage).
- Periodic raising of the sprinkler heads is needed; otherwise they become buried.

5. Cross-media effects

- Water consumption.
- Energy consumption.

6. Technical considerations relevant to applicability
- The technique is usually applied in combination with other techniques.
- Contaminated water (e.g. contaminated produced water) cannot be used for water spraying.
- The applicability may be restricted in the case of an inappropriate supply of and storage capacity for suitable sprinkling water. The system can also encounter problems with freezing in cold climates.

7. Economics
- No information provided.

8. Driving force for implementation
- Legal requirements on dust emissions control.
- Local air quality standards.

9. Example sites
- LKAB Kiruna Iron ore Mine (SE)
- LKAB Malmberget Iron ore Mine (SE)
- Aughinish Alumina Ltd (IE)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- Alcoa (Kwinana, Wagerup, Pinjarra), Western Australia

10. Reference literature
(EC-JRC 2009)
(Honeywell 2014)

4.3.3.1.3 Wind protection systems

These techniques were mentioned in the questionnaires but no 10-heading description was provided.

This BAT candidate is relevant for exposed surfaces of extractive waste.

Wind protection systems are aimed at reducing the wind speed and preventing dust emissions and soil erosion and include:
- *wind fences*;
- *windbreaks*, which consist of one or more rows of plants along the border of the extractive waste deposition area (including the EWF) and/or extractive waste handling area.

The environmental performance of wind protection systems may be limited for high heaps (e.g. > 100 m).

The technique is implemented in all the life cycle phases of the extractive waste management:
- *Planning and design phase*
  Wind protection systems are planned and designed considering site-specific contextual information.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, the technique is implemented.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

4.3.3.1.4 Landscaping and geomorphic reclamation

Landscaping and geomorphic reclamation is a technique used to reduce the visual impact, but also wind erosion, as the slopes of the extractive waste deposition area (including the EWF) are reshaped to simulate natural heaps, thus reducing also the impact of dusting of exposed surfaces of extractive waste. Further details on landscaping and geomorphic reclamation are provided in Section 4.3.2.1.4. This BAT candidate is relevant for exposed surfaces of extractive waste. It is relevant for NAG extractive waste.

4.3.3.1.5 Progressive rehabilitation

See Section 4.3.1.3.1.

4.3.3.1.6 Temporary covers with non-dusting materials

See Section 4.3.1.3.2.

4.3.3.1.7 Vegetative covers

See Section 4.3.1.3.3.

4.3.3.1.8 Permanent covers with non-dusting materials

4.3.3.1.8.1 Permanent dry covers

See Section 4.3.1.3.4.1.

4.3.3.1.8.2 Permanent wet covers

See Section 4.3.1.3.4.2.

4.3.3.2 Additional techniques to prevent or minimise dusting from extractive waste handling and transport

4.3.3.2.1 Continuous conveyor systems

1. Description
This technique consists of transporting extractive waste by conveyor belts, covered and encapsulated where recommended due to local conditions, or by pipelines in order to prevent or minimise emissions to air.

2. Technical description
This BAT candidate is relevant for handling and transport of extractive waste.

<u>Conveyor belts</u>
According to the MTWR BREF (EC-JRC 2009), several approaches can be applied for reducing dust emissions from operations where the extractive waste is transported on conveyor belts and discarded onto heaps, such as:

- *primary approaches*: spraying the extractive waste;
- *secondary approaches*:
  - o organisational:
    - reducing the transport distances;
    - maintenance of possible sources of noise emissions;

        - logistics of stacking areas;
    - technical:
        - use of wind protection (e.g. covering of conveyor belt);
        - keeping discharge heights to a minimum;
        - transverse/reverse conveyor belt;
        - moistening of the solid extractive waste from mineral processing;
- *tertiary approaches*: not depositing at high wind speeds.

For example, according to the MTWR BREF (EC-JRC 2009), at the German potash mines, processing and extractive waste management are operated continuously. The transport to the extractive waste heap is carried out using conveyor belts. This set-up creates less noise than truck transport. Belt drives are commonly encapsulated.

Transfer stations are commonly enclosed in conveyor systems.

Pipelines
Pipelines are used to transport pumpable extractive waste.

See also Sections 4.1.2.2 and 4.2.2.1.4.

The technique is applied in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  Transport of extractive waste is planned and designed considering site-specific contextual information.
- *Operational (construction, management and maintenance) phase*
  During the operational phase, the technique is implemented.

3. Achieved environmental benefits
- Prevention or minimisation of air pollution by:
    - preventing or minimising dusting from the handling and transport of the extractive waste.
- Prevention or minimisation of noise and vibration emissions from the management, including handling and transport, of extractive waste.

4. Environmental performance and operational data
- According to the MTWR BREF (EC-JRC 2009), at German potash operations, dry solid extractive waste from electrostatic separation is moistened indoors. The extractive waste is transported on conveyor belts and stacked with a moisture content of ~ 5-6 %. This leads to low dust emissions, due to the recrystallisation of the surface layer. The only atmospheric pollution which then arises is salt dust from stacking the extractive waste on the top of the heap, especially when discharging from a conveyor belt onto a heap in very strong winds. To avoid this, stacking is stopped automatically if the wind speed exceeds a predetermined limit.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- Continuous conveying systems are not applicable in the case of sites with highly variable loading points and deposition points of the extractive waste. In this case, truck transport might be the only practical solution, according to the MTWR BREF (EC-JRC 2009).
- The applicability may be restricted in the case of windy conditions for uncovered conveyor belts, as material discharge from conveyor belts can often be interrupted, according to the MTWR BREF (EC-JRC 2009).

7. Economics

- Transporting extractive waste from excavation by conveyor belts can be more expensive than transporting it by trucks, such as at the Kiruna site. The cost of transport by truck to the point of disposal is ~ EUR 0.5-1/t of extractive waste from mineral processing of metal ores, according to the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation

- Legal requirements on dust emissions control.
- Local air quality and noise standards.

9. Example sites

- No information provided.

10. Reference literature

(EC-JRC 2009)

4.3.3.2.2 Organisational techniques for handling extractive waste

1. Description

This technique consists of optimising distances for the transportation of extractive waste on site and establishing an appropriate speed limit for trucks handling extractive waste on site to reduce the dusting during on-site transport.

2. Technical description

This BAT candidate is relevant for transport and handling of extractive waste.

According to the MTWR BREF (EC-JRC 2009), in order to reduce the dusting from on-site transport, the following operational techniques can be applied:

- *optimising distances* for the transportation of extractive waste;
- establishing an appropriate *speed limit* (e.g. 30 km/h) for trucks handling extractive waste on-site.

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Transport of extractive waste is planned and designed considering site-specific contextual information.
- *Operational (construction, management and maintenance) phase*
  The technique is implemented.

3. Achieved environmental benefits

- Prevention or minimisation of air pollution by:
  - preventing or minimising dusting from handling and transport of the extractive waste.

4. Environmental performance and operational data

- No information provided.

5. Cross-media effects

- None identified.

6. Technical considerations relevant to applicability

- None identified.

7. Economics

- No information provided.

8. Driving force for implementation

- No information provided.

9. Example sites

- No information provided.

10. Reference literature

(EC-JRC 2009)

4.3.3.2.3 Water or water-based solutions spraying

This technique is particularly relevant for transport and handling of dry inert extractive waste.

See Section 4.3.3.1.2.

4.3.3.3 Techniques to prevent or minimise emissions of VOCs and other potential air pollutants from drilling muds and other extractive wastes from oil and gas exploration and production

4.3.3.3.1 Reduced emissions completions

1. Description

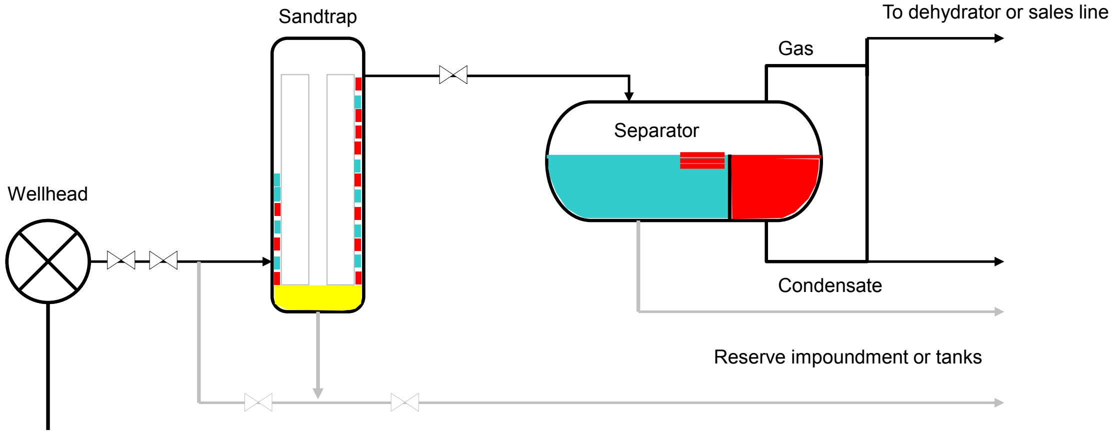
Reduced emissions completions (RECs), also called reduced flaring completions or green completions, is a practice that enables the capture of gases extracted during well completions.

2. Technical description

This BAT candidate is relevant for liquid extractive waste from well completion containing VOCs or other potential air pollutants, in particular for flowback water.

Separation of the gaseous phase from liquid and solid phases can be achieved using portable or fixed equipment.

The most common separation technique consists of sandtraps and three-phase separators used to separate first the sand from the outflow and then the gas from the water and condensate (see Figure 4.44). The separated gas is sent to a dehydrator to remove the residual water prior to distribution (US EPA 2011).



Source: (US EPA 2011)

Figure 4.44: Reduced emissions completion equipment layout

The technique is applied in the life cycle phases of the extractive waste management listed below:

- *Planning and design phase*
  Reduced emissions completion is planned and designed prior to drilling operations.
- *Operational (construction, management and maintenance) phase*
  The technique is implemented in the well completion phase.

3. Achieved environmental benefits

- Prevention or minimisation of air pollution by:
  - preventing or minimising the emission of VOCs and other potential air pollutants from drilling muds and other extractive wastes from oil and gas exploration and production;
  - eliminating the need for flaring.

4. Environmental performance and operational data

As much as 708 000 m^3 (25 million cubic feet) of natural gas per well can be lost during well completion depending on well production rates, the number of zones completed and the amount of time it takes to complete each zone (US EPA 2011).

In Wyoming and Colorado, operators of new wells are required to complete wells without flaring or venting. This has reduced flaring by 70 % to 90 % (US EPA 2011).

The annual volume of natural gas savings has been estimated at 7 645 million m^3 (270 000 million cubic feet) for an annual REC programme of 25 wells (US EPA 2011).

5. Cross-media effects

- No information provided.

6. Technical considerations relevant to applicability

- Small volumes of collectable gases may limit the applicability of the technique in the exploration phase.

7. Economics

- The incremental costs of recovering natural gas and condensate during well completions result from the use of additional equipment such as sandtraps, separators, portable compressors, membrane acid gas removal units and desiccant dehydrators.

- According to the US Environmental Protection Agency (US EPA 2011), typical costs associated with undertaking a REC at a single well are:
    - one-time transportation and incremental set-up costs: EUR 429 (USD 600, year 2011) per well;
    - incremental REC equipment rental and labour costs: EUR 500 to EUR 4 645 (USD 700 to USD 6 500, year 2011) per day, taking into account ausual well clean-up time of 3 to 10 days.

- In general, the implementation of REC generates revenues that will cover the costs of implementation and maintenance. Ultimately, the profits generated will depend on the gas price.

8. Driving force for implementation
- Separated gas and condensates will be sold and generate additional revenues.
- Local requirements.

9. Example sites
- Sites in the states of Wyoming and Colorado where operators of new wells are required to carry out well completion without flaring or venting.

10. Reference literature
(US EPA 2011)

4.3.3.3.2 Temporary storage and handling in closed systems followed by off-site treatment and/or disposal

1. Description
This technique consists of temporarily storing drilling muds and other extractive wastes in closed bunded containers/tanks and of considering the transport of these wastes by pipelines, followed by off-site treatment and/or disposal.

2. Technical description
This BAT candidate is relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water, possibly releasing VOCs or other potential air pollutants.

Based on literature information ((UK EA 2016) and (IOGP 2016)), drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water, possibly releasing VOCs or other potential air pollutants, are temporarily stored in closed bunded containers prior to off-site treatment and/or disposal.

These extractive wastes may be transported by pipeline.

The technique is implemented in the life cycle phases of the extractive waste management listed below:
- *Planning and design phase*
  The temporary storage and handling in closed systems is planned and designed.
- *Operational (construction, management and maintenance) phase*
  The technique is implemented.

3. Achieved environmental benefits
- Prevention or minimisation of air pollution by:
    - preventing or minimising the emission of VOCs and other potential air pollutants from drilling muds and other extractive wastes from oil and gas exploration and

production, including flowback and produced water, possibly releasing VOCs or other potential air pollutants.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- No information provided.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- No information provided.

8. Driving force for implementation
- Legal and environmental requirements and local legislation.

9. Example sites
- No information provided.

10. Reference literature
(UK EA 2016)
(IOGP 2016)

4.3.3.4 Monitoring of emissions to air

4.3.3.4.1 Techniques to model emissions to air

No information was provided on modelling of emissions to air in the questionnaires.

Modelling of emissions to air is only an option if these models can be validated with appropriate measurement data.

4.3.3.4.2 Techniques to monitor emissions to air

1. Description
This technique consists of identifying possible emission sources and monitoring emissions to air, including monitoring of ambient air quality and dust deposition from diffuse emissions, and monitoring the efficiency of the measures applied for prevention and reduction of these emissions.

2. Technical description
A monitoring plan for emissions to air includes the following activities:
- Identification of the possible emission sources considering both point and diffuse sources. This may include modelling of diffuse emissions, which also encompasses fugitive emissions (e.g. EN 15445:2008).
- Planning the monitoring of emissions to air and the efficiency of the measures applied for prevention and reduction of these emissions. This may include monitoring of ambient air quality and dust deposition from diffuse emissions while using meteorological data.

Both point source emissions and diffuse emissions may be quantified by micrometeorological methods, e.g. dynamic plume measurements.

Monitoring parameters and frequencies are properly selected according to the site-specific conditions, including the extractive waste characteristics, with particular regard to the potential risk of air pollution, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions.

If the emissions to air from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed

Monitoring is planned in accordance with EN standards. If EN standards are not available, ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.

The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.

The technique is applied in all the life cycle phases of the extractive waste management:

- *Planning and design phase*
  A monitoring plan is set up.
- *Operational (construction, management and maintenance) phase*
  Monitoring is carried out and the information collected is used as feedback for possible corrective measures in the extractive waste management.
  The monitoring plan is adapted based on the monitoring findings over time.
- *Closure and after-closure phase*
  Monitoring is carried out and the information collected is used as feedback for possible corrective measures in the closure and after-closure phase.
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

3. Achieved environmental benefits

- Prevention or minimisation of air pollution by:
  - determining whether the implemented measures are effective or if additional corrective measures are necessary to prevent or minimise air pollution.
- Prevention and reduction of negative environmental impacts from the management of extractive waste. Optimisation of the extractive waste management and treatment strategies.
- Mitigation of accidents.
- Ensuring a high level of protection of the environment as a whole.
- Maintaining the appropriate operation, closure and after-closure of the extractive waste management site.

4. Environmental performance and operational data

- At the Żelazny Most tailings pond, ambient air quality is monitored at 23 points located close to the pond. There are three continuous measurement stations for PM_{10} measurement. Additionally, the collected particulate matter is analysed to determine the copper, lead and arsenic content.
  Furthermore, dust deposition is monitored on a monthly basis, including measurement of the copper and lead content. Additionally, the zinc, cadmium, manganese, nickel and iron content are measured quarterly.
- At Rio Narcea, a number of dust sampler monitoring units were placed along the perimeter of the site, with data being recovered and analysed on a monthly basis. This monitoring system worked in parallel with the existing Occupational Health and Safety programme

which already included dust monitoring through personal samplers, according to the MTWR BREF (EC-JRC 2009).

Reported monitoring parameters and frequencies are presented in

Table 4.57.

Table 4.57: Reported monitoring parameters and frequencies for ambient air quality and dust deposition from diffuse emissions to air (based on information exchanged, including via the questionnaires)

Reported monitoring parameter*	Reported unit*	Number of sites*	Reported annual monitoring frequency range (min.-max., unless only one value reported)*	Reported EN/ISO standard*
Diffuse dust emissions:				
TSP	µg/m^3	5	1-84	NS***
PM_{10}	µg/m^3	8	365-Continuous****	EN 12341
$PM_{2.5}$	µg/m^3	1	Continuous****	NI**
Dust deposition:				
Deposition rate	mg/m^2/day	8	1-56	NS***
Dust characteristics:				
Metals and metalloids content (e.g. As, Cd, Zn, Ni, Cu, Fe, Cr, Hg, Ti, Co)	µg/m^3 µg/m^2/day	8	1-679	NS***
Dust conductivity	mS/m	1	56	NI*
Total sulphur content	µg/m^3	1	12	NI*
Diffuse gas emissions:				
VOCs	NI**	0	NI**	NI**
Other air pollutants	NI**	0	NI**	NI**

* *Parameters, information and data reported by operators via the questionnaire (in total 87 questionnaires).*
** *NI stands for No Information, meaning that operators did not provide information.*
*** *NS stands for National Standard provided only.*
**** *Includes long-term campaign (several months) of continuous (automated) monitoring of particles.*

Monitoring of diffuse emissions originating solely from EWFs may not be possible due to the proximity of other sources of emissions such as the extractive site itself.

5. Cross-media effects
- None identified.

6. Technical considerations relevant to applicability
- Monitoring of emissions to air, including monitoring of ambient air quality and dust deposition from diffuse emissions, can be carried out at any extractive waste management site. However, the range of monitored parameters and the monitoring frequency depend on the type of extractive waste, size of the EWF and local/geographical conditions (Kauppila *et al.* 2013).

7. Economics
- No information provided.

8. Driving force for implementation
- Legal and environmental requirements.
- Surveillance and early warning.

9. Example sites

- Welton Gathering Centre (UK)
- Preston New Road (UK)
- KGHM Polska Miedź S.A. Żelazny Most tailings pond (PL)
- El Cogulló (ES)
- El Fusteret (ES)
- K+S Kali GmbH, Werk Neuhof-Ellers (DE)
- K+S Kali GmbH, Werk Sigmundshall (DE)
- K+S Kali GmbH, Werk Werra, Standort Wintershall (DE)
- K+S Kali GmbH, Werk Zielitz (DE)
- Pyhäsalmi Mine Oy (FI)
- Kisladag Gold Mine (TR)
- Efemçukuru Gold Mine (TR)

10. Reference literature

(EC-JRC 2009)
(Kauppila *et al.* 2013)

4.4 Other risk-specific BAT candidates

4.4.1 Techniques to prevent or minimise noise emissions from the management of extractive waste

4.4.1.1 Noise barriers

1. Description
Noise barriers consist of the construction of noise protection walls, embankments, fences or vegetative barriers to reduce noise emissions.

2. Technical description
Noise protection walls or embankments can be constructed to reduce noise emissions. Fences or vegetative barriers such as trees can also be used.

At the <u>coal mines in the Ruhr and Saar regions</u>, ramps and benches are transferred into the heap's inner area as far as possible, where they are shielded by embankments, to minimise dust and noise emissions from extractive waste transport, dumping and spreading operations.

In some cases, an outer slope is first created to keep noise, dust and the movement of machinery out of the view of the neighbourhood. With this technique, it is first necessary to manage the outside of the heap in such a way as to ensure quick revegetation, so that it can then act as an appropriate noise barrier. According to feedback from site neighbours, the most annoying noise is the warning noise of reversing dumpers, as reported in the MTWR BREF (EC-JRC 2009).

The technique is applied in the following life-cycle phases of the extractive waste management:
- <u>*Planning and design phase*</u>
  Noise barriers are planned.
- <u>*Operational (construction, management and maintenance) phase*</u>
  Noise barriers are put in place.

3. Achieved environmental benefits
- Prevention or minimisation of noise and vibration emissions from the management of extractive waste.

4. Environmental performance and operational data
- At the Zinkgruvan mine, ~ 0.5 Mt of extractive waste from excavation has been used to build a noise barrier close to the exhausted open pit.

5. Cross-media effects
- Material consumption.
- Fuel consumption for transportation of materials.

6. Technical considerations relevant to applicability
- None identified.

7. Economics
- No information provided.

8. Driving force for implementation
- Local requirements.

9. Example sites
- Zinkgruvan Mining AB (SE)

10. Reference literature
(EC-JRC 2009)

4.4.1.2 Continuous conveyor systems

See Section 4.3.3.2.1.

4.4.1.3 Landscaping and geomorphic reclamation

See Section 4.3.2.1.4.

4.4.2 Techniques to prevent or minimise odour emissions from the management of extractive waste

No detailed information was provided on techniques to prevent or minimise odour emissions from the management of extractive waste which could be presented using the 10-heading structure.

4.4.2.1 Progressive rehabilitation

See Section 4.3.1.3.1.

4.4.2.2 Temporary covers

See Section 4.3.1.3.2.

4.4.2.3 Vegetative covers

See Section 4.3.1.3.3.

4.4.2.4 Permanent covers

4.4.2.4.1 Permanent dry covers

See Section 4.3.1.3.4.1.

4.4.2.4.2 Permanent wet covers

See Section 4.3.1.3.4.2.

4.4.3 Techniques to prevent or minimise the visual impact and footprint from the management of extractive waste

4.4.3.1 Techniques to prevent solid extractive waste generation

See Section 4.1.3.1.

4.4.3.2 Techniques for the solid/liquid control of extractive waste

The use of thickened or dry extractive waste management can decrease the footprint of the extractive waste deposition area (including the EWF).

For further information see Section 4.2.2.1.4.1.

4.4.3.3 Techniques to compact, consolidate and deposit extractive waste

See Section 4.2.2.1.4.

4.4.3.4 Landscaping and geomorphic reclamation

See Section 4.3.2.1.4.

4.4.4 Techniques to minimise resource consumption from the management of extractive waste

4.4.4.1.1 Techniques to reduce consumption of energy from the management of extractive waste

See Section 4.1.2.2 and Section 4.2.1.1.1.

4.4.4.1.2 Techniques to reduce water consumption from the management of extractive waste

See Section 4.3.2.1 and Section 4.1.3.3.1.

4.4.4.1.3 Techniques to reduce consumption of reagents, auxiliary materials and feedstock from the management of extractive waste

See Section 4.1.2.2 and 4.2.1.1.1.

4.4.5 Techniques to manage extractive waste containing NORMs

4.4.5.1 NORMs monitoring plan

This BAT candidate is relevant for extractive waste potentially containing NORMs.

The technique consists of extractive waste radioactivity monitoring, segregation and appropriate management according to national standards.

The management of radioactive materials is not within the scope of this document. Nevertheless, monitoring of radioactivity and appropriate management of materials classified as non-radioactive according to the national classification but containing TE-NORMs can be required on site.

IAEA developed a set of standards and guidelines for the management of radioactive materials and wastes in the extractive industry.

The most relevant for the management of extractive waste are:

- Classification of radioactive waste, General Safety Guide No. GSG-1, 2006;
- Management of Radioactive Waste from Mining and Milling of Ores, Safety Guide No. WS-G-1.2, 2002;
- Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry, Safety Report Series No. 34, 2003;
- Best Practice in Environmental Management of Uranium extraction, IAEA Nuclear Energy Series No. NF-T-.2, 2010.

The technique is applied in the life cycle phases on the extractive waste management listed below:

- *Planning and design phase*
  A monitoring plan is developed.
- *Operational (construction, management and maintenance) phase*
  The monitoring plan is implemented and reviewed.
- *Closure and after-closure phase*
  The technique described in the operational phase is adapted to the specifics of the closure phase and implemented.
  The technique described in the operational phase is adapted to the specifics of the after-closure phase and implemented, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.

4.4.5.2 Sorting and selective handling

See Section 4.1.3.2.2.

4.4.6 Techniques to prevent induced seismicity brought about as a result of the management of extractive waste

See Section 4.2.1.4.2.

4.4.7 Techniques to prevent or minimise impacts on biodiversity brought about as a result of the management of extractive waste

See Section 4.4.3.

5 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS

5.1 General considerations

Best Available Techniques

The Best Available Techniques Reference Document for the Management of Waste from Extractive Industries (MWEI BREF) is a technical document representing the results of the latest exchange of information, organised by the Commission, on Best Available Techniques (BAT) for the management of extractive waste and associated monitoring, based on the developments in the extractive waste management sector since the elaboration of the initial Best Available Techniques Reference Document for the Management of Tailings and Waste-Rock in Mining Activities (MTWR BREF). This chapter contains the BAT Conclusions derived from that exchange of information, consisting of a concise description of techniques that are considered BAT.

The role and proper use of BAT is explained in the Extractive Waste Directive:

- Member States shall ensure that operators responsible for the management of extractive waste take all measures necessary to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of extractive waste. These measures shall be based, *inter alia*, on the best available techniques without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the waste facility, its geographical location and the local environmental conditions.
- Member States shall take the necessary measures to ensure that competent authorities periodically reconsider and, where necessary, update permit conditions in light of the information exchange on substantial changes in best available techniques.

This document does not provide legal interpretation, nor should it be used to such purpose. It aims to provide technical information related to BAT referring to a broad range of materials and processes. Reference to extractive waste in this document does not imply a legal interpretation of the status of this material as either extractive waste or not extractive waste.

The BAT Conclusions should therefore be seen as a reference aiming at:

- providing extractive industries, competent authorities and other relevant stakeholders with up-to-date information and data on the management of extractive waste;
- supporting decision makers by providing a list of identified BAT to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of extractive waste, duly taking into account that the techniques listed and described in this chapter are neither prescriptive nor exhaustive and that other techniques may be used that ensure at least an equivalent level of environmental protection.

Structure of Chapter 5

In view of the site-specific conditions of extractive waste management activities, Chapter 5 presents conclusions on two distinct groups of BAT:

- generic BAT, which are generally applicable, unless otherwise stated;
- risk-specific BAT, which are applicable to sites where specific risks of adverse effects on the environment or human health are identified through a proper Environmental Risk and Impact Evaluation.

Generic BAT focus on:

- corporate management;
- information and data management (including the site-specific information and the evaluation of environmental risks and impacts);
- waste hierarchy.

Risk-specific BAT comprise BAT identified to prevent or reduce as far as possible specific risks that are identified by a proper Environmental Risk and Impact Evaluation, duly considering the relevant site-specific information:

- BAT on safety are relevant for sites where a risk of a major accident and/or risk of pollutant leaching/release is identified. These comprise BAT related to:
    - the structural stability of the extractive waste deposition area;
    - the physical and chemical stability of the extractive waste.
- BAT on the prevention or minimisation of water status deterioration and air and soil pollution are relevant for sites where a risk of water, air and/or soil pollution is identified. These comprise BAT related to:
    - prevention or minimisation of groundwater status deterioration and soil pollution;
    - prevention or minimisation of surface water status deterioration;
    - prevention or minimisation of air pollution.
- Other risk-specific BAT are relevant for sites where other environmental or human health risks are identified. These comprise BAT related to:
    - prevention or minimisation of noise emissions from the management of extractive waste;
    - prevention or minimisation of odour nuisance from the management of extractive waste;
    - prevention or minimisation of visual and footprint impacts from the management of extractive waste;
    - management of extractive waste containing Naturally Occurring Radioactive Materials (NORMs).

Processes and activities covered by the BAT Conclusions

The following processes and activities are covered:

- the management of extractive waste from onshore extractive activities;
- the handling/transport of extractive waste (e.g. loading, unloading and on-site transport);
- the treatment of extractive waste:
    - physical and mechanical treatment (e.g. sorting, blending, dewatering, thickening);
    - chemical treatment (e.g. desulphurisation, cyanide detoxification);
    - biological treatment (e.g. biological sulphide reduction);
- the deposition of extractive waste:
    - temporary deposition;
    - permanent deposition;
- the activities directly associated with the management of extractive waste:
    - treatment of Extractive Waste Influenced Water (EWIW);
    - preparing extractive waste to be placed back into excavation voids.

The TWG acknowledges that progress has been made in improving the knowledge base on sea tailings disposal (STD) but, following the exchange of information, no consensus has been reached either on the inclusion or on the exclusion of BAT for STD in this document. The TWG encourages the technoscientific community to further expand the knowledge base on impacts and benefits of STD. Finally, the TWG acknowledges that Norway continues to acquire experience in this field and has shared experience to this extent.

Additional sources of information

Reference document	Subject
Economics and Cross-Media Effects (ECM) [3]	Economics and cross-media effects of techniques
Emissions from Storage (EFS) [4]	Storage, transfer and handling of solids and liquids
Energy Efficiency (ENE) [5]	General aspects of energy efficiency
Iron and Steel Production (IS) [6]	Production of iron and steel in an integrated works as well as the production of steel in electric arc furnace steelworks
Ferrous Metals Processing Industry (FMP) [7]	Activities for the processing of semi-finished products obtained from ingot casting or continuous casting
Monitoring of emissions to air and water from IED installations (ROM) [8]	Monitoring of emissions to air and water
Non-Ferrous Metals Industries (NFM) [9]	Production of both primary and secondary non-ferrous metals
Production of Cement, Lime and Magnesium Oxide (CLM) [10]	Waste quality control and safety management for the use of hazardous waste materials
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector (CWW) [11]	Waste water and waste gas treatment techniques and treatment of water-based liquid waste
Waste Treatment (WT) [12]	Waste treatment

[3] ECM REF – http://eippcb.jrc.ec.europa.eu/reference/ecm.html
[4] EFS BREF – http://eippcb.jrc.ec.europa.eu/reference/esb.html
[5] ENE BREF – http://eippcb.jrc.ec.europa.eu/reference/ene.html
[6] IS BREF – http://eippcb.jrc.ec.europa.eu/reference/i&s.html
[7] FMP BREF – http://eippcb.jrc.ec.europa.eu/reference/fmp.html
[8] ROM REF – http://eippcb.jrc.ec.europa.eu/reference/mon.html
[9] NFM BREF – http://eippcb.jrc.ec.europa.eu/reference/nfm.html
[10] CLM BREF – http://eippcb.jrc.ec.europa.eu/reference/cl.html
[11] CWW BREF – http://eippcb.jrc.ec.europa.eu/reference/cww.html
[12] WT BREF – http://eippcb.jrc.ec.europa.eu/reference/wt.html

5.2 Generic BAT Conclusions

5.2.1 Corporate management

BAT 1. In order to improve the overall environmental performance of the extractive waste management operators, BAT is to use the following techniques:

	Technique	Description	Applicability
a	Organisational and Corporate Management system (O&CMS)	<u>*Planning and design phase*</u> To adhere to the principles of an Organisational and Corporate Management System (O&CMS) and tools relevant to the planning and design of the extractive waste management that encompass the following elements: • Risk Management; • Extractive Waste Inventory Management Tools such as stream inventory or mass balances; • Operational Management Tools such as Quality Assurance and Quality Control (QA/QC) systems (see BAT 12.a) or Management of Changes (see BAT 12.b); • Strategic Management Tools such as Benchmarking.	Generally applicable to all organisations. The level of detail and nature of the O&CMS are adapted to the site-specific conditions, including the technical characteristics of the Extractive Waste Facility (EWF), its geographical location and the local environmental conditions, to the size of the organisation and to the type of operation.
		<u>*Operational (construction, management and maintenance) phase*</u> To review and adapt the O&CMS based on the observed environmental performance findings over time.	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

b	Environmental Management System (EMS)	<u>*Planning and design phase*</u>
		To adhere to the principles of an Environmental Management System (EMS) relevant to the planning and design of the extractive waste management, e.g. EMAS, ISO 14001 or equivalent, which incorporates all the following features:
		• commitment of the managers, including senior managers;
		• development of an environmental policy that includes the continuous improvement for the extractive waste management by the operators;
		• planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
		• implementation of the procedures paying particular attention to:
		  o structure and responsibility;
		  o training, awareness and competence;
		  o communication;
			Generally applicable to all organisations.
			
			The level of detail and nature of the EMS (e.g. standardised or non-standardised) are adapted to the site-specific conditions, including the technical characteristics

		o employee involvement; o documentation; o efficient process control; o maintenance programmes; o emergency preparedness and response; o safeguarding compliance with environmental legislation; • checking performance and taking corrective action, paying particular attention to: o monitoring and measurement; o corrective and preventive action; o maintenance of records; o independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained; • review of the EMS and its continuing suitability, adequacy and effectiveness by senior management; • developing a clear protocol for major management activities taking into account BAT and practices: the operator can be informed about new BAT and practices by other operators in the sector, consultants, sectoral associations, as well as by consulting reference documents such as this and other BREF documents; • consideration for the environmental impacts possibly occurring at the closure phase (the final decommissioning) as well as the after-closure phase, from the stage of designing a new extractive waste deposition area (including the EWF) or an extension of an existing one that will cover new land surface, and throughout its entire operating life; • application of sectoral benchmarking of the environmental performance against the best performance achievable for the extractive waste management on a regular basis, if possible, in order to identify areas of excellence and areas where further improvement is needed. This can be achieved through systematic monitoring and reporting of the overall environmental performance. In this way, the EMS can more effectively focus on the areas with the lowest performances or the highest improvement potential; • integration of the Risk Management Systems and the Environmental Management System. This implies that a continuous exchange of information is ensured among the EMS, the Environmental Risk and Impact Evaluation (see BAT 5) and all Organisational and Corporate Management tools (see BAT 1.a and BAT 12).	of the EWF, its geographical location and the local environmental conditions, to the size of the organisation and to the type of operation.
		<u>*Operational (construction, management and maintenance) phase*</u> To review and adapt the EMS based on the observed environmental performance findings over time.	
		<u>*Closure and after-closure phase*</u>	

		To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.1.1.1 and 4.1.1.2]

5.2.2 Information and data management

5.2.2.1 Extractive waste characterisation

BAT 2. In order to support the identification of potential environmental risks and impacts associated with the extractive waste characteristics, BAT is to use the following technique:

Technique	Description	Applicability
Initial extractive waste characterisation	<u>*Planning and design phase*</u> To investigate the behaviour and characteristics of representative samples of the extractive waste according to the provisions of Commission Decisions 2009/359/EC and 2009/360/EC as well as the guidance documents developed by CEN/TC 292 (see Table 5.1). To use the EN standards identified in the CEN/TC 292 guidance documents. If EN standards for certain parameters/methods are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards. Such characterisation may be complemented with predictive modelling tools.	Generally applicable.

Table 5.1: Guidance documents and standard on extractive waste characterisation developed by CEN/TC 292

Standard	Description
CEN/TR 16376:2012	"Characterization of waste. Overall guidance document for characterisation of waste from the extractive industries"
CEN/TR 16365:2012	"Characterization of waste. Sampling of waste from extractive industries"
CEN/TR 16363:2012	"Characterization of waste. Kinetic testing for assessing acid generation potential of sulphidic waste from extractive industries"
CEN/TS 16229:2011	"Characterization of waste. Sampling and analysis of weak acid dissociable cyanide discharged into tailings ponds"
EN 15875:2011	"Characterization of waste. Static test for determination of acid potential and neutralisation potential of sulphidic waste."

[This BAT conclusion is based on information given in Section 4.1.2.1.1]

BAT 3. BAT is to review and verify the extractive waste characteristics as follows:

Technique	Description	Applicability
Review and verification of the extractive waste characteristics	<u>*Planning and design phase*</u> To develop a plan for the review and verification of extractive waste characteristics based on the initial extractive waste characterisation (see BAT 2) and the Environmental Risk and Impact Evaluation (see BAT 5). Parameters and frequencies for the review and verification of extractive waste characteristics are properly selected according to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions, as identified in the baseline studies and in the Environmental Risk and Impact Evaluation and reflected in the EWMP, with reference to the Annexes to CEN/TR 16376. Review and verification is planned in accordance with the guidance documents developed by CEN/TC 292 (see Table 5.1). BAT is to use the EN standards indicated in these guidance documents. If EN standards for certain parameters/methods are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards. For inert extractive waste, the provisions of Commission Decision 2009/359/EC apply.	Generally applicable.
	<u>*Operational (construction, management and maintenance) phase*</u> To implement the plan for the review and verification of the extractive waste characteristics, while applying management systems (see BAT 1). The plan, including selected parameters and frequencies, is adapted based on the necessary design objectives (see BAT 22 for example) and the Environmental Risk and Impact Evaluation (see BAT 5). This may imply adding/removing parameters and/or increasing/decreasing frequencies.	
	<u>*Closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	

[This BAT conclusion is based on information given in Section 4.1.2.1.2]

5.2.2.2 Extractive waste site and management options

BAT 4. In order to support the identification of potential environmental risks and impacts associated with the extractive waste site and extractive waste management options, BAT is to use all of the following techniques:

Technique		Description	Applicability
a	Identification of extractive waste site options	<u>*Planning and design phase*</u> To identify distinct site options based on a preliminary characterisation of the sites and the extractive waste (see BAT 2) considering the whole life cycle of the extractive waste management and using the information from all relevant expert studies covering safety aspects, geotechnical aspects, environmental aspects, local conditions and preliminarily identified potential impacts.	Generally applicable. The level of detail and nature of the identification of extractive waste site options are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.

b	Identification of extractive waste handling/ transport, treatment and deposition options	<u>*Planning phase*</u>
		To identify distinct extractive waste handling/transport, treatment and deposition options based on a preliminary characterisation of the extractive waste site options (see BAT 4.a) and the extractive waste (see BAT 2) considering the whole life cycle of the extractive waste management and using the information from all relevant expert studies covering safety aspects, geotechnical aspects, environmental aspects, local conditions and preliminarily identified potential impacts. This includes the identification of the following elements:
		• intended handling/transport and deposition techniques:
		  o handling/transport of extractive waste:
		    ▪ handling of extractive waste from excavation, e.g.:
		      • conveyor belts;
		      • trucks;
		    ▪ handling/transport of extractive waste from mineral processing, e.g.:
		      • conveyor belts;
		      • pipelines;
		      • trucks;
		    ▪ handling/transport of drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production, e.g.:
			Generally applicable.
			
			The level of detail and nature of the identification of extractive waste handling, treatment and deposition options are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.

		• pipelines; o temporary storage of extractive waste: ▪ temporary storage of extractive waste from excavation, e.g.: • heaps; ▪ temporary storage of extractive waste from mineral processing, e.g.: • heaps; • ponds; ▪ temporary storage of drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production, e.g.: • closed containers/tanks; o permanent deposition of extractive waste: ▪ permanent deposition of extractive waste from excavation, e.g.: • heaps; • co-disposal in ponds; • excavation voids (where deposited as extractive waste); ▪ permanent deposition of extractive waste from mineral processing, e.g.: • heaps (wet and dry filter cake deposition or dry stacking); • ponds confining paste or thickened extractive waste from mineral processing; • ponds and dams confining slurried extractive waste from mineral processing; • excavation voids (where deposited as extractive waste); ▪ permanent deposition of drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production, e.g.: • off-site treatment and/or disposal; • intended construction method of ponds, dams and heaps, including the basal structure concept design and possible future covers. *Design phase* To develop an extractive waste mass balance addressing all relevant types of extractive waste: • extractive waste from excavation; • extractive waste from mineral processing; • drilling muds and other extractive wastes (solid and liquid) from oil and gas exploration and production.	

		For each type of extractive waste, the mass balance may include the following information: • planned annual amounts of extractive waste temporarily stored in extractive waste deposition areas (including EWFs) or containers/tanks; • planned annual amounts of extractive waste permanently stored in extractive waste deposition areas (including EWFs); • planned annual amounts of extractive waste permanently sent off site for treatment and disposal.	
		<u>*Operational (construction, management and maintenance) phase*</u> To review the extractive waste mass balance based on data recorded over time (see BAT 12.a).	
		<u>*Closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	

[This BAT conclusion is based on information given in Sections 4.1.2.2.1 and 4.1.2.2.2]

5.2.2.3 Environmental Risk and Impact Evaluation

BAT 5. In order to determine the potential environmental risks and impacts brought about as a result of the management of extractive waste, BAT is to use all of the following techniques:

Technique		**Description**	**Applicability**
a	Hazards and risk elements identification	<u>*Planning and design phase*</u> To identify the hazards and risk elements, including source-pathway-receptor linkages (also physical failure modes), associated with specific extractive waste characteristics (see BAT 2) and extractive waste site and management options (see BAT 4).	Generally applicable. The level of detail and nature of the hazards and risk elements identification are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.
		<u>*Operational (construction, management and maintenance) phase*</u> To review the hazards and risk elements identification in the case of changes influencing the management of extractive waste (see management of changes in BAT 1), based on findings from the monitoring of the following: • extractive waste characteristics (see BAT 3); • physical stability of the extractive waste and extractive waste deposition area (including the EWF) (see BAT 23); • emissions to soil and groundwater (see BAT 40); • emissions to surface water (see BAT 48); • emissions to air (see BAT 52); • other parameters considered relevant for the hazards and risk elements identification.	
		<u>*Closure and after-closure phase*</u>	

		To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Environmental Risk and Impact Evaluation	<u>*Planning and design phase*</u> To carry out an initial Environmental Risk and Impact Evaluation(1) based, among others, on the extractive waste characteristics (see BAT 2) and the extractive waste site and management options (see BAT 4), considering the relevant principles of the standards ISO 31000:2009, ISO GUIDE 73:2009 and IEC/ISO 31010:2009 prioritising environment, human health and safety. It consists of a structured, dynamic and often iterative process, which is part of the risk management, where all the environmental risks and impacts brought about as a result of the extractive waste management (including all EWFs) are identified, analysed and evaluated over the whole life cycle. It includes due assessment of, *inter alia*, the generic and risk-specific BAT included in this document, in order to identify all appropriate measures/techniques aimed at preventing and reducing, as far as possible, any adverse effects on the environment and human health.	Generally applicable. The level of detail and nature of the Environmental Risk and Impact Evaluation are adapted to the site-specific conditions, including the technical characteristics of the EWF, its geographical location and the local environmental conditions.
		<u>*Operational (construction, management and maintenance) phase*</u> To review the Environmental Risk and Impact Evaluation in the case of changes influencing the management of extractive waste (see management of changes in BAT 1), based on findings from the monitoring of the following: • extractive waste characteristics (see BAT 3); • physical stability of the extractive waste and extractive waste deposition area (including the EWF) (see BAT 23); • emissions to soil and groundwater (see BAT 40); • emissions to surface water (see BAT 48); • emissions to air (see BAT 52); • other parameters considered relevant for the Environmental Risk and Impact Evaluation.	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

(1) The Environmental and Risk Evaluation may be integrated into existing procedures on Environmental Impact Assessment, including screening, for those activities falling under Directive 2011/92/EU amended by Directive

2014/52/EU.

[This BAT conclusion is based on information given in Sections 4.1.2.3.1 and 4.1.2.3.2]

5.2.3 Waste hierarchy

5.2.3.1 Prevention of solid extractive waste generation

BAT 6. In order to prevent the generation of solid extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Pre-sorting and selective handling of extractive materials that in principle qualify as by-products/products	*Particularly relevant for heterogeneous extractive materials* *<u>Planning and design phase</u>* To include in the design the pre-sorting of extractive materials that in principle qualify as by-products/products and the selective handling of these materials. This may include: • selective separation of solid extractive materials, e.g. based on visually, physically or chemically detected properties. *<u>Operational (construction, management and maintenance) phase</u>* To carry out pre-sorting and selective handling.	Generally applicable as far as it is technically and economically feasible and environmentally sound.
b	Placing extractive materials that in principle qualify as by-products/products back into excavation voids	*<u>Planning and design phase</u>* To include in the design the placing back of extractive materials that in principle qualify as by-products/products (such as extractive materials from excavation or mineral processing), combined or not with water and cementitious binders, into excavation voids, e.g. for structural and/or rehabilitation purposes. These activities form an integral part of the extraction operation. The term excavation voids includes both surface and underground excavation voids from mineral resources extraction. *<u>Operational (construction, management and maintenance) phase</u>* To implement the technique. *<u>Closure phase</u>* To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	Generally applicable as far as it is technically and economically feasible and environmentally sound.
c	Using extractive materials that in principle qualify as by-products/products for internal or external purposes	*<u>Planning and design phase</u>* To include in the design the use of extractive materials that in principle qualify as by-products/products for the following: • internal purposes within the extractive industry (such as for site rehabilitation, construction purposes – see also BAT 14, ARD management or use of muds in drilling processes); or	Generally applicable as far as it is technically and economically feasible and environmentally sound.

		• external purposes outside the extractive industry (such as for selling on the market as construction products when complying with Regulation (EU) No 305/2011 or selling as raw material for agricultural purposes).	
		Operational (construction, management and maintenance) phase To implement the technique.	
		Closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	

[This BAT conclusion is based on information given in Sections 4.1.3.1.1, 4.1.3.1.2 and 4.1.3.1.3]

5.2.3.2 Reduction of non-inert extractive waste and hazardous extractive waste generation

BAT 7. In order to reduce the generation of non-inert extractive waste and hazardous extractive waste, BAT is to use the following techniques:

Technique		Description	Applicability
a	Management of extractive waste accumulated during exploration /prospecting	*Relevant for extractive waste from exploration/prospecting activities other than oil and gas exploration and production activities*	The applicability depends on the characteristics and quantity of extractive waste (see BAT 2), and site-specific conditions.
		Planning and design phase To plan for an appropriate management and storage of extractive waste generated on site or to send the extractive waste off site for appropriate treatment and/or disposal.	
b	Sorting and selective handling of extractive waste	*Particularly relevant for heterogeneous extractive waste*	The applicability depends on the characteristics of extractive waste (see BAT 2).
		Planning and design phase To include in the design the appropriate separation of hazardous, non-hazardous non-inert and inert extractive waste streams, followed by selective handling of each stream.	
		Operational (construction, management and maintenance) phase To carry out sorting and selective handling.	

[This BAT conclusion is based on information given in Sections 4.1.3.2.1 and 4.1.3.2.2]

5.2.3.3 Reduction of extractive waste volumes to be deposited

BAT 8. In order to minimise the overall generation of liquid extractive waste from oil and gas exploration and production, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Preparing for re-useof liquid extractive wastes	*Relevant for flowback and produced water from oil and gas exploration and production* <u>*Planning and design phase*</u> To plan to prepare part of the flowback and produced water for re-use. The preparing for re-use of flowback and produced water is possible after the solid, condensate and gaseous phases are separated from the flowback and produced water by using a phase separator. Flowback and produced water are appropriately stored in order to prevent or reduce emissions to air, soil and water in temporary tanks. They are re-used in a subsequent hydraulic fracturing process, whenever possible. <u>*Operational (construction, management and maintenance) phase*</u> To re-use the flowback and produced water.	Applicable: • where the water quality and quantity matches the requirements for future use; and • as far as it is technically and economically feasible and environmentally sound.
b	Desalinisation of liquid extractive wastes	*Relevant for flowback and produced water from oil and gas exploration and production* <u>*Planning and design phase*</u> To include in the design the desalinisation of flowback and produced water by physical/chemical means, e.g.: • Multistage Flash Distillation (MSF); or • Multiple-Effect Distillation (MED); or • Vapour Compression Distillation (VCD); or • hybrids of more than one desalination technology; or • membrane filtration (e.g. reverse osmosis). <u>*Operational (construction, management and maintenance) phase*</u> To carry out distillation of flowback and produced water from oil and gas exploration and production.	Applicable as far as it is technically and economically feasible and environmentally sound. Multistage flash distillation and multiple-effect distillation are applicable to liquid streams with high TDS.
c	Dehydration of liquid extractive wastes	*Relevant for flowback and produced water from oil and gas exploration and production* <u>*Planning and design phase*</u> It includes, e.g.: • freeze/thaw evaporation, which combines a freezing and thawing cycle with conventional evaporation technology; or • dewvaporation, which involves humidification and dehumidification cycles; it reduces the energy costs by using countercurrent heat exchange technology.	Applicable as far as it is technically and economically feasible and environmentally sound. Freeze/thaw evaporation is applicable to liquid streams with a high

		Operational (construction, management and maintenance) phase To carry out dehydration of flowback and produced water from oil and gas exploration and production.	TDS content. Dewvaporation is applicable to liquid streams with a high TDS content and a broad variety of water chemistry makeup.

[This BAT conclusion is based on information given in Sections 4.1.3.3.1.1, 4.1.3.3.1.2 and 4.1.3.3.1.3]

BAT 9. In order to minimise the overall amount of extractive waste from oil and gas exploration and production to be deposited, BAT is to use the following technique:

Technique	Description	Applicability
Preparation of drilling muds and other drilling extractive wastes from oil and gas exploration and production for off-site treatment and/or disposal	*Relevant for drilling muds and other drilling extractive waste from oil and gas exploration and production* *Planning and design phase* To include in the design: • the separation of drill cuttings from the drilling muds by means of solid/liquid control techniques (e.g. shale shakers or equivalent) (see BAT 27.a); • the further removal of the finer fraction of drill cuttings from the drilling muds by means of e.g. mud cleaners, hydro-cyclones and centrifuges (see BAT 27.b and BAT 27.d); • the characterisation of the drill cuttings (see BAT 2); • the re-use of the recovered drilling muds for the drilling operation; • the sorting and selective handling of drill cuttings derived from the use of water-based muds from drill cuttings derived from oil-based muds; • the temporary storage of drill cuttings not releasing VOCs or other potential air pollutants into open containers (e.g. skips) designated for either oil-based cuttings or water-based cuttings and separate from any spent drilling muds pending collection; • the temporary storage of drill cuttings releasing VOCs or other potential air pollutants into closed containers/tanks designated for either oil-based cuttings or water-based cuttings and separate from any spent drilling muds pending collection (see BAT 51.b); • the sorting and selective handling of hazardous and non-hazardous waste (see BAT 7.b); • the covering of open containers for the temporary storage of drill cuttings, to prevent the ingress of water; • the reduction of the hydrocarbon concentrations in drill cuttings (see BAT 34) orthe removal of drill cuttings from the site, followed by off-site	Generally applicable.

	treatment and/or disposal (see also BAT 51.b).	
	Operational (construction, management and maintenance) phase To implement the technique.	

[This BAT conclusion is based on information given in Sections 4.1.3.3.2]

5.2.3.4 Recovery of extractive waste

BAT 10. In order to encourage the re-use and recycling of solid extractive waste, BAT is to use the following technique:

Technique	Description	Applicability
Re-processing of extractive waste	*Relevant for solid extractive waste containing valuable resources that can be re-used or recycled* To re-process extractive waste in order to recover valuable resources.	Applicable as far it is technically and economically feasible and environmentally sound. The applicability depends on the characteristics and quantity of extractive waste (see BAT 2).

[This BAT conclusion is based on information given in Section 4.1.3.3.3]

5.3 Risk-specific BAT Conclusions to ensure safety

5.3.1 Structural stability of the extractive waste deposition area

5.3.1.1 Short-term and long-term structural stability

5.3.1.1.1 Design for closure

BAT 11. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use the following technique:

Technique	Description	Applicability
Design for closure	*Relevant for ponds, dams and heaps (permanent and temporary)*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	<u>*Planning and design phase*</u> To apply a design for closure and after-closure approach by including an initial closure and after-closure planning of the extractive waste deposition area (including the EWF) that may contain the following: • a preliminary identification of the covering techniques (see BAT 38); • a preliminary identification of the techniques to prevent and control water and wind erosion (see BAT 21 and BAT 49); • an assessment of costs related to the proposed and alternative closure strategies including a cost benefit analysis; • an Environmental Risk and Impact Evaluation (see BAT 5); • a specific indication of the closure process to be followed, specifying if the rehabilitation will be progressively carried out during the operation phase or when progressive rehabilitation is not possible, it will be entirely carried out in the closure phase; in the latter case, the initial closure and after-closure planning explicitly states if a dry or wet cover will be implemented and provides details on the final landform and surface rehabilitation; • a design of the EWF that takes into consideration possible premature closure; • long-term stability analysis (see BAT 22); • a proposal for the control and monitoring procedures to be carried out during the after-closure phase (see BAT 3, BAT 23, BAT 40, BAT 48 and BAT 52). If possible, the closure and after-closure planning of the extractive waste deposition area (including the EWF) is integrated into the periodic extraction plans.	
	<u>*Operational (construction, management and maintenance) phase*</u> To review the closure and after-closure planning by updating the design assumptions, in particular when progressive rehabilitation is carried out during operation (see BAT 38.a).	
	<u>*Closure and after-closure phase*</u> To review the closure and after-closure planning by updating the design assumptions and by providing the final closure plan.	

[This BAT conclusion is based on information given in Section 4.2.1.1.1]

5.3.1.1.2 Additional Organisational and Corporate Management tools

BAT 12. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use one or a combination of techniques, appropriately selected from the following list:

<table>
<tr><th colspan="2">Technique</th><th>Description</th><th>Applicability</th></tr>
<tr><td rowspan="4">a</td><td rowspan="4">Quality Assurance and Quality Control (QA/QC) system [1]</td><td></td><td rowspan="4">Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).</td></tr>
<tr><td><u>Planning and design phase</u>
To implement a quality assurance and quality control (QA/QC) system, documenting the following information:
• Extractive waste characterisation (see BAT 2);
• Extractive waste site and management options (see BAT 4);
• Environmental Risk and Impact Evaluation (see BAT 5);
• Extractive waste deposition area (including the EWF) design (see Section 5.3.1.1.3).</td></tr>
<tr><td><u>Operational (construction, management and maintenance) phase</u>
To implement the QA/QC system by documenting the following information relating to the:
• construction phase:
    o records of any deviation and change from the original design;
    o records of the results of test work carried out before and during construction;
    o "as-built" documentation.
• operational phase:
    o Operation Supervision and Maintenance (OSM) manual for dams (see BAT 12.c);
    o internal and/or external (independent) auditing plans and reports, and/or inspection reports, conformity/non-conformity reports;
    o documented corrective measures and results;
    o monitoring reports.</td></tr>
<tr><td><u>Closure and after-closure phase</u>
To implement the QA/QC system by documenting the following information:
    o "as-built" documentation and adjustments of the closure plan highlighting the long-term closure objectives including physical, chemical and biological stability and subsequent land use;
    o specific closure issues for:
        ▪ heaps;
        ▪ ponds, including:
            − water covered ponds;
            − dewatered ponds;</td></tr>
</table>

		− water management facilities.	
b	Management of changes	<u>*Operational (construction, management and maintenance) phase*</u> To adhere to a Management of Changes system, which defines the procedures to follow when any changes in the design/construction/personnel occur and includes the systematic documentation of these changes (see BAT 1 and BAT 12.a). <u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
c	Operation, Supervision and Maintenance (OSM) manual for dams	*Relevant for ponds with dams where free water has to be properly managed* <u>*Operational (construction, management and maintenance) phase*</u> To develop a dam safety manual, which is a living document that compiles all the relevant information related to the dam and which may include: • dam safety organisation; • emergency planning, including the internal emergency plan specifically required for Category A EWFs, and information from the external emergency plan in as far as available to the operator; • Environmental Risk and Impact Evaluation; • dam design and construction; • hydrology and decant systems; • operation; • monitoring; • closure and after-closure planning; • permits. <u>*Closure and after-closure phase*</u> To maintain and review the OSM manual.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
d	Mitigation of accident procedures including emergency planning	*Relevant for ponds, dams and heaps (permanent and temporary) and for excavation voids where extractive waste is placed back* <u>*Operational (construction, management and maintenance) phase*</u> To implement a system for documenting all information related to accidents and incidents, including follow-up procedures. It may include emergency planning, the internal emergency plan specifically required for Category A EWFs, information from the external emergency plan insofar as it is available to the operator, investigation of accidents and incidents, and suggestions on how to prevent the event from happening again. It may also include warning systems and a plan for uncontrolled discharge of extractive waste or EWIW in consequence of, e.g. the EWF failure due to the loss of structural integrity or the breakage of the basal structure. To review the procedures according to BAT 1. <u>*Closure and after-closure phase*</u>	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		To maintain and review the documentation.	
[(1)] Information, including reports, collected and documented for other purposes may be re-used to this end.			

[This BAT conclusion is based on information given in Sections 4.2.1.2.1, 4.2.1.2.2, 4.2.1.2.3 and 4.2.1.2.4]

5.3.1.1.3 Extractive waste deposition on surface areas (including the EWFs)

5.3.1.1.3.1 Ground investigation

BAT 13. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use the following technique:

Technique	Description	Applicability
Investigation of the geotechnical properties of the supporting strata	*Relevant for ponds with dams and for heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	Planning and design phase To investigate the geotechnical and hydrogeological properties of the supporting strata before the extractive waste deposition area (including the EWF) is constructed, in accordance with Eurocode 7-2 (EN 1997-2:2007 - Part 2), when relevant, or other ISO, national or international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.	
	Operational (construction, management and maintenance) phase To verify the geotechnical and hydrogeological properties of the supporting strata.	

[This BAT conclusion is based on information given in Section 4.2.1.3.1]

5.3.1.1.3.2 Dam construction materials selection

BAT 14. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use the following technique:

Technique	Description	Applicability
Dam construction materials selection	*Relevant for dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	Planning and design phase To determine the suitability of materials for the dam construction with reference to geotechnical and environmental characteristics in accordance with Eurocode 7-2 (EN 1997-2:2007 - Part 2), when relevant, or other ISO, national or international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.	
	Operational (construction, management and maintenance) phase To verify the geotechnical and environmental	

	characteristics of the dam construction materials.	

[This BAT conclusion is based on information given in Section 4.2.1.3.2]

5.3.1.1.3.3 Construction methods for dams and heaps

5.3.1.1.3.3.1 Dam/embankment construction methods

BAT 15. In order to help ensure the short-term and long-term structural stability of the pond-type extractive waste deposition area (including the EWF), intended for water and solids retention by means of a dam, BAT is to use the following techniques:

Technique		Description	Applicability
a	Water and solids retention dam construction method	*Relevant for water and solids retention dams* *Relevant for non-inert extractive waste including PAG extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22. Applicable when: • a pond is required for the storage of water and extractive waste during the whole life cycle; or • retention of water is needed over an extended period; or • the site is in a remote and inaccessible location; or • the natural inflow into the pond is large or subject to high variations and water storage is needed for its control.
		<u>*Planning and design phase*</u> To design the construction of the structure (foundations, core, filters and initial shoulders) of an impermeable dam before extractive waste deposition into the pond. It encompasses one stage or various stages raised throughout the lifetime of the dam. Water and solids retention dams are designed as dams with low-hydraulic-conductivity upstream layers, filters and drainage systems and a dam basal structure to prevent or reduce seepage.	
		<u>*Operational (construction, management and maintenance) phase*</u> To construct the water and solids retention dam and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor and maintain the water and solids retention dam, while applying management systems and implementing the design for closure (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor and maintain the water and solids retention dam, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Basal structure	*Relevant for ponds and dams* *Relevant for non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 13, BAT 14 and
		<u>*Planning and design phase*</u> To include in the design an impermeable basal structure (see BAT 35.a and BAT 35.b).	
		<u>*Operational (construction, management*</u>	

		<u>*and maintenance) phase*</u> To construct the basal structure and to monitor and maintain it, while applying management systems (see BAT 1, BAT 11 and BAT 12).	BAT 22. Only applicable to new extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor the basal structure, while applying management systems (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the basal structure, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.2.1.3.3.1.1.1 and 4.2.1.3.3.1.3.3]

BAT 16. In order to help ensure the short-term and long-term structural stability of the pond-type extractive waste deposition area (including the EWF), intended for total solids and partial water retention by means of a dam, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Starter dam for total solids retention and partial water retention dam construction method	*Relevant for total solids retention and partial water retention dams* *Relevant for inert and non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22.
		<u>*Planning and design phase*</u> To design the construction of a solids retention starter dam (usually with a low-hydraulic-permeability core) considering the raising method with extractive materials (see below). To include in the design filters and drainage zones to permit the safe drainage of the dam, along with the EWIW collection and management systems.	
		<u>*Operational (construction, management and maintenance) phase*</u> To construct the solids retention starter dam and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments, while applying management systems and implementing the design for closure (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments, for as long as may be necessary, taking into account the nature and duration of the	

		residual risks and hazards.	
b	Upstream raising method	*Relevant for slurried extractive waste retention dams* <u>*Planning and design phase*</u> To design the raising of the dam in stages by building embankments on the beach of the previous stage. The centreline of the embankment crest moves upstream with each stage. The dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events (see BAT 20), and that the phreatic surface is controlled. The design usually includes filters and drainage zones to permit the safe drainage of the dam, along with the EWIW collection and management systems. <u>*Operational (construction, management and maintenance) phase*</u> To raise the dam with an upstream method and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12). <u>*Closure and after-closure phase*</u> In the closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments built with an upstream method, while applying management systems the design for closure (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments built with an upstream method, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22. Not applicable when: • the slightest risk of liquefaction has been identified after seismic evaluation of (small and large[1]) dams according to ICOLD Bulletin 139 and to ICOLD Bulletin 148 (referred to in BAT 22.a), applied equally to all kinds of upstream dams; or • permanent free water storage is necessary; or • the dam is not rigorously designed using modern engineering principles to ensure that the embankments are adequately drained and the phreatic surface is controlled.
c	Downstream raising method	*Relevant for slurried extractive waste retention dams* <u>*Planning and design phase*</u> To design the raising of a dam in stages in a way that the centreline of the embankment crest moves downstream with each stage. The dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events (see BAT 20), and that the phreatic surface is controlled. The design usually includes filters and drainage zones to permit the safe drainage of the dam along with the EWIW collection and management systems.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22. Not applicable when the dam is not rigorously designed using modern engineering principles to ensure that the embankments are adequately drained and the

		<u>*Operational (construction, management and maintenance) phase*</u> To raise the dam with a downstream method and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12). <u>*Closure and after-closure phase*</u> In the closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments built with a downstream method, while applying management systems and implementing the design for closure (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments built with a downstream method, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	phreatic surface is controlled. Not applicable when insufficient amounts of dam construction material are available.
d	Centreline raising method	*Relevant for slurried extractive waste retention dams* <u>*Planning and design phase*</u> To design the raising of a dam in stages in a way that the location of the centreline of the embankment crest does not change with each stage. The upstream toe of each embankment stage is constructed slightly over the beach, but the majority of each new stage is founded on the previous embankment stage. The dam is rigorously designed using modern engineering principles to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events (see BAT 20), and that the phreatic surface is controlled. The design usually includes filters and drainage zones to permit the safe drainage of the dam along with the EWIW collection and management systems. <u>*Operational (construction, management and maintenance) phase*</u> To raise the dam with a centreline method and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12). <u>*Closure and after-closure phase*</u> In the closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments built with a centreline method, while applying management systems and implementing the design for closure (see BAT 1, BAT 11 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22. Not applicable when: • the slightest risk of liquefaction has been identified after seismic evaluation of (small and large[1]) dams according to ICOLD Bulletin 139 and to ICOLD Bulletin 148 (referred to in BAT 22.a), applied equally to all kinds of centreline dams; or • construction materials with high plasticity are used; or • the water storage is permanent; or • the dam is not rigorously designed using modern engineering principles to ensure that the embankments are adequately drained and the phreatic surface is

		In the after-closure phase, to monitor and maintain the final dam structure comprised of the starter dam and raised embankments built with a centreline method, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	controlled. Temporary flood storage is acceptable with proper design.
e	Composite basal structure system	*Relevant for ponds and dams* *Relevant for non-inert extractive waste* *Planning and design phase* To include in the integrated design an impermeable basal structure (see BAT 35.a and BAT 35.b), in combination with a proper drainage system (see BAT 21.a), designed based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see BAT 2), the water balance (see BAT 18) and based on the design criteria resulting from BAT 14 and BAT 22. *Operational (construction, management and maintenance) phase* To construct the composite basal structure system and to monitor and maintain it, while applying management systems (see BAT 1, BAT 11 and BAT 12). *Closure and after-closure phase* In the closure phase, to monitor the composite basal structure system, while applying management systems (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the composite basal structure system, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22. Only applicable to new extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.
f	Low-permeability natural soil basal structure	*Relevant for ponds and dams* *Relevant for inert extractive waste* *Planning and design phase* To include in the integrated design a low-permeability natural soil layer as basal structure and to allow partial seepage through the basal structure. If the ground hydraulic conductivity cannot ensure proper drainage at all times, which could possibly lead to structural instability, to include in the design an additional drainage system (see BAT 21.a) based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see BAT 2), the water balance (see BAT 18) and based on the design criteria resulting from BAT 14 and BAT 22. *Operational (construction, management and maintenance) phase* To construct the low-permeability natural soil basal structure and to monitor and	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 14, BAT 19, BAT 20, BAT 21 and BAT 22. Only applicable to inert extractive waste.

		maintain it, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor the low-permeability natural soil basal structure, while applying management systems (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the low-permeability natural soil basal structure, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
(1) According to (ICOLD 2016), *a large dam is one more than 15 m high or one between 10 m and 15 m high satisfying one of the following criteria: a) more than 500 m long; b) reservoir capacity exceeding 1 million m^3; c) spillway capacity exceeding 2 000 m^3/s.*			

[This BAT conclusion is based on information given in Sections 4.2.1.3.3.1.1.2, 4.2.1.3.3.1.2.1, 4.2.1.3.3.1.2.2, 4.2.1.3.3.1.2.3, 4.2.1.3.3.1.3.1 and 4.2.1.3.3.1.3.2]

5.3.1.1.3.3.2 Heap construction methods

BAT 17. In order to help ensure the short-term and long-term structural stability of the heap-type extractive waste deposition area (including the EWF), BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Bottom-up construction method	*Relevant for heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable to non-inert extractive waste as a stand-alone solution (i.e. without a basal structure or leaching/ARD prevention measures/techniques).
		<u>*Planning and design phase*</u> To include in the design the deposition of the extractive waste in layers, followed by compaction if necessary and by the construction of benches when these can improve stability and facilitate further rehabilitation. Heaps are built in layers with thicknesses varying according to the nature of materials. Benches increase the stability and facilitate the covering and rehabilitation works.	
		<u>*Operational (construction, management and maintenance) phase*</u> To construct the heap with a bottom-up method and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor and maintain the final heap built with a bottom-up method, while applying management systems and implementing design for closure (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the	

		final heap built with a bottom-up method, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Top-down construction method	*Relevant for heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable to non-inert extractive waste as a stand-alone solution (i.e. without a basal structure or leaching/ARD prevention measures/techniques).
		Planning and design phase To include in the design the deposition of the extractive waste from the crest. Material segregation occurs during deposition as coarser particles slide down the slope and rest at approximatively the specific angle of repose of the material, depending on heterogeneity and granulometry of the extractive waste. In the closure phase, extractive waste heaps are usually reshaped to the angle of natural repose, depending on the extractive waste characteristics (see BAT 2), and resulting in a geomorphic shape (see BAT 42.d) that either in itself or after the placing of a cover, provides long-term stability (see BAT 22.b) and adequate protection against wind and water erosion.	
		Operational (construction, management and maintenance) phase To construct the heap with a top-down method and to monitor and maintain it, while applying management systems and design for closure (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase In the closure phase, to monitor and maintain the final heap built with a top-down method, while applying management systems and implementing design for closure (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the final heap built with a top-down method, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
c	Composite basal structure system	*Relevant for heaps* *Relevant for non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 21 and BAT 22. Only applicable to new deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.
		Planning and design phase To include in the integrated design an impermeable basal structure (see BAT 35.a and BAT 35.b), in combination with a proper drainage system (see BAT 21.b), designed based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see BAT 2), the water balance (see BAT 18) and based on the design criteria resulting from BAT 22.	
		Operational (construction, management and maintenance) phase To construct the composite basal structure system and to monitor and maintain it,	

		while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor the composite basal structure system, while applying management systems (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the composite basal structure system, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
d	Low-permeability natural soil basal structure	*Relevant for heaps* *Relevant for inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 11, BAT 13, BAT 21 and BAT 22. Only applicable to inert extractive waste.
		<u>*Planning and design phase*</u> To include in the integrated design a low-permeability soil layer as basal structure and to allow partial seepage through the basal structure. If the ground hydraulic conductivity cannot ensure proper drainage at all times, which could possibly lead to structural instability, to include in the design an additional drainage system (see BAT 21.b) based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see BAT 2), the water balance (see BAT 18) and based on the design criteria resulting from BAT 22.	
		<u>*Operational (construction, management and maintenance) phase*</u> To construct the low-permeability natural soil basal structure and to monitor and maintain it, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor the low-permeability natural soil basal structure, while applying management systems (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, to monitor the low-permeability natural soil basal structure, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.2.1.3.3.2.1, 4.2.1.3.3.2.2, 4.2.1.3.3.2.3.1 and 4.2.1.3.3.2.3.2]

5.3.1.1.3.4 Water-related structures

5.3.1.1.3.4.1 Water balance analysis

BAT 18. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use all of the following techniques:

Technique		Description	Applicability
a	Water balance analysis	*Relevant for ponds, dams and heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To complete a detailed water balance for any surface extractive waste deposition area (including the EWF) encountered in the operational phase and in the closure and after-closure phase. It is used to predict the variation of volumes and quality of water entering, circulating and leaving the deposition area (including the EWF).	
		Operational (construction, management and maintenance) phase To review the detailed water balance analysis based on the monitoring findings.	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Water management plan	*Relevant for all ponds, dams and heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To use the results of the water balance analysis for developing a water management plan. If the EWIW issue is considered together with the water that comes from the extraction site, e.g. Acid Mine Drainage (AMD), and is sent to the pond, an integrated water management plan may be developed.	
		Operational (construction, management and maintenance) phase To implement and review the water management plan.	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.2.1.3.4.1 and 4.2.1.3.4.2]

5.3.1.1.3.4.2 Design flood

BAT 19. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use the following technique:

Technique	Description	Applicability
Design flood evaluation	*Relevant for ponds with dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 20 and BAT 22.
	<u>Planning and design phase</u> To include in the design the design flood evaluation. The design flood is the flood of suitable probability and magnitude adopted for the dam/pond design to ensure a high level of dam safety. It refers to the computed maximum inflow at the dam site, affected by the reservoir, for the sizing of the spillways and the pond storage capacity. It is necessary to allow all ponds and retaining dams to accommodate extreme hydrologic events, considering also climate change scenarios, by using the design flood parameters specified below for the design of the combined discharge capacity of the pond, decant systems and emergency spillways: <u>For the short-term design (operational phase)*</u> • at least the once in a 200-year flood as the design flood for the sizing of a low-risk dam (as identified in the Environmental Risk and Impact Evaluation, see BAT 5); • at least the once in a 500- or 1 000-year flood (depending on the level of risk) as the design flood for the sizing of a moderate-risk dam (as identified in the Environmental Risk and Impact Evaluation, see BAT 5); • the Probable Maximum Flood (PMF) as the design flood for the sizing of a high-risk dam (as identified in the Environmental Risk and Impact Evaluation, see BAT 5). <u>For the long-term design (after-closure phase)*</u> • the PMF as the design flood for the sizing of low-, moderate- and high-risk dams (as identified in the Environmental Risk and Impact Evaluation, see BAT 5).	
	<u>Operational (construction, management and maintenance) phase</u> To review the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	
	<u>Closure and after-closure phase</u> To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	
* Other national guidelines providing equivalent protection may be used.		

[This BAT conclusion is based on information given in Section 4.2.1.3.4.3]

5.3.1.1.3.4.3 Free water management

BAT 20. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
Removal of free water			
a	Vertical decant tower	*Relevant for ponds with dams* *<u>Planning and design phase</u>* To include in the design a permanent decant system for removing the free water from the surface of the supernatant pond by gravity through an underlying conduit. Vertical decant towers are designed to accommodate total loads resulting from the deposited extractive waste during all relevant life cycle phases (see BAT 14 and BAT 22). Other associated structures (e.g. the conduit) are designed to accommodate total embankment loads during all relevant life cycle phases (see BAT 14 and BAT 22). *<u>Operational (construction, management and maintenance) phase</u>* To carry out the removal of free water by a vertical decant tower, while applying management systems (see BAT 1, BAT 11 and BAT 12). *<u>Closure and after-closure phase</u>* To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22. Generally applicable: • in climates without major precipitation-free periods with a positive water balance; or • for paddock-style ponds. Only applicable if continuously surrounded by water.
b	Decant well	*Relevant for ponds with dams* *<u>Planning and design phase</u>* To include in the design a permanent decant system for removing the free water from the surface composed by a perforated tube surrounded by rock-fill. In this case the dam does not contain a conduit/drain. Decant wells are designed to accommodate total loads resulting from the deposited extractive waste during all relevant life cycle phases (see BAT 14 and BAT 22). *<u>Operational (construction, management and maintenance) phase</u>* To carry out the removal of free water by a decant well, while applying management systems (see BAT 1, BAT 11 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22. Generally applicable: • in climates with major precipitation-free periods with a negative water balance; or • for paddock-style ponds; or • if a high operating freeboard is maintained.

		<u>*Closure and after-closure phase*</u> To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	
c	Decant chute or inclined decant	*Relevant for ponds with dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22. Generally applicable to manage free water in a pond.
		<u>*Planning and design phase*</u> To include in the design a permanent decant system usually founded in natural ground on a flank of the pond and occasionally on the upstream face of the dam. Decant chutes or inclined decants are designed to accommodate total loads resulting from the deposited extractive waste during all relevant life cycle phases (see BAT 14 and BAT 22).	
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out the removal of free water by a decant chute or inclined decant, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	
d	Floating decant system	*Relevant for ponds with dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22. Not applicable in the case of small ponds.
		<u>*Planning and design phase*</u> To include in the design a movable decant system with a floating platform where pumps are installed.	
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out the removal of free water by a floating decant system, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> To monitor and verify that embankments are adequately drained and the phreatic surface is controlled.	
e	Lowering the phreatic surface at closure and after-closure	*Relevant for ponds with dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22.
		<u>*Closure and after-closure phase*</u> To permanently lower the phreatic surface during the entire closure phase and for the long term in the case of dewatered ponds, by using modern engineering principles to ensure that the embankments are adequately drained and the phreatic surface is controlled.	
Beach			
f	Minimum	*Relevant for ponds with dams*	Based on the results of a

	beach length	*Planning and design phase* To include in the design a minimum beach length in order to control stability. The minimum length depends on the risk of the dam (see BAT 5), the water content and the physical characteristics of the extractive waste and the local conditions. Modern engineering principles are applied to ensure that the embankments are adequately drained, that an appropriate beach length is guaranteed at all times, including a minimum beach length during extreme flood events, and that the phreatic surface is controlled. *Operational (construction, management and maintenance) phase* To monitor and maintain a minimum beach length, while applying management systems (see BAT 1, BAT 11 and BAT 12). *Closure and after-closure phase* To monitor and verify that embankments are adequately drained and the phreatic surface is controlled.	proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19, BAT 21 and BAT 22. Not applicable for dry stacking.
Freeboard			
g	Freeboard	*Relevant for ponds with dams* *Planning and design phase* To include in the design a minimum freeboard, to be maintained during the Probable Maximum Flood event above the minimum required beach, as defined in the ICOLD guidelines or stricter national guidelines. Modern engineering principles are applied to ensure that the embankments are adequately drained, an appropriate freeboard is guaranteed at all times, including the minimum freeboard during extreme flood events, and the phreatic surface is controlled. *Operational (construction, management and maintenance) phase* To monitor and maintain a minimum freeboard, while applying management systems (see BAT 1, BAT 11 and BAT 12). *Closure and after-closure phase* To monitor and verify that embankments are adequately drained and the phreatic surface is controlled.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19, BAT 21 and BAT 22.
Emergency discharge			
h	Large-dimension pipes	*Relevant for ponds with dams* *Planning and design phase* To include in the design the installation of pipes through the dam at such a level so that the predetermined minimum	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		freeboard will always be maintained. *<u>Operational (construction, management and maintenance) phase</u>* To maintain the emergency discharge by large-dimension pipes, while applying management systems (see BAT 1, BAT 11 and BAT 12). *<u>Closure and after-closure phase</u>* To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22.
k	Controlled overflows	*Relevant for ponds with dams* *<u>Planning and design phase</u>* To include in the design controlled overflows over the dam body designed to discharge any excessive water without hampering the integrity of the dam. *<u>Operational (construction, management and maintenance) phase</u>* To maintain the emergency discharge by controlled overflows, while applying management systems (see BAT 1, BAT 11 and BAT 12). *<u>Closure and after-closure phase</u>* To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22.
j	A spillway or open channel in natural ground	*Relevant for ponds with dams* *<u>Planning and design phase</u>* To include in the design a spillway or an open channel in natural ground designed to work automatically and to discharge any excessive water without hampering the integrity of the dam. For such systems, erosion protection is critical. *<u>Operational (construction, management and maintenance) phase</u>* To maintain the emergency discharge by a spillway or an open channel in natural ground, while applying management systems (see BAT 1, BAT 11 and BAT 12). *<u>Closure and after-closure phase</u>* To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22. Not applicable to paddock-style ponds.
i	Alternative discharge	*Relevant for ponds with dams* *<u>Planning and design phase</u>* To include in the design alternative discharge facilities, possibly into another	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		pond. Alternative discharges are designed to accommodate total embankment loads during all relevant life cycle phases (see BAT 14 and BAT 22), where appropriate.	Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22.
		Operational (construction, management and maintenance) phase To maintain an alternative discharge as emergency discharge, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	
l	Second decant facilities	*Relevant for ponds with dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 14, BAT 18, BAT 19 and BAT 22.
		Planning and design phase To include in the design second decant facilities (e.g. emergency overflow) and/or standby pump barges for emergencies, if the level of the free water in the pond reaches the predetermined minimum freeboard	
		Operational (construction, management and maintenance) phase To maintain a second decant facility as emergency discharge, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase To monitor and verify the design flood evaluation. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	

[This BAT conclusion is based on information given in Sections 4.2.1.3.4.4 and 4.2.1.3.4.5]

5.3.1.1.3.5 Drainage systems

BAT 21. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Drainage systems for ponds and dams	*Relevant for ponds and dams*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 18, BAT 22 and
		Planning and design phase To include in the design a proper drainage system to capture and collect the EWIW originating from a pond or dam in order to ensure the physical stability of the deposited extractive waste and prevent or reduce	

		seepage to the ground.
		
		Examples of drainage systems are:
		• drains placed:
		  o beneath the confining dam;
		  o within the confining dam;
		  o at the toe of the dam.
		• drains placed above the basal structure, for example with a fishbone configuration (see BAT 15.b and BAT 16.e);
		• a continuous gravel layer overlying the basal structure with a typical thickness of 200-1 000 mm (see BAT 15.b and BAT 16.e).
			BAT 42.b.

		<u>*Operational (construction, management and maintenance) phase*</u> To construct drainage systems for ponds and dams and to monitor and maintain them, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards. To ensure that the EWF continues to meet all flood design criteria (see BAT 11, BAT 12, BAT 14 and BAT 22).	
b	Drainage systems for heaps	*Relevant for heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 18, BAT 22 and BAT 42.b.
		<u>*Planning and design phase*</u> To include in the design a proper drainage system to capture and collect the EWIW originating from a heap in order to ensure the physical stability of the deposited extractive waste and prevent seepage to the ground. Examples of drainage systems are: • collection ditches in the heap perimeter; • drains below the heap, for example with a fishbone configuration, above the basal structure (see BAT 17.c); • a continuous gravel layer overlying the basal structure with a typical thickness of 200-1 000 mm (see BAT 17.c).	
		<u>*Operational (construction, management and maintenance) phase*</u> To construct drainage systems for heaps and to monitor and maintain them, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u>	

		To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards. To ensure that the EWF continues to meet all design criteria (see BAT 11, BAT 12 and BAT 22).	

[This BAT conclusion is based on information given in Sections 4.2.1.3.5.1 and 4.2.1.3.5.2]

5.3.1.1.3.6 Geotechnical analysis and physical stability monitoring

5.3.1.1.3.6.1 Geotechnical analysis of the extractive waste deposition area (including the EWF)

BAT 22. In order to help ensure the short-term and long-term structural stability of the extractive waste deposition area (including the EWF), BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Geotechnical analysis of dams and ponds	*Relevant for ponds and dams* <u>Planning and design phase</u> To consider in the geotechnical analysis all the mechanisms that can negatively affect the partial or total structural stability of dams and ponds. To analyse the physical stability in the short and long term according to Eurocode 7–1 (EN 1997-1:2004 - Part 1) or equivalent national standards and to the provisions of the ICOLD guidelines (including Bulletin 139 and 148) or equivalent national standards in the case of large dams (1). The geotechnical analysis usually covers the following aspects: • the overall slope stability of the dam, including the basal structure; • the bearing capacity and stability of the foundation of the dam; • the physical and chemical stability of the extractive waste, including static and dynamic liquefaction, freezing and thawing, following ICOLD guidelines or equivalent international or national guidelines; • the stability against internal erosion (i.e. piping) and surface erosion; • the stability of free water removal systems, water drainage systems and emergency spillways; • where present, the assessment of internal and external bunds is considered. The geotechnical analysis takes into consideration the results of the water balance analysis (see BAT 18.a).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). The applicability of the observational method may be restricted in the case of failure modes that could develop very quickly, e.g. if a potential risk of static liquefaction of loose extractive waste exists.

		The selection of seismic parameters in this analysis is based on site-specific analysis of the seismic risk(2). According to the ICOLD guidelines, the Safety Evaluation Earthquake (SEE) used for the long-term geotechnical analysis of large dams and spillways is characterised by a level of motion equal to that expected from the occurrence of a deterministically evaluated Maximum Credible Earthquake (MCE) or equal to the probabilistically evaluated earthquake ground motion with a return period of 10 000 years. Shorter return periods may be specified for dams with lower failure risk potential. By applying Eurocode 7–1, the design values are determined by using appropriate partial factors as defined in Annex A to this standard. The overall stability of slopes is analysed in the ultimate geotechnical (GEO) or structural (STR) limit states by applying: • an over-design factor (ODF) of at least 1, where the ODF is the ratio between the design resistance (Rd) and the design effect of the loads (Ed). Assessment of liquefaction potential is extended beyond the recommendations given in EN 1998 Eurocode 8 and in particular Part 5. By using equivalent national standards that do not apply partial factors and evaluate global safety factors, the overall stability is analysed by applying: • a safety factor of at least 1.3 for extreme conditions with flooding associated with dimensioning flow or sudden falls of water level; • a safety factor of at least 1.5 in the operational phase (short term) and after-closure phase (long term).	
		<u>*Operational (construction, management and maintenance) phase*</u> To review the geotechnical analysis, while applying management systems (see BAT 1, BAT 11 and BAT 12). When prediction of geotechnical behaviour is difficult during the design phase and when the design is reviewed during construction, to apply the observational method according to Eurocode 7–1 or equivalent.	
		<u>*Closure and after-closure phase*</u> To review the geotechnical analysis, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
b	Geotechnical analysis of heaps	*Relevant for heaps*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). The
		<u>*Planning and design phase*</u> To consider in the geotechnical analysis all the mechanisms that can negatively affect the partial or total structural stability of heaps. To analyse the physical stability in the short and long term according to Eurocode 7–1 (EN 1997-1:2004 - Part 1) or equivalent national standards. The geotechnical analysis usually covers the following	

		aspects: • the overall slope stability of the heap, including the basal structure; • the bearing capacity and stability of the foundation of the heap; • the physical and chemical stability of the extractive waste, including static and dynamic liquefaction, freezing and thawing; • the stability of water drainage systems. The geotechnical analysis takes into consideration the results of the water balance analysis (see BAT 18.a). The selection of seismic parameters in this analysis is based on site-specific analysis of the seismic risk(2). By applying Eurocode 7-1, the design values are determined by using appropriate partial factors as defined in Annex A to this standard. The overall stability of slopes is analysed in the ultimate geotechnical (GEO) or structural (STR) limit states by applying: • an over-design factor (ODF) of at least 1, where the ODF is the ratio between the design resistance (Rd) and the design effect of the loads (Ed). Assessment of liquefaction potential is extended beyond the recommendations given in EN 1998 Eurocode 8 and in particular Part 5. By using equivalent national standards that do not apply partial factors and evaluate global safety factors, the overall stability is analysed by applying: • a safety factor of at least 1.3 in the operational phase (short-term) or equivalent level of safety justified by complex numerical models and taking into account BAT 2, BAT 4 and BAT 5 and the uncertainty on the information from these BAT; • a safety factor of at least 1.5 in the after-closure phase (long term) or at least equivalent level of safety justified by complex numerical models and taking into account BAT 2, BAT 4 and BAT 5, the uncertainty on the information from these BAT and provided that appropriate monitoring is in place.	applicability of the observational method may be restricted in the case of failure modes that could develop very quickly, e.g. if a potential risk of static liquefaction of loose extractive waste exists.
		Operational (construction, management and maintenance) phase To review the geotechnical analysis, while applying management systems (see BAT 1, BAT 11 and BAT 12). When prediction of geotechnical behaviour is difficult during the design phase and when the design is reviewed during construction, to apply the observational method according to Eurocode 7-1 or equivalent.	
		Closure and after-closure phase To review the geotechnical analysis, while applying management systems (see BAT 1, BAT 11 and BAT 12).	

(1) According to (ICOLD 2016), *a large dam is one more than 15 m high or one between 10 m and 15 m high satisfying one of the following criteria: a) more than 500 m long; b) reservoir capacity exceeding 1 million m^3; c)*

spillway capacity exceeding 2 000 m³/s. (2) Seismic risk is defined at Member State level.

[This BAT conclusion is based on information given in Sections 4.2.1.3.6.1 and 4.2.1.3.6.2]

5.3.1.1.3.6.2 Monitoring of the physical stability of the extractive waste deposition area (including the EWF)

BAT 23. BAT is to monitor the physical stability of the extractive waste deposition area (including the EWF) as follows:

Technique	Description	Applicability
Monitoring of the physical stability of the extractive waste deposition area (including the EWF)	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	<u>*Planning and design phase*</u> To develop a physical stability monitoring plan and to plan conformance checks by operators, reviews, audits and safety evaluations. Monitoring parameters and frequencies are properly selected according to the site-specific conditions of the extractive waste deposition area (including the EWF), with particular regard to the potential risk of short-term and long-term structural instability, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP. To this end, the monitoring parameters and frequencies in Table 4.18 and frequencies of conformance checks, reviews, audits and safety evaluations in Table 4.20 may be considered. The physical stability monitoring plan may include the following aspects: • number and location of control stations; • scheduling (control periods and conformance checks by operators); • type and purpose of monitoring measure (visual conformance checks by operators, measurements and parameters); • appropriate instrumentation selection; • conformance check methods and evaluation; • identification of the person/function responsible for the monitoring and reporting; • data storage and reporting systems; • criteria to assess the monitoring plan; • schedule of the monitoring plan review. Furthermore, this plan may include the following practices: • a dam surveillance plan (for dams); • emergency planning, including the internal emergency plan specifically required for Category A EWFs (see BAT 12.d).	
	<u>*Operational (construction, management and maintenance) phase*</u> To implement the physical stability monitoring plan, while applying management systems (see BAT 1, BAT 11 and	

	BAT 12). The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies. To encourage the use of systems that provide real-time monitoring systems coupled to automatic warnings.	
	Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Section 4.2.1.3.6.3]

BAT 24. In order to support the monitoring of the physical stability of the extractive waste deposition area (including the EWF), BAT is to use one or a combination of techniques, appropriately selected fromf the following list:

Technique		Description	Applicability
a	Conformance checks (with or without third party)	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To plan conformance checks (with or without a third party) for the evaluation of the performance and safety of an extractive waste deposition area (including the EWF) on a regular basis by a qualified and experienced expert. The monitoring frequencies of conformance checks in Table 4.20 may be considered.	
		Operational (construction, management and maintenance) phase To carry out conformance checks (with or without a third party), while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Internal audits	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back*	Based on the results of a proper Environmental Risk and Impact Evaluation (see
		Planning and design phase To plan internal audits for the evaluation of the	

		performance and safety of an extractive waste deposition area (including the EWF) on a regular basis by a qualified and experienced expert. The monitoring frequencies of internal audits in Table 4.20 may be considered.	BAT 5).
		<u>Operational (construction, management and maintenance) phase</u> To carry out internal audits, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>Closure and after-closure phase</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
c	External audits	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		<u>Planning and design phase</u> To plan external audits for the evaluation of the performance and safety of an extractive waste deposition area (including the EWF) on a regular basis by a qualified and experienced expert. The monitoring frequencies of external audits in Table 4.20 may be considered.	
		<u>Operational (construction, management and maintenance) phase</u> To carry out the external auditing, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>Closure and after-closure phase</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Section 4.2.1.3.6.4]

5.3.1.1.4 Extractive waste containment in underground extractive waste deposition areas

5.3.1.1.4.1 Containment of extractive waste in underground extractive waste deposition areas

BAT 25. In order to help ensure the appropriate containment of extractive waste from oil and gas exploration and production underground, BAT is to use the following technique:

<table>
<tr><th>Technique</th><th>Description</th><th>Applicability</th></tr>
<tr><td rowspan="3">Closure of the access to the underground extractive waste deposition area</td><td>Relevant for underground extractive waste deposition areas accessed via a wellbore</td><td rowspan="3">Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).</td></tr>
<tr><td><u>Planning and design phase</u>
To evaluate the containment of extractive waste in the underground deposition areas, also taking into consideration the information from fracture propagation during well completion, where relevant. To design the plugging and closure of any wellbore used for the deposition of extractive waste in order to ensure the containment of extractive waste in the underground deposition area.</td></tr>
<tr><td><u>Closure and after-closure phase</u>
To close the access by applying the following closure practices:
to design the closure of the wellbore that connects the surface with the underground extractive waste deposition area in order to contain the extractive waste underground and prevent any migration of extractive waste and/or pollutants which could have negative effects on the environment and human health;
to cement any identified pathway to groundwater inside or outside the casing;
to avoid by appropriate cementation inside or outside the casing any contact between different geological structures in order to isolate the producing formation and the aquifers in particular in the case of freshwater aquifers;
to plug the well in order to avoid any leaking to the surface; plugs need to cover the full diameter of the hole, with only casing (no cables) within the cement in order to achieve full lateral coverage;
to assure the well casing is appropriately covered;
to clean up the site after production and to rehabilitate it as far as possible to its original state or agreed re-use.</td></tr>
</table>

[This BAT conclusion is based on information given in Section 4.2.1.4.1]

5.3.1.1.4.2 Monitoring of the fracture propagation and induced seismicity in the underground extractive waste deposition area

BAT 26. BAT is to monitor the fracture propagation and induced seismicity in the underground extractive waste deposition area, resulting from pressure injection operations in oil and gas exploration and production, as follows:

Technique	Description	Applicability
Monitoring of the fracture propagation and induced seismicity resulting from pressure injection operations in oil and gas exploration and production	*Relevant for underground extractive waste deposition areas* <u>Planning and design phase</u> To develop a monitoring plan for fracture propagation and induced seismicity resulting from pressure injection operations of extractive waste, purposely placed or unavoidably remaining in the underground deposition area. <u>*Operational (construction, management and maintenance) phase*</u> To implement and review the fracture propagation and induced seismicity monitoring plan, while applying management systems (see BAT 1, BAT 11 and BAT 12). To monitor fracture propagation and induced seismicity in the underground extractive waste deposition area, resulting from pressure injection operations of extractive waste, by means of appropriate monitoring techniques, e.g. seismometers, tiltmeters and microseismic monitoring during the production/operational phase, in order to facilitate the identification of the extent of any extractive waste dispersion/migration.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

[This BAT conclusion is based on information given in Section 4.2.1.4.2]

5.3.2 Physical and chemical stability of extractive waste

5.3.2.1 Physical stability of extractive waste

5.3.2.1.1 Solid/liquid control of extractive waste

BAT 27. In order to help ensure the physical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
Mechanical treatment techniques			
a	Mechanical screening	*Relevant for extractive waste from excavation and extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds* *Relevant for drilling muds and other extractive wastes from oil and gas exploration and production* <u>Planning and design phase</u> To include in the design mechanical screening. The technique consists of passing a liquid-solid flow through a screening device to separate the coarse fractions of the solid phase from the liquid phase. This includes the use of, e.g.: rotating or vibrating screens and shale shakers. The technique is designed to achieve maximum density and efficient deposition. <u>*Operational (construction, management and maintenance) phase*</u> To carry out mechanical screening, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable when meeting design criteria in BAT 14 and BAT 22, and in combination with BAT 2. Not applicable for the removal of fine particles from EWIW.

b	Hydro-cycloning	*Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds* *Relevant for drilling muds and other extractive wastes from oil and gas exploration and production*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable when meeting design criteria in BAT 14 and BAT 22, and in combination with BAT 2.
		<u>Planning and design phase</u> To include in the design the separation of the fine particles from the liquid phase by using hydro-cyclones: • to obtain slurried extractive waste from mineral processing (30-40 % solids) that is transported to a pond; • to remove particles of ~ 15 µm during the production phase (for oil and gas exploration and production). The technique is designed to achieve maximum density and efficient deposition. The resulting slurry contains much more water, in comparison with thickened extractive waste from mineral processing, which will need to be managed/treated.	
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out hydro-cycloning, while applying management systems (see BAT 1 and BAT 12).	
c	Thickening and clarifying	*Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds; particularly relevant for extractive waste from alumina refining (red muds)*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable when meeting design criteria in BAT 14 and BAT 22, and in combination with BAT 2. Particularly advantageous where: • the topography is flat; or • the management of slurried extractive waste from mineral processing may be costly. Not applicable with a content of less than 15 % of particles < 20 µm (dry basis) in the extractive waste from mineral
		<u>*Planning and design phase*</u> To include in the design the use of mechanical equipment to produce the following dewatered extractive waste from mineral processing: • thickened extractive waste (45-65 % solids content) obtained by means of hydro-cyclones, thickeners, lamella clarifiers, etc., while using additional coagulants/flocculants; • paste extractive waste (65-70 % solids content) obtained by means of deep bed/cone thickeners, while using additional coagulants/flocculants. The technique is designed to achieve maximum density and efficient deposition. Thickened extractive waste is less mobile than slurried extractive waste, which is beneficial in the event of a dam burst.	
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out thickening and clarifying, while applying management systems (see BAT 1 and BAT 12).	

			processing.
d	Dewatering by means of a pressure gradient or a centrifugal force	*Relevant for extractive waste from mineral processing; particularly relevant for extractive waste from mineral processing to be deposited into ponds; particularly relevant for extractive waste from alumina refining (red muds)* *Relevant for drilling muds and other extractive wastes from oil and gas exploration and production*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable when meeting design criteria in BAT 14 and BAT 22, and in combination with BAT 2. Particularly advantageous where: • the available space is limited *or* • the facility is small or medium-sized.
		Planning and design phase To include in the design the use of filter presses, vacuum filters and centrifuges to produce wet filter cakes (nearly saturated) or dry filter cakes (70-85 % saturated). The technique is designed to achieve maximum density and efficient deposition.	
		Operational (construction, management and maintenance) phase To carry out dewatering by means of a pressure gradient or a centrifugal force, while applying management systems (see BAT 1 and BAT 12).	

[This BAT conclusion is based on information given in Sections 4.2.2.1.1.1, 4.2.2.1.1.2, 4.2.2.1.1.3 and 4.2.2.1.1.4]

5.3.2.1.2 Stabilisation of extractive waste for placing back into excavation voids

BAT 28. In order to help ensure the physical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Preparing cemented coarse extractive waste to be placed back into excavation voids	*Relevant for extractive waste to be placed back into excavation voids*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 2.
		Planning and design phase To include in the design the preparation of cemented extractive waste. It generally consists of mixing coarse fractions of extractive waste from mineral processing, sometimes including extractive waste from excavation, with cementitious binders (such as cement or fly ash).	
		Operational (construction, management and maintenance) phase To carry out the preparation of cemented extractive waste to be placed back into excavation voids, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	
b	Preparing	*Relevant for extractive waste to be placed back*	Based on the results of a

	extractive waste slurry (uncemented and cemented) to be hydraulically placed back into excavation voids	*into excavation voids* <u>*Planning and design phase*</u> To include in the design the preparation of extractive waste slurry to be hydraulically placed back into excavation voids. It consists of classifying extractive waste from mineral processing into a coarse fraction (a slurry with a solids content of approximately 65-70 %) and a fine fraction (slimes, which are then discarded). The slurry with the coarse fraction may be mixed with cementitious binders, if needed. <u>*Operational (construction, management and maintenance) phase*</u> To carry out the preparation of extractive waste slurry (uncemented and cemented) to be placed back into excavation voids, while applying management systems (see BAT 1, BAT 11 and BAT 12). <u>*Closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 2. Not applicable when the extractive waste slurry has a high fines content and the particle shape is very flat. Not applicable if the local hydrogeology can oxidise the extractive waste that is placed back. Not applicable to drilling muds and other extractive wastes from oil and gas exploration and production.
c	Preparing paste extractive waste to be placed back into excavation voids	*Relevant for extractive waste to be placed back into excavation voids* <u>*Planning and design phase*</u> To include in the design the preparation of paste extractive waste. Mixing the extractive waste from mineral processing (fine and coarse fractions) with cementitious binders to create a paste with a solids content of 75-80 %. The density of the mixture is higher compared to other stabilisation methods and more extractive waste can be stored in the voids underground. <u>*Operational (construction, management and maintenance) phase*</u> To carry out the preparation of paste extractive waste to be placed back into excavation voids, while applying management systems (see BAT 1, BAT 11 and BAT 12). <u>*Closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 2. Generally applicable when: • there is more than 15 % fine particles (< 20 µm, dry basis) in the tailings; or • the extractive waste has a high fines content; or • it is desirable to keep water out of the extraction site; or • it is costly to pump back the water recovered from the extractive waste from mineral processing (i.e. over a large distance).

			Not applicable to drilling muds and other extractive wastes from oil and gas exploration and production.

[This BAT conclusion is based on information given in Section 4.2.2.1.2]

5.3.2.1.3 Compaction, consolidation and deposition of extractive waste

BAT 29. In order to help ensure the physical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Thickened/ paste extractive waste subaerial deposition	*Relevant for extractive waste from mineral processing*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicability may be restricted in the case of wet climatic conditions, i.e. where heavy rainfall may occur, retaining dykes may be necessary.
		<u>*Planning and design phase*</u> To design the spreading of thickened or paste extractive waste from mineral processing in layers over the deposition area. Retention structures (embankments/dams) are built along the perimeter to contain the deposited extractive waste. A composite basal structure system (see BAT 15.b and BAT 16.e) is usually included, particularly for non-inert extractive waste. Sequential construction of small deposition areas (cells) within the extractive waste deposition area allows progressive rehabilitation and concurrent closure by means of dry covers. Special systems for collecting surface water run-off and drainage are usually constructed (see BAT 21).	
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out the subaerial deposition of thickened/paste extractive waste, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
b	Wet or dry filter cake deposition (or dry stacking)	*Relevant for extractive waste from mineral processing;particularly relevant for extractive waste from alumina refining (red muds)*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicability may be restricted in the case of wet climatic conditions, i.e. where heavy rainfall may occur, retaining dykes and composite basal structure (see BAT 15.b and BAT 16.e) may be necessary.
		<u>*Planning and design phase*</u> To design the transport of wet or dry filter cakes by conveyors or trucks, followed by placing and compacting them to form a dense and stable "dry stack" without the need for a retention dam. The dry stack is more stable if it is divided into zones (small lined cells) that can be progressively covered and rehabilitated. Perimeter ditches for collecting surface water run-off and drainage are usually constructed (see BAT 21).	

		<u>*Operational (construction, management and maintenance) phase*</u> To carry out the deposition of wet or dry filter cake extractive waste, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
c	Placing extractive waste back into excavation voids	*Relevant for non-hazardous extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5) and as far as it is technically and economically feasible and environmentally sound. Not applicable to PAG extractive waste, unless deposited under water cover. Not applicable to partially oxidised extractive waste with residual ARD potential. Not applicable during operation if it inhibits the extraction activities.
		<u>*Planning and design phase*</u> To design the placing back of extractive waste, including stabilised extractive waste, into excavation voids for construction and/or rehabilitation purposes. It might be carried out concurrently with the extraction operation. Both surface excavation voids and underground excavation voids from mineral resources extraction are included. Extractive waste can be placed back progressively during operation, if possible, including at closure. The following types of activities may be considered: • placing dry extractive waste back into excavation voids followed by compaction if necessary for site rehabilitation purposes; • placing extractive waste back into surface excavation voids permanently covered by water if parts of the extractive waste (e.g. waste-rock) have a net ARD potential; • where extractive waste has to act as a support when placed back into excavation voids for structural purposes (such as preventing roof or wall rock collapse or subsidence underground) and rehabilitation purposes, it is converted into a stabilised material after being placed back into excavation voids and after curing.	
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out the placing back of extractive waste into excavation voids, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase.	
d	Mud farming	*Relevant for extractive waste from alumina refining (red muds)*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 30.a. Applicable where mud
		<u>*Planning and design phase*</u> To design an additional dewatering technique to thicken and clarify (see BAT 27.c) or dewater by means of a pressure gradient or a centrifugal force (see BAT 27.d) red muds. The technique consists of compacting and dewatering red mud layers by special equipment	

		and enhancing the exposure of the layers to atmospheric carbonation. *<u>Operational (construction, management and maintenance) phase</u>* To carry out mud farming, while applying management systems (see BAT 1, BAT 11 and BAT 12).	farming can be carried out safely (see BAT 22.a).
e	Co-disposal of fine and coarse fractions of extractive waste	*Relevant for extractive waste from excavation* *Relevant for extractive waste from mineral processing* *<u>Planning and design phase</u>* To design the co-disposal of coarse extractive waste from excavation and finer extractive waste from mineral processing. Usually, three main types of co-disposal techniques are implemented: • co-mixing: extractive waste from excavation and extractive waste from mineral processing are mixed before delivery to the deposition area; • co-mingling: extractive waste from excavation and extractive waste from mineral processing are mixed in the deposition area and deposited as one stream; • co-placement: extractive waste from excavation and extractive waste mineral processing are deposited together but not mixed to create a single stream, e.g. excavation waste can be used to create internal embankments or retaining walls to create cells in which extractive waste from mineral processing is deposited. *<u>Operational (construction, management and maintenance) phase</u>* To carry out the co-disposal of fine and coarse fractions of extractive waste, while applying management systems (see BAT 1, BAT 11 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

[This BAT conclusion is based on information given in Sections 4.2.2.1.4.1, 4.2.2.1.4.2, 4.2.2.1.4.3, 4.2.2.1.4.4 and 4.2.2.1.4.5]

5.3.2.2 Chemical stability of extractive waste

5.3.2.2.1 Prevention or minimisation of pollutant leaching

BAT 30. In order to help ensure the chemical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Reduction of extractive waste alkalinity	*Relevant for extractive waste with high alkalinity; particularly relevant for extractive waste from alumina refining (red muds)* *<u>Planning and design phase</u>*	Based on the results of a proper Environmental

		To include in the design the removal of alkaline substances/reagents from the extractive waste and resulting from the mineral processing.	Risk and Impact Evaluation (see BAT 5).
		Operational (construction, management and maintenance) phase To carry out the alkalinity reduction of extractive waste, while applying management systems (see BAT 1 and BAT 12).	
b	Compaction, consolidation and deposition of extractive waste	*Relevant for non-inert extractive waste*	
		See BAT 29	
c	Progressive rehabilitation	*Relevant for non-inert extractive waste*	
		See BAT 38.a	
d	Temporary covers	*Relevant for non-inert extractive waste*	
		See BAT 38.b	

[This BAT conclusion is based on information given in Sections 4.2.2.2.1.1, 4.2.2.2.1.2, 4.2.2.2.1.3 and 4.2.2.2.1.4]

5.3.2.2.2 Prevention or minimisation of Acid Rock Drainage (ARD)

BAT 31. In order to help ensure the chemical stability of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	ARD management system	*Relevant for PAG extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		To ensure that the O&CMS and the EMS (see BAT 1) duly take into account the ARD properties of the extractive waste.	
b	Segregation of PAG and NAG extractive waste by sorting and selective handling/ deposition	*Relevant for PAG extractive waste*	
		See BAT 7.b	
Physico-chemical treatment techniques			
c	Desulphurisation	*Relevant for PAG extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To include in the design the partial or full separation of the PAG extractive waste fractions by froth flotation and separate handling before the final disposal into the extractive waste deposition area (including the EWF).	
		Operational (construction, management and maintenance) phase To carry out desulphurisation of extractive waste, while applying management systems (see BAT 1 and BAT 12).	

d	Blending with buffering materials	*Relevant for PAG extractive waste* *<u>Planning and design phase</u>* To include in the design the addition of buffering materials (such as limestone, cement-based and pozzolanic materials) to extractive waste from mineral processing and/or extractive waste from excavation. *<u>Operational (construction, management and maintenance) phase</u>* To carry out blending of extractive waste with buffering materials, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable if the buffering materials are available on site, or close to the site, and preferably as part of the extractive waste generated. Usually associated with an impermeable basal structure. Applicability may be restricted by adverse climatic conditions and the chemical armouring of alkaline materials.
Basal structure			
e	Impermeable natural soil basal structure	*Relevant for PAG extractive waste* See BAT 35.a	
f	Impermeable artificial basal structure	*Relevant for PAG extractive waste* See BAT 35.b	
Progressive rehabilitation and temporary covers			
g	Progressive rehabilitation	*Relevant for PAG extractive waste* See BAT 38.a	
h	Temporary covers	*Relevant for PAG extractive waste* See BAT 38.b	
Permanent dry covers			
i	Impermeable and low-flux dry covers	*Relevant for PAG extractive waste* See BAT 38.e	
j	Oxygen consuming dry covers	*Relevant for PAG extractive waste* See BAT 38.f	
Permanent wet covers			
k	Free water covers	*Relevant for PAG extractive waste* See BAT 38.g	
l	Wet covers	*Relevant for PAG extractive waste* See BAT 38.h	

[This BAT conclusion is based on information given in Sections 4.2.2.2.2.1, 4.2.2.2.2.2, 4.2.2.2.2.3, 4.2.2.2.2.4, 4.2.2.2.2.5.1, 4.2.2.2.2.5.2, 4.2.2.2.2.6, 4.2.2.2.2.7, 4.2.2.2.2.8.1 and 4.2.2.2.2.8.2]

5.3.2.2.3 Prevention or minimisation of self-ignition of extractive waste

BAT 32. In order to help ensure the chemical stability of extractive waste, BAT is to reduce the combustible matter content, to compact the extractive waste using appropriate mechanical equipment and/or to carry out landscaping and geomorphic reclamation (see BAT 42.d).

Relevant for extractive waste with self-ignition potential

Applicability
Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

[This BAT conclusion is based on information given in Section 4.2.2.2.3]

5.3.2.3 Reduction of dangerous substances in extractive waste

5.3.2.3.1 Reduction of the cyanide concentration in ponds

BAT 33. In order to help reduce the cyanide concentration in ponds, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description		Applicability
a	Cyanide destruction using SO_2/air	*Relevant for extractive waste containing cyanides* *Planning and design phase* To design the destruction of cyanides by oxidation through the SO_2/air process. The reaction is typically carried out at a pH of ~ 7.5 to 9.5, and lime is added automatically to neutralise the acid (H^+) formed in the reaction to maintain the pH in this range. *Operational (construction, management and maintenance) phase* To carry out the destruction of cyanides by oxidation through the SO_2/air process, while applying management systems (see BAT 1 and BAT 12).		Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable in combination with equalisation (homogenisation of waste streams) prior to treatment.
b	Cyanide destruction using hydrogen peroxide	*Relevant for extractive waste containing cyanides* *Planning and design phase* To design the treatment of extractive waste from mineral processing with hydrogen peroxide in order to enhance oxidation and destroy cyanides. Unlike the SO_2/air process, no sulphates are generated. *Operational (construction, management and maintenance) phase* To carry out the destruction of cyanides by using hydrogen peroxide, while applying management systems (see BAT 1 and BAT 12).		Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable in combination with equalisation (homogenisation of waste streams) prior to treatment.
c	Application of safety measures for cyanide destruction	*Relevant for extractive waste containing cyanides* *Planning and design phase* To design: • the size of the cyanide destruction circuit with a capacity twice the actual requirement; • the installation of a backup system for lime addition;		Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable in combination with equalisation

		• the installation of backup power generators. *<u>Operational (construction, management and maintenance) phase</u>* To implement safety measures, while applying management systems (see BAT 1 and BAT 12).		(homogenisation of waste streams) prior to treatment.

[This BAT conclusion is based on information given in Sections 4.2.2.3.1.1, 4.2.2.3.1.2 and 4.2.2.3.1.3]

5.3.2.3.2 Reduction of hydrocarbon concentrations in drilling extractive wastes

BAT 34. In order to help reduce hydrocarbon concentrations in drilling extractive wastes, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Thermal desorption	*Relevant for drilling extractive wastes from oil and gas drilling activities, in particular for drill cuttings* *<u>Planning and design phase</u>* To include in the design the application of heat to drilling muds and other drilling extractive wastes. It includes: • systems working at temperatures from 250 °C to 350 °C that allow for the recovery of hydrocarbons and water from wastes; • low-temperature systems, which may be sufficient to treat wastes with light oils. *<u>Operational (construction, management and maintenance) phase</u>* To implement the technique, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with a solid/liquid control technique (e.g. a shale shaker) (see BAT 27).
b	Mechanical cuttings dryer	*Relevant for drilling extractive wastes from oil and gas drilling activities, in particular for drill cuttings* *<u>Planning and design phase</u>* To include in the design the application of a high gravity force on the cuttings in order to separate fluids from solids, e.g. for drill cuttings. The following types of cuttings dryers are usually available: • *centrifugal cuttings dryer;* • *vacuum cuttings dryer.* *<u>Operational (construction, management and maintenance) phase</u>* To implement the technique, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with a solid/liquid control technique (e.g. a shale shaker) (see BAT 27).
c	In-vessel composting	*Relevant for drilling extractive wastes from oil and gas drilling activities, in particular for drill cuttings* *<u>Planning and design phase</u>* To include in the design the decontamination of organic matter by causing the biological oxidation of organic substances contained in drilling wastes in controlled conditions within a vessel.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		<u>*Operational (construction, management and maintenance) phase*</u> To implement the technique, while applying management systems (see BAT 1 and BAT 12).	Applicable in combination with a solid/liquid control technique (e.g. a shale shaker) (see BAT 27). A high salt content may negatively affect the microbial activity.

[This BAT conclusion is based on information given in Sections 4.2.2.3.2.1, 4.2.2.3.2.2 and 4.2.2.3.2.4]

5.4 Risk-specific BAT Conclusions for the prevention or minimisation of water status deterioration, air and soil pollution

5.4.1 Prevention or minimisation of groundwater status deterioration and soil pollution

5.4.1.1 Basal structures and physical barriers

BAT 35. In order to prevent or minimise groundwater status deterioration and soil pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Impermeable natural soil basal structure	*Relevant for ponds, dams and heaps* *Relevant for non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 13, BAT 14 and BAT 22. Applicable to new surface-based extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface. Applicable when extractive waste should remain water-saturated after-closure (for ponds). Particularly suitable for PAG extractive waste and where extractive waste has the potential to leach metals, cyanides or other contaminants. Only applicable when large amounts of impermeable natural soils are available. Not needed if the natural ground in its natural state under the extractive waste deposition area (including the EWF) is an impermeable continuous layer (with a hydraulic conductivity $< 10^{-9}$ m/s and thickness > 0.5 m).
		<u>*Planning and design phase*</u> To include in the integrated design the impermeable natural soil basal structure by selectively placing and compacting low-permeability natural soils (such as natural clay, marl, peat) (see BAT 15.b, BAT 16.e and BAT 17.c). To design the basal structure based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see BAT 2), the water balance (see BAT 18) and based on the design criteria resulting from BAT 14 and BAT 22. To amend the hydraulic conductivity of soils by using sodium or calcium bentonite.	
		<u>*Operational (construction, management and maintenance) phase*</u> To construct the impermeable natural soil basal structure and to monitor and maintain it, while applying management systems (see BAT 1, BAT 11, BAT 12, BAT 30 and BAT 31.a).	
		<u>*Closure and after-closure phase*</u> In the closure phase, to monitor the impermeable natural soil basal structure, while applying management systems (see BAT 1, BAT 11, BAT 12, BAT 30 and BAT 31.a). In the after-closure phase, to monitor the impermeable natural soil basal structure, for as long as may be necessary, taking into account the	

		nature and duration of the residual risks and hazards.	
b	Impermeable artificial basal structure	*Relevant for ponds, dams and heaps* *Relevant for non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable to new surface-based extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface. Applicable in combination with BAT 13, BAT 14 and BAT 22. Applicable when extractive waste should remain water-saturated after closure (for ponds). Particularly suitable for PAG extractive waste and where extractive waste has the potential to leach metals, cyanides or other contaminants. A geosynthetic basal structure may not be suitable due to structural stability issues, demonstrated by a proper geotechnical analysis (see BAT 22).
		<u>Planning and design phase</u> To include in the integrated design the use of geosynthetics and drainage systems in the basal structure to provide a very low hydraulic conductivity, at least lower than 10^{-9} m/s (see BAT 15.b, BAT 16.e and BAT 17.c). To design the basal structure based, among others, on the hydraulic conductivity of the basal structure, the extractive waste characteristics (see BAT 2), the water balance (see BAT 18) and based on the design criteria resulting from BAT 14 and BAT 22.	
		<u>Operational (construction, management and maintenance) phase</u> To construct the impermeable artificial basal structure and to monitor and maintain it, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>Closure and after-closure phase</u> To monitor the impermeable artificial basal structure, while applying management systems (see BAT 1, BAT 11 and BAT 12). In the after-closure phase, monitoring of the impermeable artificial basal structure is carried out, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
c	Seepage barriers	*Relevant for ponds, dams and heaps* *Relevant for non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		<u>Planning and design phase</u> To design the use of cut-off trenches, slurry walls or grout curtains.	
		<u>Operational (construction, management and maintenance) phase</u> To construct the seepage barriers and to monitor and maintain them, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>Closure and after-closure phase</u> To monitor and maintain the seepage barriers, while applying management systems (see BAT 1, BAT 11 and BAT 12).	

[This BAT conclusion is based on information given in Sections 4.3.1.1.1, 4.3.1.1.2 and 4.3.1.1.3]

BAT 36. In order to prevent or minimise groundwater status deterioration and soil pollution, BAT is to use the following techniques:

	Technique	Description	Applicability
a	Lining the surface for temporary storage of drilling muds and other extractive wastes	*Relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water* *Planning and design phase* To include in the design an impermeable liner across all the surface areas where drilling muds and other extractive wastes from oil and gas exploration and production are temporarily stored in bunded containers/tanks. *Operational (construction, management and maintenance) phase* To implement the technique, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
b	Temporary storage of drilling muds and other extractive wastes in containers /tanks	*Relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water* *Planning and design phase* To include in the design the temporary storage of drilling muds and other extractive wastes from oil and gas exploration and production in bunded containers/tanks. *Operational (construction, management and maintenance) phase* To implement the technique, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

[This BAT conclusion is based on information given in Sections 4.3.1.1.4 and 4.3.1.1.5]

5.4.1.2 Water streams management

BAT 37. In order to prevent or minimise groundwater status deterioration and soil pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description
a	Diversion of water run-off systems	See BAT 42.b
b	Drainage systems for ponds and dams	See BAT 21.a
c	Drainage systems for heaps	See BAT 21.b
d	Landscaping and geomorphic reclamation	See BAT 42.d

[This BAT conclusion is based on information given in Sections 4.3.1.2.1, 4.3.1.2.2.1, 4.3.1.2.2.2 and 4.3.1.2.3]

5.4.1.3 Covering

BAT 38. In order to prevent or minimise groundwater status deterioration and soil pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Progressive rehabilitation	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back* *Planning and design phase* To design the rehabilitation activities for the operational phase. *Operational (construction, management and maintenance) phase* To carry out progressive rehabilitation, while applying management systems (see BAT 1, BAT 11 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable during operation in the case of heaps constructed using the top-down method. Not applicable if the non-hazardous extractive waste will be re-used or recycled during the operation according to a specific timeframe as defined in the closure and after-closure planning (see BAT 11).
b	Temporary covers	*Relevant for ponds, dams and heaps, for excavation voids where extractive waste is placed back and for temporary storage* *Planning and design phase* To design temporary covers that may include: • covering the external slopes and/or the dry extractive waste surfaces (e.g. beaches) with inorganic materials, such as sand, crushed waste-rock and topsoil, or with organic materials, such as compost, bark, straw and peat, while ensuring that the use of such covers does not lead to any additional adverse environmental or human health impacts; • impregnating surfaces of extractive waste from mineral processing with chemicals and bituminous emulsions that can repel water or bind particles; • consolidating extractive waste from mineral processing by using its chemical characteristics. *Operational (construction, management and maintenance) phase* To install temporary covers, while	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable when the beaches are raised continuously. Not applicable if extractive waste deposited on heaps is removed again from the heap on a regular basis during operation, when this would require the removal of the cover. May not be suitable to cover steep heaps due to structural stability issues, demonstrated by a proper geotechnical analysis (see BAT 22).

		applying management systems (see BAT 1, BAT 11 and BAT 12).	
c	Vegetative covers	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). The applicability may be restricted by the height and slope of the heap design.
		<u>*Planning and design phase*</u> To design the placement of: • a soil layer or multiple layers sufficient to support root development and to maintain a suitable degree of moisture; and • a vegetative layer consisting of growing media and, if necessary, soil improvers, including compost, with the necessary micro and macro nutrients, while ensuring that the use of such a layer does not lead to any additional adverse environmental or human health impacts. When using a vegetative cover on top of covered PAG extractive waste, to include only the use of vegetation with shallow roots to prevent breakage of the underlying cover (e.g. low-flux or impermeable cover).	
		<u>*Operational (construction, management and maintenance) phase*</u> To install vegetative covers, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To monitor and maintain the vegetative covers in the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
Permanent dry covers			
d	Permeable dry covers	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back* *Relevant for covering non-hazardous extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not suitable for covering of PAG extractive wastes unless an oxygen-consuming layer is included in highly engineered composite covers which will then be considered an oxygen-consuming dry cover (see below point f). May not be suitable to cover steep heaps due to structural
		<u>*Planning and design phase*</u> To design the covering of the extractive waste with a single layer or multiple layers of soil or equivalent materials, while ensuring that the use of such a layer or layers does not lead to any additional adverse environmental or human health impacts, (such as till, clay, coarse gravel/rock, etc.) permeable to water	

		and oxygen. It usually includes: • vegetative covers (see BAT 38.c); • non-vegetative covers (coarse gravel). The typical layer thickness ranges from 0.3 m to 1.5 m.	stability issues, demonstrated by a proper geotechnical analysis (see BAT 22).
		<u>Closure and after-closure phase</u> To install permeable dry covers in the closure phase, while applying management systems (see BAT 1, BAT 11 and BAT 12). To monitor and maintain the permeable dry covers in the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
e	Impermeable and low-flux dry covers	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back* *Relevant for covering non-inert extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Suitable for covering PAG extractive waste, or extractive waste with the potential to leach metals, cyanides and other contaminants, or for controlling radon emissions from uranium extractive waste. May not be suitable to cover steep heaps due to structural stability issues, demonstrated by a proper geotechnical analysis (see BAT 22). Cover structures consisting of compacted clay layers are applicable in cold climates if thicker than the freezing depth. The applicability of bentonite layers may be restricted in the case of dry climatic conditions (desiccation cracks formation) or if cation exchange reactions occur.
		<u>Planning and design phase</u> To design the covering of the extractive waste with multiple functional layers in order to inhibit the oxygen influx and to limit the meteoric water infiltration. It usually includes an appropriate combination of two or more of the following elements: • a coarse layer combined with the impermeable layer and the extractive waste; • a capillary break system composed of a coarse layer or a fine-textured soil layer sandwiched between coarse-textured layers; • a barrier layer composed of two or more layers of natural granular soil (such as clays and tills, loess, bentonite); • a woven geotextile; • a geosynthetic materials layer (such as geomembrane, geosynthetic clay liners and bituminous geomembranes) when needed; • a drainage layer; • a topsoil layer; • a vegetative layer on the top. The low-flux cover does not contain any geosynthetic layer. The typical total thickness ranges from	

		0.5 m to 3.0 m and the hydraulic conductivity of the impermeable layer is generally < 10^{-9} m/s.	
		<u>*Closure and after-closure phase*</u> To install impermeable and low-flux dry covers in the closure phase, while applying management systems (see BAT 1, BAT 11 and BAT 12). To monitor and maintain the impermeable and low-flux dry covers in the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
f	Oxygen-consuming dry covers	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back* *Relevant for covering PAG extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable to certain types of NAG and PAG extractive waste where Dissolved Organic Carbon (DOC) originating from the cover and present in leachate may increase metal leaching from extractive waste through complexation reactions. Applicable if organic materials are available close to the extractive waste deposition area (including the EWF).
		<u>*Planning and design phase*</u> To design covers using organic materials (such as wood waste, peat, sewage sludge, compost, manure, hay/straw/silage) for covering PAG extractive waste to consume oxygen and reduce its infiltration, while ensuring that the use of such covers does not lead to any additional adverse environmental or human health impacts. Influenced by the capacity of the material to consume oxygen, the moisture content and the degree of compaction.	
		<u>*Closure and after-closure phase*</u> To install oxygen-consuming dry covers in the closure phase, while applying management systems (see BAT 1, BAT 11 and BAT 12). To monitor and maintain the oxygen-consuming dry covers in the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
Permanent wet covers			
g	Free water covers	*Relevant for ponds and dams and for excavation voids where extractive waste is placed back* *Relevant for covering PAG extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable only to ponds containing PAG extractive waste where the dry cover option is not retained. Applicable to new extractive
		<u>*Planning and design phase*</u> To design the covering of extractive waste with a water layer in order to isolate contaminants and to reduce erosion, dusting and oxygen	

		infiltration. It includes: • deposition of extractive waste into constructed ponds, usually with water- and solids-retaining dams (see BAT 15) and an impermeable basal structure (see BAT 35); • placing back of extractive waste into excavation voids covered by water (subaqueous in-pit disposal).	waste deposition areas (including EWFs) or hydraulically separated extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface if: • it is demonstrated that the water cover poses lower long-term risks to human health and the environment than a dry cover, through a proper risk and impact evaluation; and • hydrological conditions provide sufficient water to maintain a suitable water barrier (see BAT 18). Not applicable: • if the water balance is negative (see BAT 18), e.g. in arid or semi-arid regions; or • if secondary minerals can dissolve and worsen the acid-generating potential of the extractive waste.
		<u>*Operational (construction, management and maintenance) phase*</u> To install free water covers, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To monitor and maintain the free water covers in the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
h	Wet covers	*Relevant for ponds and dams and for excavation voids where extractive waste is placed back* *Relevant for covering low-PAG extractive waste or low paste PAG extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable if the water balance is negative (see BAT 18), e.g. in arid or semi-arid regions.
		<u>*Planning and design phase*</u> To design a system: • allowing the water to infiltrate the extractive waste, thus forming a wet cap on the top; and • adding organic matter, to enhance the establishment of wetland vegetation in the pond, while ensuring that the use of such material does not lead to any additional adverse environmental or human health impacts. Wetland establishment as a closure method uses the same principle as the water cover, but with a reduced water depth, since the plant cover stabilises the bottom, thereby avoiding the resuspension of extractive waste from mineral processing.	
		<u>*Operational (construction,*</u>	

		management and maintenance) phase To install wet covers, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To monitor and maintain the wet covers in the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.3.1.3.1, 4.3.1.3.2, 4.3.1.3.3, 4.3.1.3.4.1.1, 4.3.1.3.4.1.2, 4.3.1.3.4.1.3, 4.3.1.3.4.2.1 and 4.3.1.3.4.2.2]

5.4.1.4 Groundwater and soil pollution remediation

BAT 39. In order to minimise groundwater status deterioration and soil pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Examples of abated pollutants /targeted parameters	Applicability
a	Permeable Reactive Barriers (PRBs)	*Relevant for PAG extractive waste or for extractive waste with metal leaching potential* Operational (construction, management and maintenance) phase To install and use the continuous permeable treatment zone to intercept and remediate a contaminant plume. It removes contaminants from the groundwater plume flow in a passive manner by physical, chemical or biological processes. It includes: • continuous PRBs transecting the plume flow with reactive media; • funnel-and-gate PRBs using impermeable walls to direct the contaminant plume to a gate. To apply management systems (see BAT 1, BAT 11 and BAT 12). Closure and after-closure phase To implement the technique	Radionuclides, metals and metalloids (As, Cr VI, Ni, Pb, U, Fe, Mn, Se, Cu, Co, Cd and Zn) and anion contaminants (sulphates, nitrates and phosphates) Control of pH	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). If the PRB involves bacterial activity, the pH is in a range of ~ 5-7. Not applicable for the remediation of a contaminated plume with high salt levels. Applicability may be restricted in the case of biofouling and mineral precipitation can limit the barrier permeability. May require maintenance after 10-30 years. May require additional

		described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		techniques to improve the environmental performance.
b	Phyto technologies	*Relevant for PAG extractive waste or for extractive waste with metal leaching potential*	Metals and metalloids (particularly Cr and Se) and radionuclides (U, Ce and Sr)	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 38. Applicability may be restricted in the case of: • seasonality of plant growth; • pests, infestations; • limited water availability for irrigation; • high salt levels; • a very low pH; • a high sodium content.
		<u>*Operational (construction, management and maintenance) phase*</u> To use plants to treat or capture contaminants in various media (see also BAT 46.c and BAT 46.d). Contamination can be removed by means of the following: • concentration of contaminants in plant tissue, which needs to be properly removed, in particular the aerial part; • degradation of contaminants by various biotic or abiotic processes; • immobilisation of contaminants in the root zone. To apply management systems (see BAT 1, BAT 11 and BAT 12).		
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		

[This BAT conclusion is based on information given in Sections 4.3.1.4.1 and 4.3.1.4.2]

5.4.1.5 Monitoring of emissions to soil and groundwater

BAT 40. BAT is to monitor emissions to soil and groundwater as follows:

<table>
<tr><th>Technique</th><th>Description</th><th>Applicability</th></tr>
<tr><td rowspan="3">Monitoring of emissions to soil and groundwater</td><td>Relevant for non-inert extractive waste

Monitoring of the groundwater table level is also relevant for inert waste if this level can affect the structural stability of the extractive waste deposition area (including the EWF)</td><td rowspan="3">Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).</td></tr>
<tr><td><u>Planning and design phase</u>
To develop a monitoring plan for emissions to soil and groundwater through the following activities:
• Identifying possible emission sources. This may include modelling of diffuse emissions to soil and groundwater, which also encompasses fugitive emissions (such as leakage). Results from the water balance analysis may be considered (see BAT 18).
• Planning the monitoring of emissions to soil and groundwater and the efficiency of the applied measures for prevention and reduction of these emissions. This may include:
o the monitoring of groundwater characteristics together with the groundwater quality; and/or
o the monitoring of soil quality, particularly in the vadose zone.

Monitoring parameters and frequencies are properly selected according to the site-specific conditions (particularly geological and hydrogeological conditions, considering also seasonal variations), with particular regard to the potential risk of groundwater status deterioration and soil pollution, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions.
To this end, the parameters and frequencies in Table 4.33 may be considered.
If the emissions to soil and groundwater from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed.

Monitoring is planned in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.</td></tr>
<tr><td><u>Operational (construction, management and maintenance) phase</u>
To implement the monitoring plan for emissions to soil and groundwater, while applying management systems (see BAT 1, BAT 11 and BAT 12).</td></tr>
</table>

	The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.	
	<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.3.1.5.1 and 4.3.1.5.2]

BAT 41. In order to support the monitoring of the emissions to soil and groundwater, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Leakage detection systems underneath an impermeable basal structure	*Relevant for ponds, dams and heaps* *Relevant for non-inert extractive waste from excavation and non-inert extractive waste from mineral processing*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable to impermeable basal structures. Leakage detection systems are designed in a way that allows proper maintenance. In some cases, this may imply positioning the detectors in the close vicinity of a large structure, on the expected downstream pathway of the seepage, rather than directly underneath a structure where maintenance is impossible. Only applicable to new extractive waste deposition areas (including EWFs) or extensions of existing extractive waste deposition areas (including EWFs) that will cover new land surface.
		<u>*Planning and design phase*</u> To include in the design leakage detection systems (manual or automatic) underneath an impermeable basal structure in order to identify the seepage.	
		<u>*Operational (construction, management and maintenance) phase*</u> To implement leakage detection systems underneath an impermeable basal structure, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Seepage detection systems underneath	*Relevant for ponds, dams and heaps* *Relevant for non-inert extractive waste from excavation and non-inert extractive waste from mineral*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

	permeable basal structures	*processing*	Applicable to existing permeable basal structures. Not applicable if installation of the seepage detection system underneath the permeable basal structures is technically unfeasible.
		Operational (construction, management and maintenance) phase To implement seepage detection systems underneath permeable basal structures, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
c	Control wells	*Relevant for non-inert extractive waste from excavation and non-inert extractive waste from mineral processing* *Relevant for drilling muds and other extractive waste from oil and gas exploration and production*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To include in the design the drilling of control wells or the use of existing ones to support the monitoring of the seepage to soil and groundwater.	
		Operational (construction, management and maintenance) phase To drill control wells or to use existing ones, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

d	Leakage detection systems for the temporary storage of drilling muds and other extractive wastes from oil and gas exploration and production	*Relevant for drilling muds and other extractive wastes from oil and gas exploration and production*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To include in the design leakage detection systems (manual or automatic) for the temporary storage of drilling muds and other extractive wastes from oil and gas exploration and production.	
		Operational (construction, management and maintenance) phase To implement leakage detection systems, while applying management systems (see BAT 1 and BAT 12).	
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Section 4.3.1.5.3]

5.4.2 Prevention or minimisation of surface water status deterioration

5.4.2.1 Prevention or minimisation of EWIW generation

BAT 42. In order to prevent or minimise surface water status deterioration, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Re-use or recycle the excess water in the extraction, mineral processing and/or extractive waste management	*Relevant for excess water*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable to the extent that the re-use of water or the environmentally sound treatment in the case of recycled water can maintain the accumulation of reagents/components below a level where any
		Planning and design phase To include in the design the collection of the water used for the management of extractive waste and the water in contact with the extractive waste in ponds or tanks. Usually, excess water from the management of extractive waste is stored in a pond called a reclaim, sedimentation, settling, clarification, decant, polishing and/or regulation pond. The excess water may be recycled or re-used in the extraction or mineral processing plant (if water is used in the process) or extractive waste management, with or without treatment	

		(depending on the water quality and technical requirements), thereby also reducing the overall consumption of water. _Operational (construction, management and maintenance) phase_ To re-use or recycle the excess water in the extraction, mineral processing and/or extractive waste management, while applying management systems (see BAT 1 and BAT 12).	negative interference with the process remains acceptable.
b	Diversion of water run-off systems during operation	_Planning and design phase_ To include in the design diversionary structures at the perimeter of the pond, dam or heap to prevent clean natural run-off from coming into contact with extractive waste. These range from simple run-off diversions to highly complex engineered surface and subsurface structures. _Operational (construction, management and maintenance) phase_ To carry out diversion of water run-off, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicable in combination with BAT 18.
c	Covering	See BAT 38.b-f	
d	Landscaping and geomorphic reclamation	*Relevant for ponds, dams and heaps and for excavation voids where extractive waste is placed back* _Planning and design phase_ To plan and design landscaping and geomorphic reclamation. These techniques are used to recreate the shapes and functionality of the natural landscapes and take into account the geographical characteristics of the site and its surroundings. They are used to reduce the visual impact and emissions to water and groundwater, but also to control wind erosion and noise emissions, as the slopes of the extractive waste deposition areas (including the EWFs) are reshaped to simulate natural heaps while optimising the extent of re-engineering works. Any landscaping and geomorphic reclamation is designed in such a way that any confining function is not impaired and that short- and long-term geotechnical stability is not reduced (see BAT 22). _Operational (construction, management and maintenance) phase_ To implement the technique, while applying management systems (see BAT 1, BAT 11 and BAT 12). _Closure and after-closure phase_ To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicability may be restricted by land availability on existing operational sites. Applicable in combination with the BAT on structural stability (see BAT 22 and BAT 24), ARD prevention or minimisation (see BAT 31) and self-ignition prevention or minimisation (see BAT 32).

		operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
e	To use reagents or chemicals with a low environmental impact	<u>*Planning and design phase*</u> To plan the use of reagents/chemicals which are biodegradable or non-toxic or have no or demonstrated limited adverse effects on the environment and human health.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		<u>*Operational (construction, management and maintenance) phase*</u> To implement the technique, while applying management systems (see BAT 1, BAT 11 and BAT 12). To replace existing reagents or chemicals by alternatives with a lower environmental impact that continue to ensure a sufficient level of technical performance.	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.3.2.1.1, 4.3.2.1.2, 4.3.2.1.3, 4.3.2.1.4 and 4.3.2.1.5]

5.4.2.2 Prevention or minimisation of emissions to surface water

5.4.2.2.1 Drainage of EWIW

BAT 43. In order to prevent or minimise surface water status deterioration, BAT is to use the following technique:

Technique	Description	Applicability
Drained EWIW collection and handling	*Relevant for non-inert EWIW*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	<u>*Planning and design phase*</u> To include in the design phase the collection of EWIW by means of drainage systems for ponds and dams (see BAT 21.a) or drainage systems for heaps (see BAT 21.b), including a composite basal structure system (see BAT 15.b, BAT 16.e and BAT 17.c), and to plan the handling of the drained EWIW by means of return systems such as pumping stations or collection systems such as water retention basins.	
	<u>*Operational (construction, management and maintenance) phase*</u> To carry out the collection of drained EWIW and to pump it back, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
	<u>*Closure and after-closure phase*</u>	

	To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Section 4.3.2.2.1.1]

BAT 44. In order to prevent or minimise surface water status deterioration, BAT is to use the following technique:

Technique	Description	Applicability
Collection and off-site treatment of EWIW	*Relevant for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	Planning and design phase To design the collection and transfer of the EWIW that cannot be re-used, recycled or treated on site to an off-site treatment facility.	
	Operational (construction, management and maintenance) phase To carry out the collection of EWIW and to transfer it off site, while applying management systems (see BAT 1 and BAT 12).	

[This BAT conclusion is based on information given in Section 4.3.2.2.1.2]

5.4.2.2.2 Removal of suspended solids or suspended liquid particles

BAT 45. In order to prevent or minimise surface water status deterioration, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Examples of abated pollutants/ targeted parameters	Applicability
a	Gravity separation in settling ponds	*Relevant for EWIW containing TSS and TSP*	Suspended solids (TSS), suspended liquids such as oil and grease	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable for the liquid phase of spent drilling muds
		Planning and design phase To include in the design the settling of finely grained materials into ponds by gravity. It can be assisted by decantation of organic phases such as oil and grease. One or more ponds can be used in series or in parallel. Pond-type EWFs can be used as settling ponds.		
		Operational (construction,		

		management and maintenance) phase To carry out gravity separation in settling ponds, while applying management systems (see BAT 1 and BAT 12). Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		and other extractive wastes from oil and gas exploration and production, including flowback and produced water. Applicability may be restricted by location and land availability.
b	Clarification in tanks	*Relevant for EWIW containing TSS and TSP* Planning and design phase To include in the design the mechanically forced gravity settling in tanks where the settling time or specific area is controlled. It can be assisted by the use of reagents (coagulants /flocculants) Operational (construction, management and maintenance) phase To carry out clarification in tanks, while applying management systems (see BAT 1 and BAT 12). Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	Suspended solids (TSS), suspended liquids such as oil and grease	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
c	Coagulation and flocculation	*Relevant for EWIW containing TSS and TSP* Planning and design phase To include in the design the use of agents that promote sedimentation by increasing the agglomeration of particles into settleable flocs and have low environmental impacts (see BAT 42.e). Operational (construction, management and maintenance) phase To carry out coagulation and flocculation, while applying management systems (see BAT 1 and BAT 12).	Suspended solids (TSS), suspended liquids such as oil and grease, colloids	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
d	Air flotation	*Relevant for EWIW containing TSS and TSP*	Suspended solids (TSS), suspended liquids such as oil and grease, emulsions, COD	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable to particles that can naturally, or by means of flotation reagents, attach to air bubbles.
		Planning and design phase To include in the design the separation of solid and liquid particles by attaching them to air bubbles.		
		Operational (construction, management and maintenance) phase To carry out air flotation, while applying management systems (see BAT 1 and BAT 12).		
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
e	Media filtration	*Relevant for EWIW containing TSS and TSP* *Particularly relevant for non-inert-EWIW*	Suspended solids (TSS)	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		Planning and design phase To include in the design the size exclusion and/or adsorption on a filtering medium (e.g. sand, peat, anthracite, magnetite). It is driven by gravity or a pressure gradient. The media thickness is usually ~ 0.3-0.7 m.		
		Operational (construction, management and maintenance) phase To carry out media filtration, while applying management systems (see BAT 1 and BAT 12).		
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking		

		into account the nature and duration of the residual risks and hazards.		
f	Membrane filtration for suspended particles	*Relevant for EWIW containing TSS and TSP* *Particularly relevant for non-inert-EWIW*	Suspended solids (TSS), suspended liquids such as oil and grease, colloids	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicability may be restricted in the case of: • non-constant inflow quality; • high TSS.
		Planning and design phase To include in the design the transport of a liquid stream, driven by a pressure gradient, through a membrane that retains the particles based on the membrane pore size. It includes: • microfiltration, which removes particles ranging from 0.1 microns to 10 microns (such as major pathogens, bacteria and other contaminants in that size range); • ultrafiltration, which removes particles ranging from 0.0025 microns to 0.1 microns (such as flotation agents, surfactants, organometallic complexes).		
		Operational (construction, management and maintenance) phase To carry out membrane filtration for suspended particles, while applying management systems (see BAT 1 and BAT 12).		
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
g	Hydro-cycloning	See BAT 27.b		

[This BAT conclusion is based on information given in Sections 4.3.2.2.2.1, 4.3.2.2.2.2, 4.3.2.2.2.3, 4.3.2.2.2.4, 4.3.2.2.2.5 and 4.3.2.2.2.6]

5.4.2.2.3 Removal of dissolved substances

BAT 46. In order to prevent or minimise surface water status deterioration, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Examples of abated pollutants/ targeted parameters	Applicability
Oxidation-based systems				
a	Aeration and active chemical oxidation	*Relevant for EWIW containing TDS* *<u>Planning and design phase</u>* To include in the design the active water treatment process used to oxidise dissolved metals in EWIW and to transform them into less soluble forms and eventually settleable precipitates. It includes: • aeration of EWIW; • chemical oxidation using strong oxidants such as chlorine, peroxides (e.g. Fenton), ozone or permanganate. *<u>Operational (construction, management and maintenance) phase</u>* To carry out aeration and active chemical oxidation, while applying management systems (see BAT 1 and BAT 12). *<u>Closure and after-closure phase</u>* To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	Fe^{2+} for aeration, Fe^{2+}, Mn^{2+}, for chemical oxidation	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable as a stand-alone technique, but in combination with other techniques such as precipitation, solid/liquid control and pH adjustment.
b	Active aerobic biological oxidation	*Relevant for EWIW containing biologically oxidisable TDS* *<u>Planning and design phase</u>* To include in the design a	Oil/grease, nitrogen (ammonia, nitrates),	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		biological process using oxidation of carbonaceous and nitrogenous matter by means of aerobic bacterial activity. It includes a wide range of techniques, such as: • activated sludge process; • aerated lagoons; • sequencing batch reactors; • membrane bioreactors; • Biological Aerated Filters; • trickling filters; • rotating contactors; • Moving Bed Biofilm Reactors.	cyanates, COD, BOD, metals	Applicability may be restricted in the case of: • high levels of BOD or COD; • high levels of oil; • high levels of salts which would prevent proper microbial oxidation.
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out active aerobic biological oxidation, while applying management systems (see BAT 1 and BAT 12).		
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
c	Aerobic wetlands	*Relevant for EWIW containing TDS*	Dissolved solids (TDS), suspended solids (TSS), BOD, metals	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water. Applicability may be restricted in the case of: • high acidity load; • high levels of salts
		<u>*Planning and design phase*</u> To include in the design constructed shallow ponds or natural overland-flow wetlands (peatlands) containing vegetation used as a passive water treatment technique in order to increase the retention time and aeration. They are composed of: • a basal impervious structure; • a drainage system; • an organic matter layer; • vegetation.		

		Two main categories are: • free water surface flow wetlands; • subsurface flow wetlands. They can work by means of vertical or horizontal flows. The shallow pond depth is usually less than 1 m. <u>*Operational (construction, management and maintenance) phase*</u> To implement aerobic wetlands, while applying management systems (see BAT 1, BAT 11 and BAT 12). <u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		which would prevent proper microbial oxidation; • high water flow; • low land availability; • decreasing effectiveness over time; • high temperature and flow fluctuations; • adverse local climatic conditions; • sensitivity to high throughput excursions. Therefore, the technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase. Not applicable as a stand-alone technique. Maintenance may be required. Overland-flow wetlands are applicable to EWIW from peat extraction.
Reduction-based systems using bacterial activity				
d	Anaerobic wetlands	*Relevant for EWIW containing TDS* *Particularly relevant for treating ARD* <u>*Planning and design phase*</u> To include in the design anaerobic wetlands, which are similar to aerobic wetlands but contain an additional bottom layer of limestone beneath a much thicker organic substrate layer and sulphate-reducing bacteria. The size of the wetland is defined according to the acidity load: a recommended loading rate is 2 000 mg to 7 000 mg $CaCO_3/m^2$/day.	Acidity, dissolved metals and metalloids, sulphates	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water. Applicability may be restricted in the case of: • high acidity load; • high levels of salts

		<u>*Operational (construction, management and maintenance) phase*</u> To implement anaerobic wetlands, while applying management systems (see BAT 1, BAT 11 and BAT 12).		which would prevent proper microbial oxidation; • high Dissolved Oxygen (DO); • high water flow; • low land availability; • decreasing effectiveness over time; • high temperature and flow fluctuations; • adverse local climatic conditions; • sensitivity to high throughput excursions. Therefore, the technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase. Not applicable as a stand-alone technique. Maintenance may be required.
		<u>*Closure and after-closure phase*</u>. To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
e	Anoxic BioChemical Reactors (BCRs)	*Relevant for EWIW containing TDS* *Particularly relevant for treating ARD*	Acidity, dissolved metals and metalloids, sulphates	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water. Applicable to sites with little available space and very strict emission limits. Compared to other SO_4^- reduction methods (e.g. reactive barriers,
		<u>*Planning and design phase*</u> To include in the design BCRs which are similar to anaerobic wetlands but without vegetation. They can be divided into: • active BCRs that require energy and/or reagent input; • passive BCRs that filter by means of natural gravity flow through the solid porous medium. Microbial respiration is used as a catalyst for precipitation of dissolved metals, consumption of sulphates and		

		increasing the alkalinity. Optimal reduction rate occurs in a pH range of 6.5 to 7.5 and a temperature range of 25 °C to 45 °C. *Operational (construction, management and maintenance) phase* To implement anoxic BCRs, while applying management systems (see BAT 1, BAT 11 and BAT 12). *Closure and after-closure phase* To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		bioreactors), special equipment and maintenance activities are needed. Not applicable with high levels of salts which would prevent proper microbial oxidation.
Chemical precipitation				
f	Hydroxide and carbonate precipitation	*Relevant for EWIW containing TDS* *Particularly relevant for EWIW containing dissolved metals* *Planning and design phase* To include in the design an active treatment that consists of precipitating dissolved metals contained in the EWIW as metal hydroxides and/or carbonates by means of pH control based on the addition of acid or basic reagents. Reagents (such as quicklime (CaO) and sodium hydroxide (NaOH), but also limestone ($CaCO_3$), hydrated lime ($Ca(OH)_2$), soda ash (Na_2CO_3), magnesium oxides (MgO) and carbonates ($MgCO_3$)) are used to reach the targeted pH and to feed the solution with hydroxide or carbonate anions. Precipitation with, e.g. lime in combination with a coagulation/flocculation step and a clarification step is also	Dissolved metals	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable in combination with other techniques such as solid/liquid separation and final pH adjustment. Not suitable for the removal of chromium, selenium and uranium. Applicability may be restricted in the presence of chelates, such as ammonia, and metal-complexing agents, such as cyanides.

		known as a High-Density Sludge process. <u>*Operational (construction, management and maintenance) phase*</u> To carry out hydroxide and carbonate precipitation, while applying management systems (see BAT 1 and BAT 12). <u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
g	Sulphide precipitation	*Relevant for EWIW containing TDS* *Particularly relevant for EWIW containing dissolved metals* <u>*Planning and design phase*</u> To include in the design an active treatment that consists of precipitating dissolved metals as metal sulphides by adding sulphide reagents such as: • sodium sulphide (Na_2S); • sodium hydrosulphide (NaHS); • hydrogen sulphide (H_2S); • ferrous sulphide (FeS); • calcium sulphide (CaS); • polymeric organo-sulphide chemicals. The precipitation occurs in a pH range typically between 7.0 and 9.0. <u>*Operational (construction, management and maintenance) phase*</u> To carry out sulphide precipitation, while applying management systems (see BAT 1 and BAT 12). <u>*Closure and after-closure phase*</u> To implement the technique	Dissolved metals and metalloids	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable in combination with other techniques such as solid/liquid separation. Applicable to recover valuable metals from the EWIW stream.

		described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
Co-precipitation				
h	Co-precipitation with chloride or sulphate metal salts	*Relevant for EWIW containing TDS* *Particularly relevant for EWIW containing radium-226*	As, P, Se, ^{226}Ra	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Only applicable in combination with other techniques such as solid/liquid separation. Applicability may be restricted in the case of sensitiveness to higher variations in EWIW quality.
		Planning and design phase To include in the design a co-precipitation process that consists of adding ferric salts (ferric chloride ($FeCl_3$), ferric sulphate ($Fe_2(SO_4)_3$)) or aluminium salts (aluminium chloride ($AlCl_3$), aluminium sulphate ($Al_2(SO_4)_3$)) or barium chloride ($BaCl_2$) to remove elements such as radium-226.		
		Operational (construction, management and maintenance) phase To carry out co-precipitation with chloride or sulphate metal salts, while applying management systems (see BAT 1 and BAT 12).		
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
Adsorption				
i	Adsorption	*Relevant for EWIW containing TDS*	Dissolved metals, organic carbon, BTEX, oil and	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Applicability may be
		Planning and design phase To include in the design an adsorption system which attracts and/or adsorbs		

		pollutants by means of the surface properties of a medium such as: • zeolites; • activated carbon; • natural minerals and organoclays; • non-hazardous industrial mineral wastes or by-products; • natural biological materials; • non-hazardous biological waste; • iron oxides and hydroxides. The optimum pH varies from 4.0 to ~ 10.0.	grease	restricted in the case of high levels of salts which would prevent proper adsorption.
		Operational (construction, management and maintenance) phase To carry out adsorption, while applying management systems (see BAT 1 and BAT 12).		
		Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
Ion exchange				
j	Ion exchange	*Relevant for EWIW containing TDS*	Ca, Mn, Ba, Sr, Ra, nitrates, fluorides, arsenates, chromates, uranium complexes, boron and heavy metals	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable with a low pH. Only applicable following a pretreatment (e.g. microfiltration or ultrafiltration to remove suspended solids/particles).
		Planning and design phase To include in the design ion exchange, which works via an exchange of charged compounds/ions between an inflow stream and a solid medium (commercial resins or naturally occurring materials like peat and zeolites). A specific compound/ion is adsorbed by the medium and replaced in the stream with an ion liberated from the medium.		

		<u>*Operational (construction, management and maintenance) phase*</u> To implement ion exchange, while applying management systems (see BAT 1 and BAT 12).		Usually applied as a polishing step. Applicability may be restricted in the case of high levels of salts which would prevent proper ion exchange.
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
Filtration of dissolved substances				
k	Nanofiltration	*Relevant for EWIW containing TDS*	Multivalent ions	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Usually applied with pH and temperature control. Not applicable to monovalent ions. Usually not applicable to EWIW with a high TSS content. Applicability may be restricted by requirements for disposal of brine solution. Applicability may be restricted in the case of high levels of salts which would prevent proper nanofiltration.
		<u>*Planning and design phase*</u> To include in the design a pressure-driven separation technique using a semi-permeable membrane rejecting contaminants by means of size and/or charge exclusion. The typical pore size in nanofiltration is 1.5-2.5 nm. Water recovery is in between 75 % and 90 %.		
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out nanofiltration, while applying management systems (see BAT 1 and BAT 12).		
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
l	Reverse	*Relevant for EWIW containing*	Dissolved	Based on the results of a

	osmosis	*TDS* *Planning and design phase* To include in the design a water purification technology based on a semi-permeable membrane filtration where pressure is applied to overcome osmotic pressure and separate solutes from the solvent. The typical pore size in reverse osmosis is < 1.5 nm *Operational (construction, management and maintenance) phase* To implement reverse osmosis, while applying management systems (see BAT 1 and BAT 12). *Closure and after-closure phase* To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	metals, salts, macro-molecules	proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable with high temperatures. Usually applicable to treat saline streams. Applicability may be restricted by: • requirements for pretreatment and chemical addition to reduce scaling/fouling; • requirements for disposal of brine solution; • need for temperature control to minimise viscosity effects. Applicability may be restricted in the case of very high levels of salts (~ 200 g/l or higher) which would prevent proper reverse osmosis.

[This BAT conclusion is based on information given in Sections 4.3.2.2.3.1.1, 4.3.2.2.3.1.2, 4.3.2.2.3.1.3, 4.3.2.2.3.2.1, 4.3.2.2.3.2.2, 4.3.2.2.3.3.1, 4.3.2.2.3.3.2, 4.3.2.2.3.4, 4.3.2.2.3.5.1, 4.3.2.2.3.5.2, 4.3.2.2.3.6, 4.3.2.2.3.7 and 4.3.2.2.3.8]

5.4.2.2.4 Neutralisation of EWIW prior to discharge

BAT 47. In order to prevent or minimise surface water status deterioration, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Examples of abated pollutants/ targeted parameters	Applicability
Active treatment				
a	Active neutralisation	*Relevant for acidic or alkaline EWIW* *Planning and design phase* To include in the design active neutralisation.	pH, acidity, alkalinity	Based on the results of a proper Environmental Risk and Impact Evaluation (see

		Active neutralisation is performed by addition of neutralising reagents in a pond or tank such as: • sulphuric acid solution or carbon dioxide gas to neutralise alkaline EWIW; • sodium hydroxide, magnesium hydroxide, lime or ammonia to neutralise acidic EWIW. A reagent feeding system and a mixing device are needed.		BAT 5).
		<u>*Operational (construction, management and maintenance) phase*</u> To carry out active neutralisation, while applying management systems (see BAT 1 and BAT 12).		
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		
Passive treatment				
b	Oxic Limestone Drains (OLDs)/Open Limestone Channels (OLCs)	*Relevant for acidic EWIW*	Acidity, Mn, Al, Fe, Cu, Pb, Zn, Se	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable to treat high levels of metal content and/or acidity. Not applicable when the EWIW to be treated presents a: • high concentration of Fe; or • high concentration of Al; or • high acidity; or • high flow rate.
		<u>*Planning and design phase*</u> To include in the design OLDs/OLCs. OLDs/OLCs are uncovered trenches with an impermeable bottom and walls filled with limestone pebbles/cobbles that will dissolve with water and act as a carbonate agent, generating alkalinity, raising the pH and promoting precipitation of the dissolved metals in oxic conditions.		
		<u>*Operational (construction, management and maintenance) phase*</u> To implement OLDs/OLCs, while applying management systems (see BAT 1, BAT 11 and BAT 12).		
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational		

		phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		Therefore, the technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase. Not applicable as a stand-alone technique. Maintenance may be required. Not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water. Applicability may be restricted by land availability and site topography.
c	Anoxic Limestone Drains (ALDs)	*Relevant for acidic EWIW* *Planning and design phase* To include in the design ALDs. ALDs are impermeable trenches filled with limestone pebbles/cobbles and covered with a capping that will dissolve with water and act as a carbonate agent, generating alkalinity, raising the pH and promoting precipitation of the dissolved metals in anoxic conditions. *Operational (construction, management and maintenance) phase* To implement ALD, while applying management systems (see BAT 1, BAT 11 and BAT 12). *Closure and after-closure phase* To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational	Acidity	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable to treat EWIW presenting the following characteristics: • higher levels of DO; or • higher levels of [Al^{3+}]; or • higher levels of [Fe^{3+}]; or • low pH. Therefore, the technique may be particularly suitable as a polishing technique, during the operational phase, or

		phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.		for the treatment of low-load EWIW from sites in the closure or after-closure phase. Not applicable as a stand-alone technique. Maintenance may be required. Not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
d	Successive Alkalinity-Producing Systems (SAPS)	*Relevant for acidic EWIW* *<u>Planning and design phase</u>* To include SAPS in the design. SAPS combines the use of an ALD and a permeable organic substrate into one system that creates anaerobic conditions prior to water entering into contact with the limestone. It consists of watertight basins/cells/ponds containing limestone and organic matter (e.g. compost or peat) covered by several metres of water. *<u>Operational (construction, management and maintenance) phase</u>* To implement SAPS, while applying management systems (see BAT 1, BAT 11 and BAT 12). *<u>Closure and after-closure phase</u>* To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	Acidity, Al, Cu, Fe, Mn, Zn	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable to treat EWIW presenting the following characteristics: • higher levels of DO; or • low pH; or • high flow rate; or • high acidity. Therefore, the technique may be particularly suitable as a polishing technique, during the operational phase, or for the treatment of low-load EWIW from sites in the closure or after-closure phase. Not applicable as a stand-alone technique. Furthermore, an aerobic pond is required after treatment in order to

				precipitate dissolved metals. Maintenance may be required. Not applicable for the liquid phase of spent drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water.
e	Anaerobic wetlands	*Relevant for acidic or alkaline EWIW*		
		See BAT 46.d		

[This BAT conclusion is based on information given in Sections 4.3.2.2.4.1, 4.3.2.2.4.2.1, 4.3.2.2.4.2.2, 4.3.2.2.4.2.3 and 4.3.2.2.4.2.4]

Performance objectives for EWIW discharge are set considering BAT 45, BAT 46 and BAT 47, the information provided in Table 4.55 and taking into account the extractive waste characteristics, the technical characteristics of the EWF, its geographical location and the local environmental conditions.

See BAT 48 for associated monitoring.

5.4.2.2.5 Monitoring of emissions to surface water

BAT 48. BAT is to monitor emissions to surface water as follows:

Technique	Description	Applicability
Monitoring of emissions to surface water	*Relevant for non-inert extractive waste* *For inert extractive waste, only the TSS monitoring is relevant*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	<u>*Planning and design phase*</u> To develop a monitoring plan for emissions to surface water. Monitoring parameters and frequencies are properly selected according to the site-specific conditions (particularly geological, hydrological and hydrogeological conditions), with particular regard to the potential risk of surface water status deterioration, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions. To this end, the parameters and frequencies in Table 4.56and Annexes B.3.8, 3.9 and 3.10 to CEN/TR 16376 may be considered. If the emissions to surface water from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed.	

	Monitoring is planned in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.	
	<u>*Operational (construction, management and maintenance) phase*</u> To implement the emissions to surface water monitoring plan, while applying management systems (see BAT 1, BAT 11 and BAT 12). The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.	
	<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.3.2.2.6.1 and 4.3.2.2.6.2]

5.4.3 Prevention or minimisation of air pollution

5.4.3.1 Prevention or minimisation of dusting from exposed surfaces of extractive waste

BAT 49. In order to prevent or minimise air pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list:

	Technique	Description	Applicability
a	Water or water-based solutions spraying	*Relevant for exposed surfaces of extractive waste* <u>*Planning and design phase*</u> To include in the design the use of water sprinkling systems, e.g. on equipment such as conveyor belts, and trucks, including on tyres and tracks, and spraying roads with water or salt solutions containing $MgCl_2$ or NaCl to increase the moisture in the extractive waste, in order to keep the extractive waste wet and to reduce dust emissions before, during and after loading, handling and transport. <u>*Operational (construction, management and maintenance) phase*</u> To carry out water or water-based solutions spraying, while applying management systems (see BAT 1, BAT 11 and BAT 12). <u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Contaminated water cannot be used for water spraying. Applicability may be restricted in the case of limited water availability and cold climate.

		closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Wind protection systems	*Relevant for exposed surfaces of extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		<u>Planning and design phase</u> To include in the design wind protection systems aiming at reducing the wind speed and preventing dust emissions and soil erosion such as: • wind fences; • windbreaks consisting of one or more rows of plants along the border of the extractive waste deposition area (including the EWF) and/or extractive waste handling area.	
		<u>Operational (construction, management and maintenance) phase</u> To implement wind protection systems, while applying management systems (see BAT 1, BAT 11 and BAT 12).	
		<u>Closure and after-closure phase</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
c	Landscaping and geomorphic reclamation	*Relevant for exposed surfaces* *Relevant for NAG extractive waste*	
		See BAT 42.d	
d	Progressive rehabilitation	See BAT 38.a	
e	Temporary covers	See BAT 38.b	
f	Vegetative covers	See BAT 38.c	
Permanent dry covers			
g	Permeable dry covers	See BAT 38.d	
h	Impermeable dry covers	See BAT 38.e	
Permanent wet covers			
i	Free water covers	See BAT 38.g	
j	Wet covers	See BAT 38.h	

[This BAT conclusion is based on information given in Sections 4.3.3.1.2, 4.3.3.1.3, 4.3.3.1.4, 4.3.3.1.5, 4.3.3.1.6, 4.3.3.1.7, 4.3.3.1.8.1 and 4.3.3.1.8.2]

5.4.3.2 Prevention or minimisation of dusting from extractive waste handling and transport

BAT 50. In order to prevent or minimise air pollution, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	Continuous working systems	*Relevant for transport and handling of extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Not applicable in the case of operation sites with highly variable loading points and deposition points of the extractive waste. Applicability may be restricted in the case of windy conditions for uncovered conveyors belts.
		<u>Planning and design phase</u> To include in the design the handling/transport of extractive waste by conveyor belts, covered and encapsulated where recommended due to local conditions, or by pipelines.	
		<u>Operational (construction, management and maintenance) phase</u> To implement continuous working systems, while applying management systems (see BAT 1 and BAT 12).	
b	Organisational techniques	*Relevant for transport and handling of extractive waste*	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
		<u>Planning and design phase</u> To plan in the design the transport in order to optimise distances for the transportation of extractive waste on site (see BAT 11). To establish an appropriate speed limit for trucks handling extractive waste on site to reduce the dusting during on-site transport.	
		<u>Operational (construction, management and maintenance) phase</u> To implement organisational techniques, while applying management systems (see BAT 1 and BAT 12).	
c	Water or water-based solutions spraying	*Particularly relevant for transport and handling of dry inert extractive waste*	
		See BAT 49.a	

[This BAT conclusion is based on information given in Sections 4.3.3.2.1, 4.3.3.2.2 and 4.3.3.2.3]

5.4.3.3 Prevention or minimisation of emissions of VOCs and other potential air pollutants from drilling muds and other extractive wastes from oil and gas exploration and production

BAT 51. In order to prevent or minimise air pollution, BAT is to use the following techniques:

Technique		Description	Applicability
a	Reduced emissions completions (RECs)	*Relevant for liquid extractive waste from well completion containing VOCs or other potential air pollutants, in particular for flowback water* Planning and design phase To include in the design reduced emissions completions (RECs). It enables the capture of gases extracted during well completions. RECs are also called green completions or reduced flaring completions. The most common separation technique consists of three phase separators used to separate first the sand from the outflow and then the gas from the water and condensate. The separated gas is sent to a dehydrator to remove the residual water prior to distribution. *Operational (construction, management and maintenance) phase* To implement REC, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5). Small volumes of collectable gases may limit the applicability of the technique in the exploration phase.
b	Temporary storage and transport in closed systems followed by off-site treatment and/or disposal	*Relevant for drilling muds and other extractive wastes from oil and gas exploration and production, including flowback and produced water, possibly releasing VOCs or other potential air pollutants* Planning and design phase To include in the design the temporary storage of drilling muds and other extractive wastes in closed bunded containers/tanks. To consider the transport of these wastes by fixed pipelines. (see BAT 4.b) *Operational (construction, management and maintenance) phase* To implement the temporary storage and transport in closed systems, while applying management systems (see BAT 1 and BAT 12).	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

[This BAT conclusion is based on information given in Sections 4.3.3.3.1 and 4.3.3.3.2]

5.4.3.4 Monitoring of emissions to air

BAT 52. BAT is to monitor emissions to air as follows:

Technique	Description	Applicability
Monitoring of emissions to air	*Planning and design phase* To develop a monitoring plan for emissions to air through the following activities: • Identification of the possible emission sources considering both point and diffuse sources. This may include modelling of diffuse emissions, which encompasses fugitive emissions (e.g. EN 15445:2008). • Planning the monitoring of emissions to air and the efficiency of the measures applied for prevention and reduction of these emissions. This may include monitoring of ambient air quality and dust deposition from diffuse emissions while using meteorological data. Monitoring parameters and frequencies are properly selected according to the site-specific conditions, including the extractive waste characteristics, with particular regard to the potential risk of air pollution, as identified in the Environmental Risk and Impact Evaluation and reflected in the EWMP, taking into account existing monitoring activities and in line with applicable legal provisions. To this end, the parameters and frequencies in Table 4.57 may be considered. If the emissions to air from the extractive waste management are considered together with those from other activities, an integrated monitoring plan may be developed. Monitoring is planned in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that are developed according to equivalent principles of consensus, openness, transparency, national commitment and technical coherence as for EN standards.	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).
	Operational (construction, management and maintenance) phase To implement the monitoring plan for emissions to ambient air, while applying management systems (see BAT 1, BAT 11 and BAT 12). The monitoring plan, including monitoring parameters and frequencies, is adapted based on the monitoring findings over time. This may imply adding/removing parameters and/or increasing/decreasing frequencies.	
	Closure and after-closure phase To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	

[This BAT conclusion is based on information given in Sections 4.3.3.4.1 and 4.3.3.4.2]

5.5 Other risk-specific BAT Conclusions

5.5.1 Prevention or minimisation of any other adverse effects on human health, flora and fauna

5.5.1.1 Prevention or minimisation of noise emissions from the management of extractive waste

BAT 53. In order to prevent or minimise noise emissions from the management of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

<table>
<tr><th colspan="2">Technique</th><th>Description</th><th>Applicability</th></tr>
<tr><td rowspan="2">a</td><td rowspan="2">Noise barriers</td><td><u>Planning and design phase</u>
To include in the design the construction of noise protection walls, embankments, etc.</td><td rowspan="2">Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).</td></tr>
<tr><td><u>Operational (construction, management and maintenance) phase</u>
To use noise barriers, while applying management systems (see BAT 1 and BAT 12).</td></tr>
<tr><td>b</td><td>Continuous working systems</td><td>See BAT 50.a</td><td></td></tr>
<tr><td>c</td><td>Landscaping and geomorphic reclamation</td><td>See BAT 42.d</td><td></td></tr>
</table>

[This BAT conclusion is based on information given in Section 4.4.1.1, 4.4.1.2 and 4.4.1.3]

5.5.1.2 Prevention or minimisation of odour emissions from the management of extractive waste

BAT 54. In order to prevent or minimise odour emissions from the management of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description
a	Progressive rehabilitation	See BAT 38.a
b	Temporary covers	See BAT 38.b
c	Vegetative covers	See BAT 38.c
Permanent dry covers		
d	Permeable dry covers	See BAT 38.d
e	Impermeable dry covers	See BAT 38.e
Permanent wet covers		
f	Free water covers	See BAT 38.g
g	Wet covers	See BAT 38.h

[This BAT conclusion is based on information given in Sections 4.4.2.1, 4.4.2.2, 4.4.2.3, 4.4.2.4.1 and 4.4.2.4.2]

5.5.1.3 Prevention or minimisation of visual and footprint impacts from the management of extractive waste

BAT 55. In order to prevent or minimise visual and footprint impacts from the management of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description
a	Prevention of extractive waste generation	See BAT 6
b	Solid/liquid control of extractive waste	See BAT 27
c	Compaction, consolidation and deposition of extractive waste	See BAT 29
d	Landscaping and geomorphic reclamation	See BAT 42.d

[This BAT conclusion is based on information given in Sections 4.4.3.1, 4.4.3.2, 4.4.3.3 and 4.4.3.4]

5.5.1.4 Minimisation of resource consumption from the management of extractive waste

BAT 56. In order to prevent or minimise resource consumption from the management of extractive waste, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	
a	Reduction of energy consumption	<u>*Planning and design phase*</u> See BAT 4 and BAT 11	
b	Reduction of water consumption	See BAT 8 and BAT 42.a	
c	Reduction of reagents, auxiliary materials and feedstock consumption	<u>*Planning and design phase*</u> See BAT 4 and BAT 11	

[This BAT conclusion is based on information given in Sections 4.4.4.1.1, 4.4.4.1.2 and 4.4.4.1.3]

5.5.1.5 Prevention or minimisation of impacts related to the management of extractive waste containing NORMs

BAT 57. In order to prevent or minimise impacts related to management of extractive waste containing NORMs, BAT is to use one or a combination of techniques, appropriately selected from the following list:

Technique		Description	Applicability
a	NORMs monitoring plan	*Relevant for extractive waste potentially containing NORMs* <u>*Planning and design phase*</u> To develop a monitoring plan for extractive waste containing NORMs (see also BAT 3). <u>*Operational (construction, management and maintenance) phase*</u>	Based on the results of a proper Environmental Risk and Impact Evaluation (see BAT 5).

		To implement and review the monitoring plan based on the monitoring findings.	
		<u>*Closure and after-closure phase*</u> To implement the technique described in the operational phase, adapted to the specifics of the closure phase. To implement the technique described in the operational phase, adapted to the specifics of the after-closure phase, for as long as may be necessary, taking into account the nature and duration of the residual risks and hazards.	
b	Sorting and selective handling of extractive waste	*Relevant for extractive waste potentially containing NORMs*	
		See BAT 7.b	

[This BAT conclusion is based on information given in Sections 4.4.5.1 and 4.4.5.2]

6 EMERGING TECHNIQUES

6.1 Emerging techniques to improve the extractive waste characteristics

6.1.1 Dewatering by geotextile tubes

1. Description
Geotextile tubes allow the dewatering and containment of slurried extractive waste from mineral processing with a high water content.

2. Technical description
Geotextile tubes are cylindrical big bags made of geotextiles. They are characterised by diameters ranging from one to several metres and lengths of up to hundreds of metres long. In literature, examples of geotextile tubes with smaller dimensions, placed on the caisson of trucks or used as filter bags, are available. The can be made of different polymeric materials (such as polypropylene or polyester/polyethylene), depending on the different applications.

Geotextile tubes can be employed either to recover the solid particles from slurried extractive waste from mineral processing or to clarify the EWIW. They enable EWIW to rapidly drain and retain the solid fraction of extractive waste from mineral processing (Yilmaz 2011). Extractive waste is dewatered by means of the following steps:
- By filling the geotextile tubes by means of pumping the slurry or the EWIW. Usually, coagulants or polymer conditioners are added to help settling of solid particles.
- By dewatering the slurry under a hydrostatic pressure allowing EWIW to flow through the geotextile's pores. Solid particles are retained in the tubes. The filtration of extractive waste from mineral processing is also enhanced by the thickened layers of extractive waste deposited in the tube.
- By consolidating the solid fractions remaining in the tube after dewatering. A volume reduction of up to 90 % can be achieved. Hereafter, geotextile tubes can be landfilled, stored on site or used for land rehabilitation or construction elements.

(TenCate 2014)

This technique can be used for example in:
- pond and lagoon maintenance;
- management of extractive waste from mineral processing;
- water resource management (water reclamation and re-use in the mineral processing or drilling activities);
- construction elements, for example debris detention structures or breakwaters within an EWF, separation walls or rehabilitation and landform elements;
- recovery of precious metals.

Geotextile tubes have to be placed on an impermeable basal structure or containment structure and EWIW has to be collected to be further treated and re-used/recycled in the mineral processing or discharged after appropriate treatment.

3. Achieved environmental benefits
- Treatment of large amounts of slurried extractive waste from mineral processing or EWIW, including in emergency situations.
- Emergency and collapse management.
- Precious metals recovery.

4. Environmental performance and operational data
Up to 99 % of the solid fractions can be captured and water can be collected and recirculated through the system (TenCate 2014).

- In the Stratoni Mine (EE), geotextile tubes (60 m length, 14.7 m diameter and 2.5 m height) have been used on a large scale for 10 days for dewatering extractive waste from mineral processing. A final solids content of 65 % w/w has been obtained from an initial 27 % w/w (Newman *et al.* 2004).
- In a research study on dewatering fine marble slurry produced by diamond wire sawing machines in a Carrara marble quarry (IT), geotextile big bags have been tested in the laboratory and on sites reaching a solid particles retention on the geotextile surface of 76 % to 97 % (Garbarino and Cardu 2007).

5. Cross-media effects
- Groundwater and surface water contamination.

6. Technical considerations relevant to applicability
- This technique is available at the pilot scale and on a large scale.
- The geotextile choice and tube dimensions depend on several factors, such as the type of extractive waste to be dewatered and the mechanical properties and permeability of the geotextile.

7. Economics
- A constraint to the use of geotextiles tubes may be their cost.

- In the Stratoni mine, the dewatering cost was ~ EUR 1 (USD 1.20, year 2004) per cubic metre of slurry received from the concentrator (Newman *et al.* 2004).

8. Driving force for implementation
- Risk prevention.
- Management of emergencies.

9. Example sites
- Stratoni Mine (EE) (Newman *et al.* 2004).
- Svärtträsk Mine (SE): geotextile tubes have been used to treat 30 000 m^3 of sludge dredged from water treatment operations (settling pond) (SE SGU 2016).
- A research study on marble slurry in a Carrara quarry (IT) (Garbarino and Cardu 2007).
- In a Finnish nickel mine, geotextile tubes have been used after heavy rainfalls to treat the excess water from a pond. Concentration of metals in the treated EWIW complied with the emission limits set by the local legislation (TenCate 2014).
- In a Malaysian case study, geotextile tubes have been case used to contain and dewater oil sludge in order to allow the repair of the damaged impermeable HDPE liner of the storage pond (TenCate 2014).
- In Nevada (US), geotextile tubes have been used to treat sludge with a high gold content from a barren pond (containing a chemical solution waste) and a pregnant pond (containing solution which has percolated through the ore on a heap leach) (TenCate 2014).

10. Reference literature
(Garbarino and Cardu 2007)
(Newman *et al.* 2004)
(SE SGU 2016)
(TenCate 2014)
(Yilmaz 2011)

6.1.2 Passivation, microencapsulation and biological treatment

1. Description

Passivation or microencapsulation of acid-generating extractive waste involves protecting the sulphide surface from water and oxygen. Biological treatment consists of injecting and distributing inoculants and substrates to form a biological film that wraps the material particles.

2. Technical description

Preventing oxidation of sulphides on site by controlling the environmental conditions is potentially a viable alternative to treatment from a long-term perspective.

In passivation and microencapsulation, reactive extractive waste can be isolated from oxidising agents (i.e. O_2, Fe^{3+}) by chemically precipitating a ferric coating on its surface. This passivation process is also called microencapsulation.

Several chemicals (such as phosphate, silica and permanganate) can be used to coat and/or seal the surface of acid-generating extractive waste to reduce its reactivity.

Biological treatment typically has the following components (ITRC 2010e):

- *Development of an anaerobic environment* through the injection and distribution of inoculants (e.g. waste water) and substrates. The addition of materials that contain large populations of bacteria allows the formation of biological films that thrive in the organic-rich anaerobic environment.
- *Formation of a biological film* that impedes the release of contaminants from the iron reduction or encapsulates the particles by shielding them from oxygen contact.

3. Achieved environmental benefits

- Prevention or reduction of ARD by stopping the transport of oxidants to the sulphide surface and by consuming ferric irons before they become oxidants.
- Prevention of the release of heavy metals to soil, groundwater and surface water.

4. Environmental performance and operational data

- At the Gilt Edge Mine, up to 90 % reduction of metals (Al, Fe) and sulphate has been achieved by the addition of different materials (see Table 6.1). Permanganate and lime addition technologies were more effective than other techniques. However, the lime will be exhausted over time and permanganate addition showed a longer lifetime. Silica addition was expensive and failed in the field test (ITRC 2010j).

Table 6.1: Technique performance at the Gilt Edge Mine in South Dakota (US)

Technique	Achieved 90 % reduction			Achieved discharge limits			
	Al	Fe	Sulphate	pH	TDS	As	Zn
Lime	Yes	Yes	Yes	No	Yes	Yes	Yes
Metals Treatment Technologies	Yes	Yes	No	Yes	No	No	Yes
Permanganate	Yes	Yes	No	Yes	Yes	Yes	Yes
Silica	No	Yes	No	No	No	No	No

Source: adapted from (ITRC 2010j)

No data on the biological treatment of extractive waste were provided in the questionnaires.

5. Cross-media effects

- Consumption of inoculants and substrates.

6. Technical considerations relevant to applicability

- These techniques are only available at the laboratory scale and on a small/pilot scale. There are no large-scale applications. Long-term data are not available to predict the lifetime of this treatment.
- All passivation techniques use a spray-on application, either as a solution (phosphate) or as slurry (silica). Since the chemicals are applied as a solution or slurry, they can easily be applied to extractive waste that may be difficult to access or treat, such as pit highwalls.
- This technique can be applied alone or in combination with others.
- The effectiveness of passivation is limited by the surface that the sprayed chemicals are able to reach. Therefore, the treatment of thick layers of extractive waste from mineral processing or high and large stockpiles can be difficult.
- The effectiveness of the biological treatment depends on the ability to deliver adequate inoculants and substrates to the extractive waste and maintaining the biofilm on the particles surface.

7. Economics

- The cost of microencapsulation techniques varies largely depending on the chemicals used and the need for repeating the treatment.
- In (ITRC 2010j) the following costs to treat ~ 383 000 m^3 of waste-rock were reported:
  - EUR 9.40/m^3 (USD 12.50/m^3, year 2010) for lime addition;
  - EUR 7.9/m^3 (USD 10.50/m^3, year 2010) for metals treatment;
  - EUR 6.4/m^3 (USD 8.50/m^3, year 2010) for permanganate treatment;
  - EUR 24.9/m^3 (USD 33/m^3, year 2010) for silica treatment
- In the pilot-scale plant for the Golden Sunlight demonstration project (ITRC 2010j), costs varying from EUR 16.2/m^2 (USD 21.5/m^2, year 2010) to EUR 64.8/m^2 (USD 86/m^2, year 2010) for highwall treatment were reported. It may be taken into consideration that the cost of implementing this technology on small pilot plants is usually higher than applying it to a large area (ITRC 2010j).

8. Driving force for implementation

- Legal and environmental requirements.

9. Example sites

- Gilt Edge Mine and Golden Sunlight demonstration projects (US) (ITRC 2010j)

10. Reference literature

(ITRC 2010j)
(ITRC 2010e)
(Kauppila 2015b)

6.2 Emerging techniques to prevent and minimise groundwater status deterioration and soil pollution

6.2.1 Reactive basal structure

1. Description
This technique consists of adding alkaline material as a neutralising basal layer underneath the PAG extractive waste to neutralise the seepage and to reduce ARD generation potential.

2. Technical description
This technique is relevant for PAG extractive waste.

Alkaline material can be added as a neutralising reactive barrier underneath the acid-generating extractive waste to neutralise the seepage and to reduce acid drainage impacts on the surrounding environment. Neutralising reactions will also promote precipitation of harmful elements and compounds in the waste, according to the GARD guide, Kauppila and co-authors, and the Closedure project (INAP 2014c; Kauppila *et al.* 2013; Tornivaara 2015d).

3. Achieved environmental benefits
- Prevention of the risk of soil and groundwater contamination.
- Neutralisation of the seepage.

4. Environmental performance and operational data
The neutralising capacity of the basal barrier has to be calculated to match the acid-producing capacity during the whole life cycle of the EWF. If the basal structure works properly, no special maintenance is needed.

5. Cross-media effects
- Consumption of alkaline material.

6. Technical considerations relevant to applicability
- The addition of a reactive basal structure is applicable to PAG extractive waste.
- It can be applied in combination with other methods of alkaline addition, such as blending, especially if the neutralising capacity of the base is decreasing.
- It is applicable if acid-consuming/neutralising material is available on site.
- Secondary precipitates will form a passivating coating on the surface of alkaline particles and thus reduce the effectiveness of this technique (INAP 2014c), as well as clogging the basal structure.
- It may require additional liner layers to limit the spreading of drainage from the waste, according to the Closedure project (Tornivaara 2015d).

7. Economics
- No information provided.

8. Driving force for implementation
- Safety requirements.
- Legal and environmental requirements.

9. Example sites
- No information provided.

10. Reference literature
(Kauppila *et al.* 2013)
(INAP 2014c)
(Tornivaara 2015d)

6.2.2 Accelerated and controlled dissolution of extractive waste

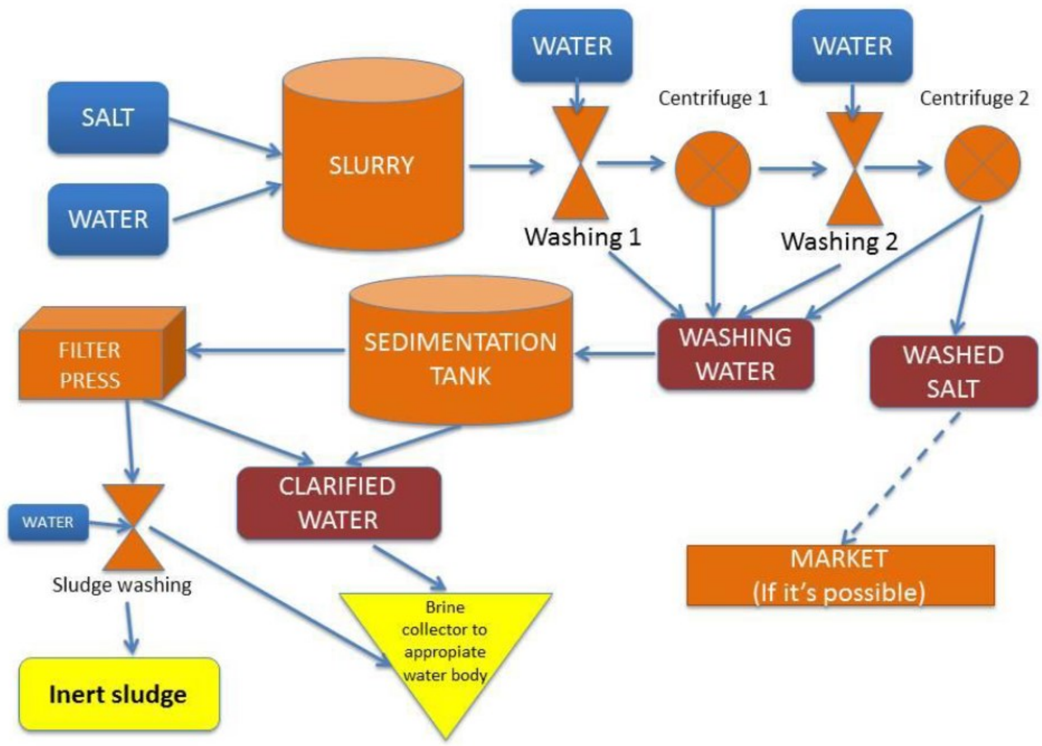
1. Description

The accelerated and controlled dissolution of extractive waste resulting from the mineral processing of potash aims at dissolving the extractive waste deposited on heaps in order to reduce the final amount of extractive waste disposed of.

2. Technical description

This technique is relevant for extractive waste from the mineral processing of potash.

The accelerated and controlled dissolution is performed by "washing" the fine fraction of extractive waste resulting from mineral processing to create a slurry (see Figure 6.1). The washing can be produced using a system formed of pumps and pipelines to bring water to the heap. An appropriate system for the collection of brine is designed and constructed to collect the slurry which is formed by mixing the extractive waste with water. It usually includes surrounding waterproof channels, water wells and drainage trenches to collect the slurry (brine). Water-soluble materials (salts) are dissolved with water. Part of the slurry (brine) may be used to produce salt. In that case, centrifuges (see Figure 6.1) are used to separate washing water from washed salt. The rest of the slurry (brine) is further treated in order to separate the liquid fraction from the undissolved solids. Sedimentation tanks, filter presses and clarification tanks are usually used for that purpose. The remaining undissolved solids (sludge) are managed as extractive waste whereas the EWIW resulting from the accelerated and controlled dissolution process is collected and may be discharged in an appropriate coastal (marine) receiving water body.



Source: Provided by the TWG

Figure 6.1: Example of accelerated and controlled dissolution flow chart

3. Achieved environmental benefits

- Reduction of the clean-up time (Rinaudo 2003) and the final amount of extractive waste disposed of onto heaps.

4. Environmental performance and operational data

From Alsatian potash mining experiences it can be deduced that the environmental performance will depend on the following:

- Design, construction and maintenance of the pumping pipes system, based on calculations (hydraulic) considering site conditions, available water and heap design. The system is regularly monitored and maintained.
- Design, construction and maintenance of appropriate slurry (brine) collection systems and appropriate drainage systems. A variety of materials and designs are in use. Usually, a composite system is used, e.g. geotextile liner and drainage material (gravel) and pipe. The design is based on calculations considering site conditions, dissolution rate, rainfall and heap design.
- All elements of the drainage system are based on calculations (hydraulic and geological) considering site conditions, the dissolution rate and heap design.

5. Cross-media effects

- Water consumption.
- Energy consumption.
- Reagents consumption (e.g. for sedimentation or clarification).

6. Technical considerations relevant to applicability

- Applicability may be restricted in the case of:
    - o unavailability of a convenient water body.

7. Economics

Two main cost elements were identified:

- Investment costs (CAPEX). These include construction of the pumping pipeline system and infrastructure to artificially dissolve the heaps.
- Operation and maintenance costs (OPEX). These cover energy used by pumps, maintenance of infrastructure, and personnel in charge of the process control programme.

8. Driving force for implementation

- Legal requirements according to national mining laws and other environmental laws.

9. Example plants

Alex (1989), Théodore (1998), Marie Louise and Anna (2001) and Amélie (2003). All of them located in Alsace (France) (MDPA 2017).

10. References, bibliography

(MDPA 2017)
(Rinaudo 2003)

6.2.3 Phytomining

Phytomining or phytoextraction is an emerging technique similar to phytotechnologies used for groundwater and soil remediation.

The technique uses plants to take up contaminants with the transpiration stream.

Plants called hyperaccumulators are usually used to mine/extract specific metals from the extractive waste or contaminated soil. These plants can absorb from 10 to 100 times higher levels of metals than other species.

Two types of hyperaccumulators can be found: natural (the plant absorbs metals without addition of chemicals) and induced (chemicals are added into the soil to make metals bioavailable to the plant).

In the latter case, special attention is paid to the use of non-toxic chemicals.

Examples of metal-specific plants used for phytomining/extraction are provided in Table 6.2. Some final concentrations of metals in the plant (expressed in mg per kg of dry matter) are also provided in the third column.

Table 6.2: Hyperaccumulators used in phytomining/extraction

Metal	Plant/hyperaccumulator	Concentration of metals in the plant (mg/kg dry matter)	Biomass (t/ha)
Au	Brassica juncea	10	20
Cd	Thlaspi caerulescens caerulescens	3 000	4
Co	Haumaniastrum robertii	10 200	4
Cu	Haumaniastrum katangense	8 356	5
Mn	Macadamia neurophylla	55 000	30
Ni	Alyssum bertolonii Berkheya coddii	13 400 17 000	9 22
Pb	Thlaspi rotundifolium	8 200	4
Th	Biscutella laevigata	4 055	4
Zn	Thlaspi cearulescens calaminare	10 000	4

Source: http://www.iap.tuwien.ac.at/~gebeshuber/20150413_SME_1062.pdf

6.2.4 Covering of large "potash heaps" with thin covers

1. Description

The covering of large heap-type EWFs used for the management of extractive waste resulting from mineral processing of potash ore ("potash heaps") is an emerging technique to minimise the EWIW and seepage from these EWFs.

2. Technical description

Different approaches for the covering of "potash heaps" are being tested, using vegetative and non-vegetative covers. Depending on site-specific characteristics (e.g. heap size, surroundings, availability of materials), the capping of "potash heaps" with one of the covers described in Section 4.3.1.3 may not be applicable. Therefore, other covers are being developed and tested for the capping of potash heaps.

An example of a "potash heap" cover being tested is the following:

- A single thin layer of material is used to cover the heap.
  The objective is to establish a thin cover / functional layer, which is more or less parallel to the heap slopes.
  As uncovered "potash heaps" have an inclination of up to 35-38 °, special requirements for the material are necessary. Materials used for conventional cover techniques (e.g. soil, gravel, recycled demolition waste) do not fulfil these requirements. The material used for the covering of "potash heaps" has specific characteristics that prevent and minimise EWIW and seepage generation by promoting storage and evaporation of precipitation. This effect can be supported by vegetation if applicable. A range of limitations are given since coverage of heaps requires significant amounts of material and depends on site-specific characteristics. Furthermore, not all materials are usable as legal requirements, technical limitations and economic reasons can be limiting factors.

3. Achieved environmental benefits
- Minimisation of EWIW and seepage.
- Minimisation of land use.
- Reduction of the visual impact if vegetation is applicable.

4. Environmental performance and operational data
A vegetative cover has been applied at the Sigmundshall site in Germany since 2006.

5. Cross media effects
- Energy consumption due to transportation of covering materials.

6. Technical considerations relevant to applicability
Depending on the size and height of the slope, the covering materials have to meet different requirements:
- the materials need to be stable even if applied almost parallel to high-gradient slopes (35-38 °); otherwise the land use would be too great for large heaps;
- a mixture of different components as covering material is necessary to maintain structural stability under these conditions as natural soils do not meet these requirements.

Other technical considerations relevant to applicability are:
- availability of covering materials with the required characteristics;
- land availability.

Other techniques described in Section 4.3.1.3 may be applied to small and medium-sized "potash heaps".

7. Economics
- The cost of "potash heap" covering techniques varies largely depending on the site, the technique and the materials used. No general information on costs can be given since costs for materials and transportation depend on the type, availability and distance to the site.

8. Driving force for implementation
- Legal and environmental requirements.
- Reduction of waste water.

9. Example sites
- Sigmundshall (DE)

10. Reference literature
- No information provided.

6.3 Emerging techniques to prevent and minimise surface water status deterioration

6.3.1 Removal of dissolved substances

6.3.1.1 Forward osmosis

1. Description
Forward osmosis is an emerging technique to improve water treatment/concentration processes. It is under study for treating EWIW (such as AMD or membrane concentrates) with a high fouling tendency when treated with more conventional membrane filtration technologies such as nanofiltration and reverse osmosis.

2. Technical description
In forward osmosis, the osmotic pressure itself is the driving force for mass transport instead of using hydraulic pressure. Therefore, compared to nanofiltration and reverse osmosis, forward osmosis does not require significant energy input other than the pumping energy for the process streams.

Forward osmosis is driven by a difference in solute concentrations across the membrane that allows the passage of water from the dilute feed to the draw solution and rejects most of the solute molecules or ions. The solvent moves across the membrane from the lower-solute-concentration side to the higher-solute-concentration side.

3. Achieved environmental benefits
- Removal of metals and sulphates.
- Recycling of water in the flotation process.

4. Environmental performance and operational data
- The PuMi project has been focused on laboratory tests on the treatment of EWIW from neutralisation ponds to be re-used in the flotation process or discharged according to the emission limits of the Finnish environmental regulations. According to the results of the PuMi project, forward osmosis removes up to 99 % of the ions, similarly to reverse osmosis. However, the fluxes in forward osmosis are low compared to more conventional membrane filtration such as nanofiltration and reverse osmosis, according to VTT (Kyllönen *et al.* 2015).

5. Cross-media effects
- Energy consumption.
- Brine generation.

6. Technical considerations relevant to applicability
- Forward osmosis is only available at the laboratory scale. However, it seems promising for the treatment of EWIW with a high fouling tendency when treated with nanofiltration or reverse osmosis.
- Pretreatment is required in general in membrane filtration (see Sections 4.3.2.2.3.7 and 4.3.2.2.3.8). However, less pretreatment appears necessary in forward osmosis compared to reverse osmosis, because of the lower fouling tendency due to the low hydraulic pressure applied (Kyllönen *et al.* 2015).
- The draw solution is an issue in forward osmosis. A low-cost way to deal with it consists of using process water solutions or seawater as draw solutions (Kyllönen *et al.* 2015).
- Although forward osmosis membranes are easy to wash by rinsing with water, a problem in forward osmosis is the precipitation of gypsum in equipment. For this reason, the addition of antiscaling products is suggested in the PuMi project. However, this can hinder the further treatment of concentrate and needs to be studied and developed further. According to some preliminary studies, scaling on the membrane surface can be prevented by applying

ultrasound. This reduces the growth of crystals and prevents the scaling of calcium on the membrane surfaces in forward osmosis, according to VTT (Kyllönen *et al.* 2015).

7. Economics

- Only when there is no requirement for the regeneration of draw solution, e.g. when the process solution works as a draw solution, the costs of forward osmosis are relatively low.

- The OPEX estimated in the PuMi project is below EUR 0.1/m^3 of produced water (Kyllönen *et al.* 2015).

8. Driving force for implementation

- Legal and environmental requirements.
- Re-use of water in the mineral processing.

9. Example sites

- Examples of laboratory tests are reported in the PuMi report (Kyllönen *et al.* 2015). As reported by VTT, a few pilot-scale or full-scale examples are available in the extractive industry.

10. Reference literature

(Kyllönen *et al.* 2015)
(Pérez-González *et al.* 2012)

6.3.1.2 Electrocoagulation

1. Description

Electrocoagulation involves the application of an electrical current to coagulate organic constituents and suspended solids in EWIW. This implies electrolysis with graphite or stainless steel cathodes in combination with a metal anode.

2. Technical description

Electrocoagulation is a process of destabilising suspended, emulsified or dissolved contaminants by introducing an electrical current in an aqueous medium. Potential applications of this technology include the pretreatment of the EWIW prior to filtration or reverse osmosis and the treatment of neutral EWIW to remove minor amounts of metals prior to discharge.

A typical electrocoagulation unit consists of a chamber with a series of iron or aluminium metal plates. As EWIW flows through the chamber, the metal plates are electrified, acting as an induced electrode and releasing metal ions into the solution.

Insoluble precipitates are formed from ions of the metal electrode and selenium, arsenic or other metals present in the EWIW. Precipitates can be separated by gravity sedimentation or membrane filtration at higher concentrations (US EPA 2014).

Electrochemical methods can be used to convert nitrogenous compounds to a desired form, facilitating nitrogen removal as nitrogen gas or as pure ammonia. EWIW can contain nitrogen from incomplete detonation of nitrogen-rich explosives and from nitrogen-containing chemicals used in enrichment processes.

The technique consists of using electrochemistry-enhanced ammonia stripping and requires only low electric potential for operation. It can result in an ammonia product for re-use (Jermakka *et al.* 2015b).

A combination of sorption and electrochemical techniques appears a potentially promising method for the treatment of large volumes of EWIW containing multiple nitrogenous compounds (Jermakka *et al.* 2015b).

3. Achieved environmental benefits

- Removal of selenium, arsenic, copper, lead, zinc and cadmium as well as phosphates and TSS.

4. Environmental performance and operational data

According to the results of a hybrid electrocoagulation-microfiltration laboratory test, metals are reduced by 95-99 % (US EPA 2014).

Systems are expected to require little maintenance.

The performance of both sorption techniques and electrochemistry-enhanced ammonia stripping have been studied in the Minimam project and will be experimentally investigated further (Jermakka *et al.* 2015a).

5. Cross-media effects

- High energy consumption.

6. Technical considerations relevant to applicability

- Electrocoagulation is only been applied at the laboratory scale and has not been applied for the full-scale treatment of extractive waste. However, it seems a promising technique due to the significant reduction in sludge production compared with other chemical processes such as iron reduction. It seems to be suitable for EWIW streams with large flow rates and a low concentration of organic constituents and suspended solids.
- Contaminant removal depends on the composition of the EWIW, the material and configuration of the electrodes and the electric current.
- Electrocoagulation is effective when the influent EWIW has a high electrical conductivity. It works more efficiently with a pH between 4 and 8.
- It is unable to treat EWIW with high acidity or sulphates. Pretreatment by lime neutralisation and sedimentation and post-treatment by microfiltration and neutralisation are usually needed.
- It raises the temperature of the outflow, making the direct discharge of treated EWIW challenging.

[EPA 2014]

7. Economics

- For some applications, the CAPEX is significantly less than alternative technologies. The OPEX can be less than EUR 0.30/m^3 (USD 0.40/m^3, year 2013), including electric power, replacement of electrodes, pump maintenance and labour (US EPA 2014).

- A potential cost advantage of the electrocoagulation process is the generation of less sludge. This may be dewatered more easily and beneficially recovered.

8. Driving force for implementation

- Legal and environmental requirements.
- Economic benefits.

9. Example sites

- Laboratory scale (US EPA 2014)

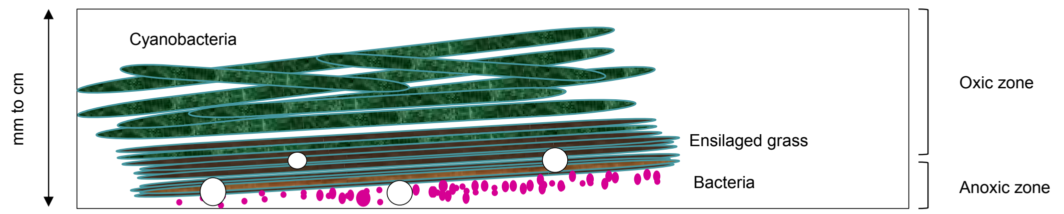
10. Reference literature

(Jermakka *et al.* 2015a)
(Jermakka *et al.* 2015b)
(US EPA 2014)

6.3.1.3 Use of microbial mats or algae

1. Description
A microbial mat aquatic bioremediation system uses naturally occurring and living organisms to remove metals from EWIW.

2. Technical description
Microbial mats are living organisms composed primarily of cyanobacteria (formerly known as blue-green algae). They are photosynthetic and can be grown and harvested as plants (Figure 6.2). Microbial mats have a rapid growth rate and the ability to survive extreme environmental conditions such as high salinity and low pH. Microbial mats also tolerate high concentrations of metals and organic contaminants.



Source: adapted from (ITRC 2010f)

Figure 6.2: Cross section showing the oxic and anoxic zones of microbial mats

Microbial mats are nitrogen-fixing, i.e. they use atmospheric nitrogen to make usable nitrogen compounds for their growth. They are photoautotrophs that can saturate the aqueous phase with oxygen (15 mg/l) during daylight hours and have the potential to degrade organics through oxidative pathways. At night, the mats consume the oxygen and provide an environment where organic contaminants can be reductively degraded (ITRC 2010f).

Algal biomass treatment occurs via enhanced cyanobacterial and algal growth through nutrients addition. It also serves as a carbon source to support microbial selenium reduction processes. This system uses a combination of ponds containing algae and bacteria in which selenate is reduced to selenite and elemental selenium (US EPA 2014).

3. Achieved environmental benefits
- Low BOC and DOC levels in the treated EWIW.
- Removal of metals, metalloids, radionuclides and oxyanions by several mechanisms such as ion exchange/sorption, reduction, oxidation and bio-flocculation. For example, many metals (e.g. U6+, Cr^{6+} and Se^{6+}) can be reduced in the anoxic reducing zones created in microbial mats at night or in dark conditions. Selenium can also be oxidised by algae biomass treatment.
- Removal of dissolved uranium and mercury, according to certain studies (ITRC 2010f)
- Potential recovery of metals.
- Decrease of the amount of waste produced.

4. Environmental performance and operational data
The cumulative uptake of metals by microbial mats could be up to 190 g/kg (wet weight). Constructed microbial mats can filter manganese from coal mine drainage at a rate of 2.5 mg/m^2 of mat per day.

- At the Savannah River site pilot-scale test, 88 % of uranium at an initial concentration of 2.4 mg/l was removed from approximately 200 l of contaminated water in 15 minutes (ITRC 2010f).

Preliminary pilot-scale results on an algal treatment demonstrate that the total selenium in the drainage water can be reduced by up to 80 %. The remaining selenium must not be readily bioavailable to aquatic organisms (US EPA 2014).

5. Cross-media effects

- Availability of land for microbial mats and algal treatment.

6. Technical considerations relevant to applicability

- Only data from pilot-scale or smaller-scale applications, such as mat bags, a multilayer filter bed and a silica beaded microbial mats reactor, are available.
- This passive technology can treat dissolved constituents (organics and inorganics) and a variety of metals, metalloids, radionuclides, and oxyanions. It can be used as a stand-alone technology or in combination with others, in temporary or permanent applications. It can be applied as a remediation technique.
- Microbial mats can survive in cold temperatures and flourish in temperatures above 25 °C with abundant sunlight. Their optimal performances are reached in hot climates. They can survive high, often phytotoxic, concentrations of metals or organic contaminants.
- Because microbial mats can be dried to 1-2 % of their wet volume, they do not produce as much waste as coagulation/precipitation, adsorption processes or ion exchange.
- The following limitations apply for microbial mats:
  - chemical characteristics of the EWIW:
    - generally not effective for low pH (pH < 2);
    - generally not effective for high concentrations of Fe, Mn, and Al;
    - may require pretreatment to remove Fe;
  - suspended solids in the EWIW need to be removed prior to treatment;
  - trace metal toxicity may inhibit the microbial viability of some mats.
- The following limitations apply for algal-bacterial selenium removal:
  - seasonal limitations related to sunlight duration and the temperature;
  - difficulties in generating sufficient biomass to promote biological reduction.

7. Economics

- The life cycle cost of a microbial mat aquatic treatment system would significantly decrease if pretreatment was used to remove suspended matter.

- The preliminary total cost estimate for an algal-bacterial selenium removal facility with a capacity of 12 335 m^3/day (10-acre-foot per day) is less than EUR 0.18 per m^3 of treated drainage water (USD 291 per acre-foot, year 2013) (US EPA 2014).

8. Driving force for implementation

- No information provided.

9. Example sites

- Lava Cap; Fort Hood, Killeen, TX (for landfill leachate); TVA, AL (for coal AMD) (US) (ITRC 2010f)
- Panoche Drainage District on the west side of the San Joaquin Valley, California (pilot-scale) (US) (US EPA 2014)

10. Reference literature

(ITRC 2010f)
(US EPA 2014)

6.3.2 Removal/destruction of extraction process contaminants

6.3.2.1 Cyanides recycling

1. Description
The technique is a hybrid of the membrane and electrowinning technologies, which allow for the recovery of metallic copper and the simultaneous liberation of free cyanide from the copper-cyanide complexes.

2. Technical description
The recycling of cyanide using membrane technology, which was under development at the time of writing the MTWR BREF (EC-JRC 2009), is planned to be applied to the gold metallurgical extraction process, where the efficacy of cyanide use is hindered due to the presence of copper (and similar metals such as zinc and silver). The presence of these metals causes an increase in the consumption of cyanide, a lowering of the gold recovery efficiency and also represents a sensitive environmental management issue for the extractive waste from mineral processing.

The free cyanide may then be recovered and returned to the front end of the milling process with beneficial savings. The process may be installed in the circuit of extractive waste from mineral processing prior to discharge to the pond or in the returned water circuit recovered from the dam.

According to the MTWR BREF (EC-JRC 2009), the basic flow diagram for this process consists of three parts:
- a solids removal step to provide a clean liquor for subsequent processing;
- a membrane step that concentrates the copper-cyanide complexes; this step also recovers a portion of the free cyanide;
- a metal recovery unit that deposits the copper electrolytically, thereby liberating a portion of the WAD CN as free cyanide.

3. Achieved environmental benefits
- Recovery of the free cyanide and re-use/recycling in the mineral processing.

4. Environmental performance and operational data
- No information provided.

5. Cross-media effects
- Energy consumption.

6. Technical considerations relevant to applicability
The MTWR BREF (EC-JRC 2009) states the following:
- The component technologies of the process are well tried and tested in industry.
- This technique is planned to be applied to any process stream that contains free cyanide and/or cyanide complexed with copper or similar (WAD CN). This may be either the stream of extractive waste from mineral processing prior to the dam or in the recovered water from the dam.
- This technique for recovering cyanide from extractive waste from mineral processing of gold can be easily retrofitted to existing gold plants. The feed for the process is either the extractive waste liquor or the return of extractive waste. This process provides a number of process benefits. Consumption of reagents is low compared to processes for the destruction of cyanide. Cyanide that would otherwise be lost to the circuit is able to be recovered from the extractive waste and re-used, reducing the cyanide inventory on site and also the costs of purchasing the cyanide and the cyanide destruction. Copper metal is recovered as a by-product.

- There are no limitations on the treatable cyanide WAD concentrations, although the efficiency of the process is dependent on the chemistry of the stream of extractive waste from mineral processing.

7. Economics

- Initial cost estimates show that the process is potentially very attractive compared to alternative approaches such as resin exchange processes, precipitation and acidification processes.

- There are also obvious environmental benefits. The amount of cyanide and copper in the extractive waste stream is reduced significantly prior to cyanide destruction or disposal of the extractive waste into the extractive waste deposition areas (including EWFs). This results in a reduced environmental risk to wildlife and waterways. Recovery of cyanide reduces the amount of make-up cyanide purchased, stored and handled on site, as reported in the MTWR BREF (EC-JRC 2009).

8. Driving force for implementation

- Materials and process efficiency.
- Legal and environmental requirements.
- Quality of the products.
- Economic benefits.

9. Example sites

- No information provided.

10. Reference literature

(EC-JRC 2009)

7 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

Timing of the review process

The key milestones of the review and information exchange process are summarised in the table below.

Table 7.1: Key milestones of the MTWR BREF review and information exchange process

Key milestone	Date
Reactivation of the TWG	20 November 2013
Call for initial positions	17 December 2013
Kick-off Meeting	19 to 22 May 2014
Collection of data and information	May 2014 to September 2015
Collection of site-specific data and information via the questionnaires	March 2015 to September 2015
First Working Document	29 April 2015
Second Working Document	14 September 2015
Draft 1 of the revised MTWR BREF (now the MWEI BREF)	28 June 2016
End of commenting period on Draft 1	1 November 2016
Final TWG Meeting	27 November to 02 December 2017

During the BREF review process, a total of seven site visits were organised:

- Aguas Teñidas (Spain) – underground base metals mine (18 February 2014);
- Rio Tinto (Spain) – mining legacy and re-mining project (20 February 2014);
- Cobre Las Cruces (Spain) – open-pit copper mine (25 February 2014);
- Pennsylvania (USA) – shale gas extraction and water treatment (29 September to 4 October 2014);
- Garpenberg, Boliden (Sweden) and Kittilä, Kevitsa (Finland) – metal, including gold, mines (26 September to 1 October 2016);
- San José de la Rinconada and Alcalá de Guadaira (Spain) – sand and aggregates quarries (26 January 2017).

In addition, two events were organised to improve the exchange of information:

- two webinars to discuss the comments on Draft 1 of the revised MTWR BREF:
  - on TWG comments relating to Draft Chapters 1, 2 and 3 (9 February 2017);
  - on TWG comments relating to Draft Chapter 4 (23 February 2017);
- two intermediate meetings requested by Industry and country representatives:
  - UEPG, Cembureau and IMA Europe (21 January 2017);
  - Euromines and Norway (8 March 2017).

Sources of information

The main sources of information for the review process were:

- scientific and technical literature (more than 2 000 books, reports, publications and standards consulted);
- 87 filled-in questionnaires from operators responsible for the management of extractive waste;
- 171 comments from 6 Member States and 5 Industry associations relating to both Working Documents;
- about 2 000 comments on Draft 1 of the revised BREF;
- information and data gathered from site visits;
- additional information from the TWG members;

- outcomes of the workshop and of the webinars mentioned above.

Degree of consensus reached during the information exchange
At the Final TWG Meeting, a high degree of consensus was reached on most of the BAT Conclusions and other sections of the BREF document proposed for discussion. However, seven dissenting views were expressed, two of which fulfilled the eligibility conditions set out in Section 4.6.2.3.2 of Commission Implementing Decision 2012/119/EU:

- EUROMINES, EUROMETAUX and EURACOAL suggest including the additional references from Section 5.1 into the bibliography and deleting the table in Section 5.1.
- EUROMINES, EUROMETAUX, EURACOAL, IMA-EUROPE, UEPG and Austria disagree with the TWG proposal for the introductory text to Table 4.55, without providing a sound alternative, and suggest an alternative header for Table 4.55: *"Selected examples of achieved and reported concentration ranges using BAT 45, BAT 46 and BAT 47, from a wide range of extractive waste management operations."*

The other dissenting views, which did not fulfil the conditions cited above, related to the objectives of the BREF, the preparing for re-use or recycling of liquid extractive wastes (BAT 8), closure of the access to underground extractive waste facilities and monitoring of the fracture propagation and induced seismicity resulting from pressure injection operations in oil and gas exploration and production (BAT 25 and BAT 26), as well as placing extractive waste back into excavation voids (BAT 28).

Recommendations for future work
At the Final TWG Meeting, it was clarified that the end of the technical discussions from the present review simultaneously marked the beginning of the data and information collection for a future review. TWG members, operators, researchers, permitting authorities and other stakeholders are encouraged to continuously follow the developments in the field and scientific literature and to actively contribute to expanding and improving the knowledge base on the management of extractive waste.

These efforts should also help to address a number of issues in the next review of the MWEI BREF:

- related to the representativity of the data:
  - to identify with the TWG sufficient and representative sites for the management of each type of extractive waste (extractive waste resulting from extraction of the main mineral resources);
- related to the treatment of EWIW and emissions to water:
  - to improve data collection allowing for a more in depth understanding of the links between site specific conditions (e.g. geological background) and the different applied techniques in view of determining achievable performances;
  - to collect data on total metal content in EWIW (dissolved and undissolved metals);
  - to collect information on the salt content in EWIW and its effect on the efficiency of pollutant treatment/removal (especially for biological treatments such as passive wetlands or biological reactors);
  - to collect data for several years and not only one year of reference (if possible to collect data before and after any major improvement in the extractive waste management or EWIW treatment);
  - to collect data on 95^{th} or 97^{th} percentile levels of pollutants in EWIW;
  - to collect data and information on background levels of pollutants at the specific site.

8 GLOSSARY

8.1 ISO country codes

ISO code	Country
***Member States* (*)**	
AT	Austria
BE	Belgium
BG	Bulgaria
CZ	Czech Republic
CY	Cyprus
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HU	Hungary
HR	Croatia
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
Non-member countries	
CH	Switzerland
MK	Former Yugoslav Republic of Macedonia
NO	Norway
TR	Turkey
US	United States
(*) The protocol order of the Member States is based on the alphabetical order of their geographical names in the original language(s).	

8.2 Monetary units

Code([1])	Country/territory	Currency
Member State currencies		
EUR	Euro area ([2])	euro (pl. euros)
GBP	United Kingdom	pound sterling (pl. pounds sterling)
SEK	Sweden	krona (pl. kronor)
Other currencies		
USD	United States	US dollar

([1]) ISO 4217 codes.
([2]) Includes Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia and Spain as of 1/1/2015.

8.3 Unit prefixes

Symbol	Prefix	10^n	Word	Decimal number
T	tera	10^{12}	Trillion	1 000 000 000 000
G	giga	10^{9}	Billion	1 000 000 000
M	mega	10^{6}	Million	1 000 000
k	kilo	10^{3}	Thousand	1 000
h	hecto	10^{2}	Hundred	100
da	deca	10^{1}	Ten	10
-------	-------	10^{0}	One	1
d	deci	10^{-1}	Tenth	0.1
c	centi	10^{-2}	Hundredth	0.01
m	milli	10^{-3}	Thousandth	0.001
µ	micro	10^{-6}	Millionth	0.000 001
n	nano	10^{-9}	Billionth	0.000 000 001
p	pico	10^{-12}	Trillionth	0.000 000 000 001

8.4 Units

Unit	Unit Name	Measure name	Conversion to SI units
A	ampere	Electric current	
atm	atmosphere	Pressure	1 atm = 101 325 Pa
bbl	barrel	Volume	1 bbl = 0.159 m^3
bbl/yr	barrels per year	Material consumption	See bbl and yr
Bq	becquerel	Radioactivity	
°C	degree Celsius	Temperature	[°C] = [K] — 273.15
cal	calorie	Energy	1 cal = 4.1868 J
cf	cubic feet	Volume	1 cf = 0.0283 m^3
Ci	curie	Radioactivity	1 Ci = $3.7 \cdot 10^{10}$ Bq
d	day	Time	1 d = 86400 s
D	darcy	Permeability A medium with a permeability of 1 darcy permits a flow of 1 cm^3/s of a fluid with a viscosity of 1 cP (1 mPa·s) under a pressure gradient of 1 atm/cm acting across an area of 1 cm^2.	1 D = $9.869233 \cdot 10^{-13}$ m²
dB(A)	decibel	Noise unit A logarithmically weighted sound pressure level	
°F	degree Fahrenheit	Temperature	[°F] = [K] · 9⁄5 — 459.67
ft	foot/feet	Length	1 ft = 0.3048 m
g	gram	Weight	1 g = 0.001 kg
gal	gallon	Volume	1 US gal = 0.0037854 m^3
gpd	gallons per day	Material consumption/production	See gal and d
h	hour	Time	1 h = 3 600 s
ha	hectare	Area	1 ha = 10^4 m^2
Hz	hertz	Frequency	1 Hz = 10^{-1} s
J	joule	Energy	
K	kelvin	Temperature	
kWh	kilowatt-hour	Energy	1 kWh = 3 600 kJ
l	litre	Volume	1 l = 0.001 m^3
m	metre	Length	
m^2	square metre	Area	
m^3	cubic metre	Volume	
min	minute	Time	1 min = 60 s
Nm^3	normal cubic metre	Volume at 101.3 kPa and 273.15 K	
Ω	ohm	Electrical resistance	
P	poise	Viscosity	1 P = 0.1 Pa·s
Pa	pascal	Pressure	1 Pa = 1 N/m^2
ppb	parts per billion	Composition of mixtures	
ppm	parts per million	Composition of mixtures	
ppmw	parts per million (by weight)	Composition of mixtures	1 ppmw = 10^{-6} kg/kg
ppmv	parts per million (by volume)	Composition of mixtures	1 ppmv = 10^{-6} m^3/m^3
s	second	Time	
t	metric tonne	Weight	1 t = 1 000 kg
t/d	tonnes per day	Material consumption/production	See t and d
t/yr	tonnes per year	Material consumption/production	See t and yr
V	volt	Voltage – Electric potential	
% v/v	percentage by volume	Composition of mixtures	1 % v/v = 10^{-2} m^3/m^3
% w/w	percentage by weight	Composition of mixtures	1 % w/w =10^{-2} kg/kg
W	watt	Power	
Yr	year	Time	1 yr = $3.15569 \cdot 10^7$ s

8.5 Chemical elements

Symbol	Name	Symbol	Name
Ac	Actinium	Mn	Manganese
Ag	Silver	Mo	Molybdenum
Al	Aluminium	N	Nitrogen
Am	Americium	Na	Sodium
Ar	Argon	Nb	Niobium
As	Arsenic	Nd	Neodymium
At	Astatine	Ne	Neon
Au	Gold	Ni	Nickel
B	Boron	No	Nobelium
Ba	Barium	Np	Neptunium
Be	Beryllium	O	Oxygen
Bi	Bismuth	Os	Osmium
Bk	Berkelium	P	Phosphorus
Br	Bromine	Pa	Protactinium
C	Carbon	Pb	Lead
Ca	Calcium	Pd	Palladium
Cd	Cadmium	Pm	Promethium
Ce	Cerium	Po	Polonium
Cf	Californium	Pr	Praseodymium
Cl	Chlorine	Pt	Platinum
Cm	Curium	Pu	Plutonium
Co	Cobalt	Ra	Radium
Cr	Chromium	Rb	Rubidium
Cs	Caesium	Re	Rhenium
Cu	Copper	Rf	Rutherfordium
Dy	Dysprosium	Rh	Rhodium
Er	Erbium	Rn	Radon
Es	Einsteinium	Ru	Ruthenium
Eu	Europium	S	Sulphur
F	Fluorine	Sb	Antimony
Fe	Iron	Sc	Scandium
Fm	Fermium	Se	Selenium
Fr	Francium	Si	Silicon
Ga	Gallium	Sm	Samarium
Gd	Gadolinium	Sn	Tin
Ge	Germanium	Sr	Strontium
H	Hydrogen	Ta	Tantalum
He	Helium	Tb	Terbium
Hf	Hafnium	Tc	Technetium
Hg	Mercury	Te	Tellurium
Ho	Holmium	Th	Thorium
I	Iodine	Ti	Titanium
In	Indium	Tl	Thallium
Ir	Iridium	Tm	Thulium
K	Potassium	U	Uranium
Kr	Krypton	V	Vanadium
La	Lanthanum	W	Tungsten
Li	Lithium	Xe	Xenon
Lr	Lawrencium	Y	Yttrium
Lu	Lutetium	Yb	Ytterbium
Md	Mendelevium	Zn	Zinc
Mg	Magnesium	Zr	Zirconium

8.6 Chemical formulae commonly used in this document

Chemical formula	Name
$AlCl_3$	Aluminium chloride
$Al_2(SO_4)_3$	Aluminium sulphate
AsO_4^{3-}	Arsenate
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide, also called lime or quicklime
$Ca(OH)_2$	Calcium hydroxide, also called slaked lime or hydrated lime
CN^-	Cyanide
CO_2	Carbon dioxide
CO_3^{2-}	Carbonate
CN^-	Cyanide
$CuSO_4$	Copper sulphate
KCl	Potassium chloride
KOH	Potassium hydroxide. Also called caustic potash
$Fe(CN)_6^{4-}$	Ferrocyanide
$FeCl_3$	Ferric chloride
$Fe_2(SO_4)_3$	Ferric sulphate
HCO_3^-	Hydrogen carbonate
H_2O	Water
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
$MgCl_2$	Magnesium chloride
$MgCO_3$	Magnesium carbonate
MgO	Magnesium oxide
$Mg(OH)_2$	Magnesium hydroxide
NaCl	Sodiun chloride
Na_2CO_3	Sodium carbonate. Also called soda ash
NaHS	Sodium hydrosulfide
NaOH	Sodium hydroxide. Also called caustic soda
Na_2S	Sodium sulphide
$Na_2S_2O_5$	Sodium bisulphite
NH_3	Ammonia
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_X	The sum of nitric or nitrogen (II) oxide (NO) and nitrogen dioxide (NO_2) expressed as NO_2
OCN^-	Cyanate
S^{2-}	Sulphide
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphate
SO_X	The sum of sulphur dioxide (SO_2) and sulphur trioxide (SO_3) expressed as SO_2

8.7 Acronyms and technical definitions

Where a reference is added, it refers to a definition from EU legislation cited further (after the last table entry). In case of doubt, the definition provided by EU legal instruments will prevail. The list below complements the list of definitions provided in Article 3 of Directive 2006/21/EC (Extractive Waste Directive).

The superscript (HC) stands for hydrocarbons. Definitions for these terms refer specifically to those used in the hydrocarbon extractive industry.

A	
Abandonment	Of an extractive waste facility (EWF) (correct use): EWF for which an owner/responsible party/licensee can no longer be identified and/or which has not been closed in a regulated manner. This is the correct use of abandonment as used in the MWEI BREF. Of a well$^{(HC)}$ (confusing use, to be avoided): to permanently close a well, usually after determining that there is insufficient hydrocarbon potential to complete the well, or after production operations have drained the reservoir. An abandoned well is plugged with cement to prevent the escape of methane to the surface or nearby aquifers. This nomenclature, although frequently used in the hydrocarbon industry, may be confusing and has been replaced by closure in the MWEI BREF.
Acid	Proton donor. A substance that, more or less readily, gives off hydrogen ions in a water solution.
Acid fracture$^{(HC)}$	A hydraulic fracturing technique using a hydrochloric acid treatment performed in carbonate formations to etch the open faces of induced fractures.
Acid generation	Production of acidity irrespective of its effect on the adjacent pore water or whether the material is net acid-producing or -neutralising.
Acid Mine Drainage (AMD), Acid Rock Drainage (ARD)	Acidic drainage stemming from open-pit underground extraction operations and EWF that contains free sulphuric acid and dissolved metals sulphate salts resulting from the oxidation of contained sulphide minerals or additives to the process. The acid dissolves minerals in the rocks, further changing the quality of the drainage water.
Acid Potential (AP)	Maximum potential acid generation from a sample. The calculation of AP (or MPA) is an integral part of acid/base accounting
Acid wash$^{(HC)}$	Wellbore acid treatment designed to remove scale or similar deposits from perforations and well-completion components. Acid-wash treatments do not include injection of treatment fluid into the reservoir formation.
Acidity	Measure of the capacity of a solution to neutralise a strong base.
AEP	Annual Exceedance Probability.
Aeration	The act of mixing a liquid with air (oxygen).
Aerobic process	A biological process that occurs in the presence of oxygen.
Air classifier	Machine equipment to separate dust (< 0.05 mm) fine particles from the dry input material (< 10 mm) or equipment to remove fine and coarse fractions from an air stream.
After-closure/ aftercare	Phase following the closure of an EWF, during which the latter is managed to prevent or reduce as far as possible adverse effects on the environment and human health.
ALD	Anoxic Limestone Drain.
Alkali	Proton acceptor. A substance that, more or less readily, takes up hydrogen ions in a water solution.
Alkalinity	Measure of the capacity of a solution to neutralise a strong acid.
AMD	Acid Mine Drainage.
Anaerobic process	A biological process which occurs in the absence of oxygen.
Angle of repose	The maximum slope at which a heap of any loose or fragmented solid material will stand without sliding or come to rest when poured or dumped in a pile or on a slope.
Annulus or annular space$^{(HC)}$	Space between casing and the wellbore, or between the tubing and casing or wellbore, or between two strings of casing.
Anticline	A downward-curving (convex) fold in rock that resembles an arch. The central part, being the most exposed to erosion, displays the oldest section of rock.
AP	Acid Potential.
Aquifer	A zone of permeable, water-saturated rock material below the surface of the earth capable of producing significant quantities of water.
ARD	Acid Rock Drainage.
Associated structures	All structures, components and facilities functionally pertaining to the dam, including, but not limited to, spillways, decant towers and pipelines, reclaim pumps, water conduits, diversion structures, etc.

Autogenous Grinding (AG)	A method of grinding rock (ore) into a fine powder using large pieces or pebbles of the ore being ground as a grinding medium instead of conventional steel balls or rods.
B	
BAF	Biological Aerated Filter.
Baryte	Mineral form of barium sulphate. An additive used to increase drilling fluid density.
BAT [(b)]	Best Available Techniques: The most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole: (i) "techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned; (ii) "available techniques" means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced in the Member State in question, as long as they are reasonably accessible to the operator; (iii) "best" means most effective in achieving a high general level of protection of the environment as a whole.
BCR	BioChemical Reactor.
Beach	Area of extractive waste from mineral processing, resulting from the settled solid fraction of a slurried extractive waste in a pond not covered by free water between the edge of the free water and the crest of the dam.
Beneficiation	See "mineral processing".
BGM	Bituminous GeoMembrane.
Bioavailability	Property of a substance which makes it accessible and potentially able to affect an organism's health. Depends on site-specific conditions.
Biocide	A substance that kills (micro)organisms.
Biodegradable	Substances that that can be broken down physically and/or chemically by microorganisms. For example, many chemicals, food scraps, cotton, wool and paper are biodegradable.
Biodiversity	The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.
Bioremediation	The use of living organisms, e.g. bacteria or plants, to clean up oil spills or remove other pollutants from soil, water and waste water.
Biota	All living organisms in a given area.
Blending	Mixing of the raw material to get input material with a steady quality for subsequent processes.
Blowout[(HC)]	An uncontrolled flow of gas, oil or water from a well, during drilling, when high formation pressure is encountered.
Blowout preventer[(HC)]	A valve device placed on the top of the well, which can be closed. It is a safety feature used in case the drill enters an overpressure formation which could result in the entire drill string being blown out of the well.
Biological Oxygen Demand or Biochemical Oxygen Demand (BOD)	Parameter used to assess the pollution of water by organic matter. Biochemical Oxygen Demand is measured by the quantity of dissolved oxygen required by microorganisms in order to decompose organic matter. The unit of measurement is mg O_2/l. In Europe, BOD is usually measured after 3 (BOD_3), 5 (BOD_5) or 7 (BOD_7) days. BOD_5 is the one used in EU environmental legislation.
Best Management Practice (BMP)	Current state-of-the-art mitigation measures, to help ensure that development is conducted in an environmentally responsible manner.
BOD	Biological Oxygen Demand
Brackish water	Water with a salinity level between that of fresh water and seawater, often encountered at the mouth of rivers.
BRDA	Bauxite Residue Disposal Area.

Breaker(HC)	A chemical used to reduce the viscosity of a fluid (break it down) after the thickened fluid has finished the task it was designed for.
BREF	Best available techniques REFerence document.
Brine	Water containing elevated levels of dissolved solids such as salts.
BTEX	Benzene, Toluene, Ethylbenzene and Xylene.
Buffer agent	A weak acid or base used to maintain the pH of a solution at or close to a chosen value.
By-product	According to Article 5(1) of the Waste Framework Directive 2008/98/EC, a by-product is defined as follows: A substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as being a by-product only if further use of the substance or object is certain *and* the substance or object can be used directly without any further processing other than normal industrial practice *and* the substance or object is produced as an integral part of a production process *and* further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.
C	
CAPEX	CAPital EXPenditure.
Casing(HC)	Large steel pipe used to "seal off" or "shut out" water and prevent caving of loose gravel formations when drilling a well. When the casings are set and cemented, drilling continues through and below the casing with a smaller bit. The overall length of this casing is called the casing string. More than one string inside the other may be used in drilling the same well.
Cellar(HC)	A dug-out area lined with cement or very large diameter (1.8 m) pipe section, located below the drill rig in which the conductor is set.
Cementation	The precipitation of a more noble metal from solution by the introduction of a less noble metal. Used for instance in the Merrill-Crowe process to recover gold from a cyanide solution by cementation with zinc particles.
CEN/TC	European Committee for Standardization / Technical Committee.
CEN/TR	European Committee for Standardization / Technical Report.
CEN/TS	European Committee for Standardization / Technical Specification.
Centrifuge	Device that uses centrifugal force to separate substances or fluids of varying densities.
Coal-bed methane (HC)	Natural gas trapped in coal seams that can be extracted by similar methods to those used for shale gas. The term refers to methane adsorbed onto the solid matrix of the coal.
Chemical additive	A product composed of one or more chemical constituents that is added to a primary carrier fluid to modify its properties.
Chemical constituent	A discrete chemical with its own specific name or identity, such as a CAS Number.
Chemical Oxygen Demand (COD)	Chemical Oxygen Demand indicates the amount of chemically oxidisable organic matter in waste waters (normally referring to analysis with dichromate oxidation).
CLM BREF	Best available techniques Reference document for Production of Cement, Lime and Magnesium Oxide http://eippcb.jrc.ec.europa.eu/reference/cl.html
Closed waste facility	A closed waste facility is an EWF where extraction activity has ceased. It has an identified former owner or licensee and has been closed in accordance with former licences or regulations.
Closure of a waste facility	Final decommissioning of the EWF, including rehabilitation.
COD	Chemical Oxygen Demand
Comminution	Size reduction of an ore by crushing and/or grinding to such a particle size that the product is a mixture of relatively clean particles of mineral and gangue. In order to produce a relatively pure concentrate, it is necessary to grind the ore fine enough to liberate the desired minerals.
Compaction	Process resulting in a reduction in volume. The change typically results from externally applied loads, creating tighter packing of the solid particles. In fine soils in particular, this requires an egress of pore water. Greater compaction often results in increased consolidation.

Competent soil	Competent soils are soils that resist settlement and would not continue to compress when bearing the weight of typical project components.
Completion(HC)	The activities and methods of preparing a well for production after it has been drilled to the objective formation. This principally involves preparing the well to the required specifications; running in production tubing and its associated downhole tools, as well as perforating and stimulating the well by the use of hydraulic fracturing, as required.
Compressor	A facility which increases the pressure of a gas to move it in pipelines or into storage.
Concentrate	Marketable product after separation in a mineral processing plant with an increased grade of the valuable mineral.
Condensate(HC)	Liquid hydrocarbons that were originally in the reservoir gas and are recovered by surface separation.
Conductor(HC)	The casing string that is usually put into the well first, particularly in land wells, to prevent the sides of the hole from caving into the wellbore.
Cone crusher	A piece of equipment, similar in operation to a gyratory crusher, for reducing the size of materials by means of a truncated cone revolving on its vertical axis within an outer chamber, the annular space between the outer chamber and cone being tapered.
Corrosion inhibitor	A chemical substance that minimises or prevents corrosion in metal equipment.
CPTU	Cone penetrometer.
Cross-media effects	The calculation of the environmental impacts of water/air/soil emissions, energy use, consumption of raw materials, noise and water extraction.
Crushing	Comminution process that reduces the particle size of ore to such a level that grinding can be carried out. Usually, this is accomplished by compression of ore against rigid surfaces, or by impact against surfaces in a rigidly constrained motion path.
Cut-off grade	The minimum ore grade that can be extracted and processed at a profit under economic conditions. The calculation of the cut-off grade is based on a cost-benefit analysis. The cut-off grade is used to determine the mineral reserves.
Cut-off trench	An impermeable wall, collar, or other structure placed beneath the base or within the dam to prevent or reduce losses by seepage along a construction interface or through porous or fractured strata. It may be made of concrete, compacted clay, interlocking sheet piling, or grout injected along a line of holes.
Cyanidation	Method of extracting gold or silver from crushed or ground ore by dissolution in a weak solution typically of sodium but also potassium or calcium cyanide. Also known as cyanide leaching. The precious metals are then recovered from the pregnant solution: ▪ either by precipitation on zinc dust (Merrill-Crowe process), ▪ or by adsorption on activated carbon in a column (carbon in leach (CIL)) or within the pulp (carbon in pulp (CIP)).
CWW BREF	Best available techniques Reference document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector - http://eippcb.jrc.ec.europa.eu/reference/cww.html
D	
D_{10}, D_{50}, D_{80}, D_{90}	A value often used in mineral processing to describe particle size distribution. It indicates the particle size at which 10 %, 50 %, 80 % or 90 % of the sample are smaller than a given size.
Dam (a)	An engineered structure designed to retain or confine water and/or slurry within a pond.
DCT	Deep Cone Thickener
Decant lines	Pipelines used to transport EWIW decanted from the pond containing extractive waste from mineral processing through, above or around the dam retaining extractive waste from mineral processing to a downstream collection point.
Decant tower	Intake structure that is raised as the pond rises. The decant tower skims off the decanted (clear) water from the surface of the pond and carries it away using decant lines.

Decommissioning	Process to remove something from service, in particular process by which an extractive operation is shut down. Decommissioning may be temporary, e.g. due to unfavourable market conditions, or final (see also "closure").
Dewatering	Process of removing water from an underground mine or open pit, or from the surrounding rock or non-lithified area. The term is also commonly used for the reduction of water content in concentrates, extractive waste from mineral processing and treatment sludge. In hydrocarbon extraction, dewatering may refer to removing water from water-based drilling muds and cuttings.
Diffuse emission	Emissions arising from direct contact of volatile or light dusty substances with the environment (atmosphere, under normal operating circumstances). These can be related to: ▪ inherent design of the equipment (e.g. filters, dryers); ▪ operating conditions (e.g. during transfer of material between containers); ▪ type of operation (e.g. maintenance activities); ▪ or a gradual release to other media (e.g. to cooling water or waste water). Fugitive emissions are a subset of diffuse emissions.
Diffuse sources	Sources of similar diffuse or direct emissions which are multiple and distributed within a defined area.
Directional drilling(HC)	Deviation of the borehole from vertical so that the borehole penetrates a productive formation in a manner parallel to the formation, although not necessarily horizontally.
Dip	The angle at which a structure or rock bed is inclined from the horizontal as measured at right angles to the strike and in the vertical plane
Disposal well	A well into which waste fluids can be injected deep underground for safe disposal.
Diversions	For ponds, diversions are usually relatively small interceptor ditches that collect run-off from the contributing watershed and divert it downstream beyond the pond and dam.
DO	Dissolved Oxygen.
DOC	Dissolved Organic Carbon.
Drainage	Natural or artificial removal of surface and subsurface water from an area, including surface streams and groundwater pathways.
Drainage chemistry	Concentrations of dissolved components in drainage water, including element concentrations, chemical species and other aqueous chemical parameters.
Drainage water	EWIW that is collected via a drainage operation.
Drill cuttings(HC)	Particles generated by drilling into subsurface geological formations and carried to the surface with the drilling fluid.
Drilling fluid or drilling mud(HC)	Mud, water, or air pumped down the drill string which acts as a lubricant for the bit and is used to carry rock cuttings back up the wellbore. It is also used for pressure control in the wellbore.
DSTD	Deep Sea Tailings Disposal
Dust	Solid particles with a size ranging from submicroscopic to macroscopic of any shape, structure or density, dispersed in the gas phase (e.g. in air).
E	
EC	European Commission.
ec	Electrical conductivity.
Ecosystem	The system composed of interacting organisms and their environments.
EEA	European Environment Agency.
ECM BREF	Reference document on Economics and Cross-media Effects http://eippcb.jrc.ec.europa.eu/reference/ecm.html
Ed	Design effect of the loads.
Effluent	Physical fluid (air or water together with contaminants) forming an emission.
EFS BREF	Best available techniques Reference document for Emissions from Storage http://eippcb.jrc.ec.europa.eu/reference/esb.html
EIA	Environmental Impact Assessment.
EIPPCB	European IPPC Bureau.
Electrostatic separation	Common term for all separation technologies utilising electric forces acting on charged or polarised particles in a static electric field.
EMAS	EU Eco-Management and Audit Scheme.

Emerging technique [(b)]	A novel technique for an industrial activity that, if commercially developed, could provide either a higher general level of protection of the environment or at least the same level of protection of the environment and higher cost savings than existing Best Available Techniques.
Emission [(b)]	The direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources into the air, water or land.
EMS	Environmental Management System.
Emulsion	A stable, heterogeneous mixture of two or more liquids (which are not normally dissolved in each other held in suspension or dispersion, one in the other, by mechanical agitation or, more frequently, by the presence of small amounts of substances known as emulsifiers. Emulsions may be oil-in-water, or water-in-oil.
EN	European Standard.
End-of-pipe technique	A technique that reduces final emissions or consumption by some additional process but does not change the fundamental operation of the core process. Synonyms: "secondary technique", "abatement technique". Antonyms: "process-integrated technique", "primary technique" (a technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumption).
ENE BREF	Best available techniques Reference document for Energy Efficiency http://eippcb.jrc.ec.europa.eu/reference/ene.html
Environment	Interrelated physical, chemical, biological and social components that affect the growth and development of living organisms.
EOP	End-Of-Pipe.
Erosion	Detachment and subsequent removal of either rock or surface material by wind, rain, wave action, freezing, thawing and other processes.
EU	European Union.
EU-28	Member States of the European Union on 1 July 2013.
Eutrophication	The deterioration of the quality of a water body, as a consequence of enrichment by nutrients (especially compounds of nitrogen and/or phosphorus such as those in sewage, fertilisers washed from the land, and industrial wastes). These compounds accelerate the growth of algae and higher forms of plant life, which results in a reduction of the oxygen content and in an undesirable disturbance of the balance of organisms present in the water.
Evaporation	Physical process by which a liquid is changed into a gas.
EWF	Extractive Waste Facility. See "waste facility" [(a)].
EWIW	Extractive Waste Influenced Water. Any water whose chemical or biological composition has been affected by coming into contact with extractive waste. It includes water contained in or stemming from extractive waste deposition areas (including extractive waste facilities).
EWMP	Extractive Waste Management Plan. See "Waste Management Plan" [(a)].
Excess water	Surplus of water generated in a process. It may include reclaim water (see definition), discharged EWIW or flowback and produced water resulting from oil and gas exploration and production.
Existing operation	Any installation that was in operation, in accordance with legislation existing, before the date of the entry into force of Directive 2006/21/EC, or any installation that was authorised, or that was to be authorised following a request to the competent authority, and that was to be put into operation within one year after the date of the entry into force of Directive 2006/21/EC.
Exploration	Drilling into a prospect and all related oil and gas operations necessary prior to production-related operations.
Exploratory well[(HC)]	A well drilled either in search of an as-yet-undiscovered pool of oil or gas (a wildcat well) or to greatly extend the limits of a known pool. It involves a relatively high degree of risk. Exploratory wells may be classified as (1) wildcat, drilled in an unproven area; (2) field extension or step-out, drilled in an unproven area to extend the proved limits of a field; or (3) deep test, drilled within a field area but to unproven deeper zones.

Extraction methods	Extraction methods include: ▪ open-pit (open-cast) mining; ▪ underground extraction; ▪ solution mining; ▪ quarrying; ▪ drilling boreholes.
Extractive industries [a]	All establishments and undertakings engaged on surface or underground extraction of mineral resources for commercial purposes, including extraction by drilling boreholes, or treatment of the extracted material.
Extractive waste [a]	Waste resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries, but excluding: ▪ waste which is generated by the prospecting, extraction and treatment of mineral resources and the working of quarries, but which does not directly result from those operations; ▪ waste resulting from the offshore prospecting, extraction and treatment of mineral resources; ▪ injection of water and reinjection of pumped groundwater as defined in the first and second indents of Article 11(3)(j) of Directive 2000/60/EC, to the extent authorised by that Article.
Extractive waste site	Parts of the site where extractive waste is managed.
Extractive waste deposition area	Any area under the responsibility of an operator where extractive waste is handled, treated, accumulated or deposited whether in a solid or liquid state or in solution or suspension. This includes, but is not limited to, Extractive Waste Facilities, excavation voids where extractive waste is placed back, and areas for temporary storage of extractive waste.
Extractive Waste Facility (EWF)	See "waste facility" [a].
EWIW recovery dam	Small water retention dam located downstream of the main dam constructed using extractive waste, whose purpose is to intercept and collect EWIW flowing through the dam.
Extractive waste line	Pipeline used to carry the extractive waste from the mineral processing plant to the pond.
Extractive waste sand	Sand obtained from the total extractive waste from mineral processing for use in construction of the dam. Often produced by cycloning the total extractive waste from mineral processing.
F	
Facility	A physical entity that facilitates a certain (industrial) operation. Note that *waste facility* is specifically defined by Directive 2006/21/EC (see "waste facility").
Fault	A fracture or fracture zone along which there has been displacement of the sides relative to each other.
Field[HC]	The general area underlain by one or more pools.
Flaring[HC]	Controlled burning of natural gas. The process is typically used as an alternative to venting, e.g. during the well completion phase.
Flashing	Evaporation of volatile substances due to a reduction in pressure.
Flocculant	Substance that causes suspended particles to aggregate or clump. Flocculants are used to aggregate small particles whose slow settling or lifting rate makes them otherwise very difficult to remove from the surrounding liquid. The larger particle size of the aggregated clumps ensures a faster settling or lifting to the surface.
Flotation	A form of separation of minerals from gangue based on their different surface reaction to certain reagents (or alternatively based on the interfacial chemistry of mineral particles in solution). Reagents are used to adhere to the target mineral, and render its surface hydrophobic. The target mineral then rises to the top of the flotation cell with the injected air, where it can be collected as a froth. When the aim is to float the gangue this process is called reverse flotation.

Flowback(HC)	Generally defined as "fluid returned to the surface after hydraulic fracturing has occurred, but before the well is placed into production". It typically consists of returned fracturing fluids following hydraulic fracturing which are progressively replaced by produced water". (AEA 2012) According to the US EPA, "flowback," is a subset of produced water. The definition of flowback is not considered to be standardised. Generally, the flowback period in shale gas reservoirs is several weeks (URS Corporation, 2009).
FMP BREF	Best available techniques Reference document for Ferrous Metals Processing Industry http://eippcb.jrc.ec.europa.eu/reference/fmp.html
Fold	A bend in rock strata.
Formation	A rock body distinguishable from other rock bodies and useful for mapping or description. Formations may be combined into groups or subdivided into members.
Fossil fuel	A natural fuel such as coal or gas, formed in the geological past from the remains of living organisms.
Fracking(HC)	Informal abbreviation for "hydraulic fracturing".
Fracking/fracturing fluid(HC)	See "hydraulic fracturing".
Free CN	The cyanide not combined in complex ions, both the molecular HCN and the cyanide ion [24, British Columbia CN guide, 1992].
Free water	The area of water held on a pond above the settled extractive waste, normally removed by pumping or decanting.
Freeboard	Vertical distance (height) between the normal maximum operating level of a pond and the crest of the dam, the purpose of which is to provide attenuation capacity in times of flood or a sudden ingress of water.
Friction angle, angle of friction	The angle between the perpendicular to a surface and the resultant force acting on a body resting at the surface, at which the body begins to slide.
Friction reducer, friction reducing agent	A chemical additive which alters the hydraulic fracturing fluid allowing it to be pumped into the target formation at a higher rate and reduced pressure.
Fugitive emission	Emissions which leave a process as a result of lack of containment or of containment failure. Example of fugitive emissions: leak from a flange, a pump, a sealed or tightened equipment.
G	
Gangue	The part of an ore that is not economically desirable but cannot be avoided in mining (see Figure 8.1).
GARD Guide	Global Acid Rock Drainage Guide.
GCL	Geosynthetic Clay Liner
GEO	Geotechnical limit states.
Geochemistry	Science of the chemistry of geological materials and the interaction between geological materials with the environment.
Geology	Study of the earth, its history and the changes that have occurred or are occurring, and the rocks and non-lithified materials of which it is composed and their mode of formation and transformation.
Geothermal well	A well drilled to explore for or produce heat from the subsurface.
GHG	GreenHouse Gas.
GM	GeoMembrane.
Grade	Dimensionless proportion of any constituent in an ore, expressed often as a percentage, grams per tonne (g/t) or parts per million (ppm).
Green completion	See "Reduced Emissions Completion".
Grinding	Comminution process yielding a fine product (< 1 mm), where size reduction is accomplished by abrasion and impact and sometimes supported by the free motion of unconnected media such as rods, balls and pebbles.
Groundwater(c)	All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.
Grout curtain	An area into which grout (a pumpable cement slurry) has been injected to form a barrier around an excavation or under a dam through which groundwater cannot seep or flow.
GT	GeoTextiles.

Gyratory crusher	A primary crusher consisting of a vertical spindle, the foot of which is mounted in an eccentric bearing within a conical shell. The top carries a conical crushing head revolving eccentrically in a conical maw.
H	
Hazardous waste	According to Article 3(2) of the Waste Framework Directive 2008/98/EC, defined as waste which displays one or more of the hazardous properties listed in Annex III to that Directive.
Hazardous substance	Substance or mixture as defined in Article 3 of Regulation (EC) 1272/2008 on classification, labelling and packaging of substances and mixtures.
HAZOP	HAZard and OPerability.
HDPE	High-Density PolyEthylene.
HDS	High-Density Sludge.
Heap [(a)], heap-type	An engineered facility for the deposit of solid waste at the surface.
High-Volume Hydraulic Fracturing (HVHF)[(HC)]	The stimulation of a well (normally a shale gas well using horizontal drilling techniques with multiple fracturing stages) with high volumes of fracturing fluid. Defined as fracturing using 1 000 m^3 of water or more per stage as the base fluid in fracturing fluid.
Horizontal drilling[(HC)]	Deviation of the borehole from vertical so that the borehole penetrates a productive formation with horizontally aligned strata, and runs more or less horizontally.
Hydraulic fracturing[(HC)]	The process by which fracturing fluids – a mixture consisting primarily of water, sand and a small percentage of chemical substances (generally between 0.5 % and 2 %) are injected under high pressure into a geological formation that contains hydrocarbons so as to break the rock and to connect the pores that trap the hydrocarbons. As the injection pressure exceeds the rock strength, the process results in the opening or enlargement of fractures. Injected sand prevents these fractures from closing after the pumping pressure is released, thereby enabling natural gas and oil to flow from the geological formation into the well. Once the hydraulic fracturing process is completed, roughly 30 % to 70 % on average of the initial fracturing fluids (depending on geological conditions), now mixed with fluids displaced from the geological formation, rises to the surface where it can be collected.
Hydraulic fracturing fluid[(HC)]	Fluid used to perform hydraulic fracturing; includes the primary carrier fluid, proppant material, and all applicable additives.
Hydraulic gradient	Difference in hydraulic head between two points divided by the travel distance between the points.
Hydrocarbon	Organic compound consisting entirely of carbon I and hydrogen (H). In the oil and gas industry, hydrocarbon is often used as a collective term for mineral oils and natural gas, plus their precursors, even when these contain compounds with other elements (such as O, S and N).
Hydrogeology	Hydrogeology deals with the distribution and movement of groundwater in the soil and rocks of the earth's crust.
Hydrology	Science of the occurrence, circulation, distribution, movement, chemical and physical properties and reaction with the environment of all water.
Hydrometallurgy	Process for the recovery of metals from ores or other materials by means of aquatic chemistry techniques.
I	
ICOLD	International Commission on Large Dams.
IED	Industrial Emissions Directive (2010/75/EU).
Igneous rock	Rock formed when molten rock (magma) has cooled and solidified (crystallised).
Impact crusher	In impact crushers, material comminution is accomplished primarily through the impact action of beaters, which hit the pieces of rock free-falling through the crusher chamber and throw them against stationary surfaces at high speed.
Impermeable	Hydraulic conductivity $\leq 10^{-9}$ m/s.
Incineration (of waste)	Incineration is a high-temperature combustion/oxidation process in which organic wastes are converted into gases and solid residue. Incineration objectives usually include reducing toxicity and volume prior to disposal of solid residues.

Industrial minerals	Non-metallic ore, non-fuel or non-gemstone rock, mineral or non-lithified material of economic value. Industrial minerals are primarily used for construction or in chemical and manufacturing industries. Examples include but are not limited to barytes, borate, feldspar, fluorspar, kaolin, limestone, phosphate, potash, strontium, and talc.
Inert waste [(a)]	Waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater.
Infiltration	Entry of water into a porous substance.
Injection well[(HC)]	A well through which fluids are injected into an underground stratum to increase reservoir pressure and to displace oil, or for disposal of produced water and other wastes.
Integrated design	A design that takes into account all the relevant parameters in order to optimise the overall environmental, human health and safety aspects of a project in the short and long term.
Interburden	Layer of natural materials lying between two or more bedded orebodies, usually coal seams. Term used primarily in strip mining.
IPPC	Integrated Pollution Prevention and Control.
IS BREF	Best available techniques Reference document for Iron and Steel Production http://eippcb.jrc.ec.europa.eu/reference/i&s.html
ISO	International Organisation for Standardisation.
ITRC	Interstate Technology and Regulatory Council
J	
Jaw crusher	A machine for reducing the size of materials by impact or crushing between a fixed plate and an oscillating plate.
Jig	Equipment in which materials are separated in a continuous flow according to their different densities.
K	
L	
Lagoon	See "pond".
LCM	Life Cycle Management.
Leachate [(a)]	According to Directive 2006/21/EC: any liquid percolating through the deposited waste and emitted from or contained within an EWF, including polluted drainage, which may adversely affect the environment if not appropriately treated. More generally: any liquid having percolated through a porous material and loaded with extracted solutes or suspended solids. Leachate may refer to polluted drainage, but it may also be generated on purpose, e.g. for the recovery of metals (see "leaching").
Leaching	Extraction of soluble components from raw materials by the action of a percolating liquid (e.g. water). For example, gold can be extracted by heap leaching of a porous ore, or pulverised extractive waste from mineral processing. Other methods are tank leaching of ore, concentrates or extractive waste from mineral processing and *in-situ* leaching. Leaching may also be an unwanted process leading to polluted drainage (see "leachate"). Bio-leaching is a particular form of leaching involving living organisms.
Liberation	Release of the valuable mineral(s) from the gangue at the coarsest possible particle size.
Life cycle of an extractive waste deposition area (including the EWF)	The life cycle of an extractive waste deposition area includes: the planning and design phase, the operational phase (construction, management and maintenance), the closure and after-closure phase.
Limestone	A sedimentary rock consisting chiefly of calcium carbonate ($CaCO_3$).

Liquefaction	Phenomenon that occurs in loose saturated soils usually when the excess pore water pressure (e.g. caused by an earthquake) becomes equal to the original confining pressure and the soil behaves like a dense fluid, unable to resist significant shear stresses.
Lithology	Composition of rocks, including physical and chemical characteristics such as colour, mineralogical composition, hardness and grain size.
LLDPE	Linear Low-Density PolyEthylene
Long-term phase	There are no commonly accepted definitions for the long-term phase. According to the literature review, it often refers to the after-closure phase. For example, the following reference time is provided in the Guidance document for a risk-based preselection protocol for the inventory of closed waste facilities: long term > 10 years (EC-DG ENV 2011). Period of time required, after the end of the rehabilitation phase, for the extractive waste to become sufficiently inert that it no longer poses any problems to the environment.
Low-grade ore	Ore that is relatively deficient in the target metals/minerals. A term usually used for materials that could be ore under favourable economic conditions. See also "waste-rock".
Low-permeable	Hydraulic conductivity $> 10^{-9}$ - $< 10^{-7}$ m/s.
Lysimeter	Device for collecting water from the pore spaces of soils and for determining the soluble constituents removed in the drainage.
M	
Make-up water	For hydrocarbon extraction: water in which proppant and chemical additives are mixed to make fracturing fluids for use in hydraulic fracturing. In general: water added to a process to start or maintain a reaction, prepare a solution, mix reagents or dilute reagents.
Major accident [(a)]	An occurrence on site in the course of an operation involving the management of extractive waste in any establishment covered by Directive 2006/21/EC, leading to serious danger to human health and/or the environment, whether immediately or over time, on site or off site.
Maximum Credible Earthquake (MCE)	Hypothetical earthquake that could be expected from the regional and local potential sources for seismic events and that would produce the severest vibratory ground motion at the site.
MBBR	Moving Bed Biofilm Reactor.
MED	Multiple-Effect Distillation
MEND	Mine Environmental Neutral Drainage program http://mend-nedem.org/default/
Metamorphic rock	A rock that has undergone chemical or structural changes produced by an increase in heat or pressure, or by replacement of elements by hot, chemically active fluids.
Milling	Operation during which ore is treated for the recovery and/or concentration of valuable minerals prior to shipment to a smelter or refinery. Milling processes include crushing, grinding, screening, concentration and dewatering. At a coal mine, the mill is referred to as a wash plant, tipple or cleaner.
Mine	Area under the control of an operator where mining occurs (see "mining"), including common related infrastructure and waste management activities. Examples of mines include but are not limited to the extraction of coal, iron, copper, zinc, silver and gold.
Mine production	For metals, the amount of metal in the concentrate after production; in all other cases, unless stated otherwise, the amount of concentrate by weight after mineral processing.

Mineral processing (also beneficiation or benefication, ore dressing, mineral dressing, milling)	Processes to produce marketable mineral products (e.g. concentrates) from mineral resources. This is usually carried out on the mine or quarry site, the plant being referred to as the mineral processing plant (mill or concentrator). The essential purpose is to reduce the bulk of the ore, which must be transported to and processed by subsequent processes (e.g. smelting), by using methods to separate the valuable (desired) mineral(s) from the gangue. The marketable product of this is called concentrate, the remaining material is called extractive waste from mineral processing (e.g. tailings). Mineral processing includes various procedures that rely on the mineral's physical characteristics (i.e. particle size, density, magnetic properties, colour) or physico-chemical properties (surface tension, hydrophobicity, wettability).
Mineral processing plant	Facility where mineral processing is carried out.
Mineral resource or mineral [(a)]	A naturally occurring deposit in the earth's crust of an organic or inorganic substance, such as energy fuels, metal ores, industrial minerals and construction minerals, but excluding water.
Mining	Any activity involved in the prospecting, extraction, treatment and storage of solid mineral resources originating from deposits in the earth's crust, other than construction minerals.
Mining operation	Any extraction of ore from which mineral substances are taken, where the corporate intent is to make an operating profit or build continuously toward a profitable enterprise.
Mitigation	Measures taken to avoid, control or reduce the severity of adverse physical, chemical, biological and/or socio-economic impacts entailed by (or caused by) (human) activity.
Monitoring	The systematic surveillance of the variations of a certain chemical or physical characteristic of an emission, discharge, consumption, equivalent parameter or technical measure, etc. The monitoring is based on repeated measurements or observations, at an appropriate frequency in accordance with documented and agreed procedures, and is done to provide useful information. This information may range from simple visual observations to specific numerical data. The information can be used for several different purposes, including for a surveillance of the correct operation of the plant processes, as well as for allowing better decision-making about industrial operations.
MSF	Multi Stage Flash distillation.
MTWR BREF	Best available techniques Reference document for Management of Tailings and Waste-rock.
Mud[(HC)]	See "drilling fluid".
Muck	Ore or waste-rock that has been broken apart usually by blasting.
MWEI	Management of Waste from Extractive Industries
N	
NAG	Non-Acid Generating.
Net AG	Net Acid Generation.
Net NP	Net Neutralisation Potential (NP-AP).
Neutralisation	Raising the pH of acidic solutions or lowering the pH of alkaline solutions to near-neutral pH (about pH 7) values through a reaction in which the hydrogen ion of an acid and the hydroxyl ion of a base combine to form water.
Neutralisation/ Precipitation	Chemical precipitation process in which the pH of an acidic EWIW containing dissolved metals is raised by addition of basic materials, in one or more steps, in order to precipitate dissolved substances such as metals. The pH is raised to a range from pH 5 up to pH 11 depending on targeted metals (e.g. to precipitate dissolved zinc, higher pH are necessary).
Neutralisation Potential (NP)	General term for a sample's or a material's capacity to neutralise acidity.
NFM BREF	Best available techniques Reference document for Non-Ferrous Metals Industries http://eippcb.jrc.ec.europa.eu/reference/nfm.html
NI	No Information.
NMD	Neutral Mine Drainage.

Non-Aqueous drilling Fluid (NAF)(HC)	A drilling fluid in which the continuous phase is a water-immiscible oleaginous fluid (e.g. diesel oil, mineral oil, enhanced mineral oil, paraffinic oil, or synthetic material such as olefins and vegetable esters) and water or brine is the dispersed phase. Non-aqueous fluids may be classified according to their aromatic hydrocarbon content (Group I: high-aromatic content fluids; Group II: medium-aromatic content fluids; Group III: low/negligible-aromatic content fluids).
NORMs	Naturally Occurring Radioactive Materials. Radionuclides occurring naturally in ores, soils, water, or other natural materials.
NP	Neutralisation Potential.
NPR	Neutralisation Potential Ratio (NPR=NP/AP).
NRD	Neutral Rock Drainage, i.e. drainage liquid that is neither acid nor alkaline.
O	
OBE	Operating Basis Earthquake.
OBM(HC)	Oil-Based Mud.
O&CMS	Organisational and Corporate Management System.
ODF	OverDesign Factor.
Offshore (a)	That area of the sea and seabed extending from the low water mark of ordinary or medium tides outwards.
O&G	Oil and Gas.
Oil-Based drilling Fluid (OBF), Oil-Based Mud (OBM)(HC)	See "Non-Aqueous drilling Fluid".
Oil shale(HC)	Shale formations containing kerogen, a semi-solid hydrocarbon that must be heated in the ground or mined and heated at the surface to produce oil (Rogner *et al.* 2012); NB: this is different from shale oil, which is an unconventional oil produced from oil shale and which can be used immediately as a fuel or upgraded to meet refinery feedstock specifications.
Oil sand (tar sand or bituminous sand)	Type of unconventional petroleum deposit.
OLC	Open Limestone Channel.
OLD	Oxic Limestone Drain.
Onshore	All activities related to exploring for, producing or processing which do not occur offshore.
Open-pit (open-cast) mining	Mining operation that takes place at the surface. Mining operation and environment are in contact over an extended area.
Operator (a)	The natural or legal person responsible for the management of extractive waste, in accordance with the national law of the Member State in which the waste management takes place, including in respect of temporary storage of extractive waste as well as the operational and the after-closure phases.
OPEX	OPerating EXPenditure.
Ore	Mineral or variety of accumulated minerals of sufficient value as to quality and quantity that it/they may be mined at a profit. Most ores are mixtures of extractable minerals and extraneous rocky material described as gangue (see Figure 8.1).
Orebody (mineral deposit)	Naturally occurring geological structure consisting of an accumulation of a desired mineral and waste-rock, from which the mineral can be extracted, at a profit, or with a reasonable expectation thereof (see Figure 8.1).
OSM	Operation, Supervision and Maintenance.
Overburden	The material that extractive operations move during the process of accessing an ore or mineral body, including during the pre-production development stage: layer of natural soil or massive rock on top of an orebody (see Figure 8.1).
P	
Paddock	Ring dykes used to contain, retain and confine the extractive waste in a pond-type EWF built on a flat terrain.
PAG	Potentially Acid Generating.
PAH	Polycyclic Aromatic Hydrocarbon.

PDMS	Pressure Driven Membrane Separation.
Perforate[HC]	To make holes through the casing to allow the oil or gas to flow into the well or to squeeze cement behind the casing.
Permeable Reactive Barrier	A permeable zone containing or creating a reactive treatment area oriented to intercept and remediate a contaminant plume. It removes contaminants from the groundwater flow system in a passive manner by physical, chemical or biological processes [123, PRB action team, 2003].
Permeability	A measure of a material's (e.g. rock's) ability to allow the passage of gas or liquid through pores, fractures, or other openings. The SI unit of measurement is m^2, although a frequently used unit is the darcy or millidarcy.
Permeable	Hydraulic conductivity $\geq 10^{-7}$ m/s.
Phreatic	Pertaining to groundwater.
Phreatic surface	The surface between the zone of saturation and the zone of aeration; the surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.
Piping	Mostly subterranean erosion of non-lithified materials caused by flowing water. Results in the formation of conduits due to the removal of particles.
Pit	See "open-pit mining".
Placer	A deposit of sand or gravel that contains particles of gold, ilmenite, gemstones, or other heavy minerals of value. The common types are stream gravels and beach sands.
PLC	Programmable Logic Controller.
PM	Particulate Matter.
Probable Maximum Earthquake (PME)	A geotechnical engineering parameter determined by the maximum recorded earthquake at the site, the maximum recorded earthquake for a site in a similar location for which historic data are available or the one-in-10 000-year earthquake predicted statistically from previous earthquakes in the region.
Probable Maximum Flood (PMF)	The most severe precipitation and/or snowmelt event considered reasonably possible at a particular geographic location. A site-specific determination based on the possible range in meteorological and hydrological events and conditions. Variables include the duration, the area and the time of year. Usually defined as the 1:10 000 year flood or two or three times the 1:200 year flood.
PMP	Probable Maximum Precipitation.
Pollution [b]	The direct or indirect introduction, as a result of human activity, of substances, vibrations, heat or noise into air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment.
Polymer	Chemical compound of unusually high molecular weight composed of numerous repeated, linked molecular units.
Pond [a]	A natural or engineered facility for disposing of fine-grained waste, normally extractive waste from mineral processing, along with varying amounts of free water, resulting from the treatment of mineral resources and from the clearing and recycling of process water.
Pool	An underground reservoir containing a common accumulation of oil and/or gas. Each zone of a structure which is completely separated from any other zone in the same structure is a pool.
Porosity	Percentage of the rock volume that can be occupied by oil, gas or water.
PP	PolyPropylene.
Primary carrier fluid	The base fluid, such as water, into which additives are mixed to form the hydraulic fracturing fluid which transports proppant.
PRB	Permeable Reactive Barrier.
Primary crushing	Process of reducing ore into smaller fragments to prepare it for further processing and/or so that it can be transported to the processing plant. In underground mines, the primary crusher is often located underground or at the entrance to the processing plant.
Primary measure/ technique	Technical modification introduced into the core process leading to the reduction of raw emissions or consumption (see also the counterpart "end-of-pipe technique").
Primary production	Production of a reservoir by natural energy in the reservoir.

Production casing(HC)	Casing set above or through the producing zone through which the well produces.
Produced water	Generally defined as "fluids displaced from the geological formation, which can contain substances that are found in the formation, and may include dissolved solids (e.g. salt), gases (e.g. methane, ethane), trace metals, naturally occurring radioactive elements (e.g. radium, uranium), and organic compounds" (AEA 2012). According to the US EPA, there is no clear transition between flowback and produced water.
Production	Beneficiation or processing of extracted raw materials to marketable products.
Production facility(HC)	Any fixed or mobile facility that is used for active recovery of hydrocarbons from producing formations. The production facility begins operations with the completion phase.
Proppant or propping agent(HC)	A granular substance (e.g. sand grains, ceramics, aluminium pellets, or other material) that is carried in suspension by the fracturing fluid and that serves to keep the cracks open when fracturing fluid is withdrawn after a fracture treatment.
Prospecting (a)	The search for mineral deposits of economic value, including sampling, bulk sampling, drilling and trenching, but excluding any works required for the development of such deposits, and any activities directly associated with an existing extractive operation.
Pump barge	Barge that floats in the pond and supports the pumps that are used to reclaim the free water in the pond for re-use in the mineral processing plant.
Q	
QA/QC	Quality Assurance/Quality Control.
QMS	Quality Management System.
Quarry (also called pit)	Area under the control of an operator where quarrying occurs (see "quarrying"), including common related infrastructures and waste management activities. Examples of quarries include but are not limited to the extraction of building stone, such as slate, limestone, gravel and sand. Many EU Member States make a distinction between quarries and mines in their national legislation which lists exhaustively the materials that are extracted in quarries or in mines (for instance France, Belgium, the UK, Ireland and Sweden). In these pieces of legislation, the main difference lies in the access to the mineral resource: • for mines, this access is usually ruled by mining concessions (authorisation may be granted by the competent authority without the agreement of the land owner); • for quarries, the operator usually has to ask for an environmental authorisation and have an agreement with the owner of the land if it is not the owner. This difference is usually justified by a strategic interest of extracting a defined list of materials. In practice, mines are used for extracting high-value material such as base metals, precious metals, iron, uranium, coal, diamonds, oil shale, rock salt and potash. Meanwhile, quarries are used for extracting materials usually used for construction purposes (crushed rocks, sand and gravels, ornamental stone, etc.). This is not an exhaustive list of the differences between mines and quarries.
Quarrying	Any activity involved in the prospecting, extraction, treatment and storage of construction minerals originating from deposits in the earth's crust.
R	
Rd	Design resistance.

Reduced Emissions Completion (REC)	Also known as green completion, this is a term used to describe a practice that captures gas produced during well completions and well workovers following hydraulic fracturing. Portable equipment is brought on site to separate the gas from the solids and liquids produced during the high-rate flowback, and produce gas that can be delivered into the sales pipeline. RECs help to reduce methane, volatile organic compound (VOC), and Polycyclic Aromatic Hydrocarbon (PAH) emissions during well clean-up and can eliminate or significantly reduce the need for flaring.
Reclaim water	Water recovered from the extractive waste deposition area (including the EWF), water treatment plant or mineral processing plant for re-use in the mineral processing plant.
Recovery	In mining operations: proportion, expressed as a percentage, of a constituent pertaining to the concentrate (or for coal final tonnage) as compared to the total amount of that mineral initially present in the feed prior to mineral processing. A measure of mining, extraction and processing efficiency. Of waste: any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II to the Waste Framework Directive (2008/98/EC) sets out a non-exhaustive list of recovery operations.
Refractory gold	Contained gold that is submicroscopic (< 1 µm) and finely disseminated in the sulphide mineral lattices.
Rehabilitation [(a)]	The treatment of the land affected by an EWF in such a way as to restore the land to a satisfactory state, with particular regard to soil quality, wildlife, natural habitats, fresh water systems, landscape and appropriate beneficial uses.
Remediation	Applies to the environmental clean-up of land, water and air contaminated by organic, inorganic or biological substances.
Reservoir[(HC)]	A subsurface, porous, permeable or naturally fractured rock body in which oil or gas has accumulated. A gas reservoir consists only of gas plus fresh water that condenses from the flow stream reservoir. In a gas condensate reservoir, hydrocarbons may exist as a gas, but, when brought to the surface, some of the heavier hydrocarbons condense and become a liquid.
Rheology	The study of how matter deforms and flows, including its elasticity, plasticity and viscosity. In geology, rheology is particularly important in studies of moving ice, water, salt and magma, as well as in studies of deforming rocks.
Roll crusher	A type of secondary crusher consisting of a heavy frame on which two rolls are mounted. These are driven so that they rotate toward one another. Rock fed in from above is nipped between the moving rolls, crushed, and discharged at the bottom.
ROC	Retention on Cuttings.
ROM	Reference report on the monitoring of emissions to air and water from IED installations – http://eippcb.jrc.ec.europa.eu/reference/mon.html.
ROM REF	See "ROM"
Rotary drilling[(HC)]	The method of drilling wells that depends on the rotation of a column of drill pipe with a bit at the bottom. A fluid is circulated to remove the cuttings.
Run-off	Part of precipitation and snowmelt that does not infiltrate but moves as overland flow.
S	
Sample	Limited quantity of material taken for analysis, which is normally intended to be representative for a larger quantity of that material.
Sandstone	Variously coloured sedimentary rock composed chiefly of sand-like quartz grains cemented by lime, silica or other materials.
SAPS	Successive Alkalinity Producing Systems.
Scale inhibitor	A chemical substance which prevents the accumulation of a mineral deposit (for example, calcium carbonate) that precipitates out of water and adheres to the inside of pipes, heaters, and other equipment.
Screening	Separating material into size fractions.
SD	Saline Drainage.

Seam	Stratiform mineralisation (typical for coal and some types of salt deposits). Due to tectonic overprint, seams may also be folded or steep lying.
Secondary measure/ technique	See "end-of-pipe technique".
Sedimentary rock	A rock formed from sediment transported from its source and deposited in water or by precipitation from solution or from secretions of organisms.
SEE	Safety Evaluation Earthquake.
Seepage	Infiltration and further migration of EWIW into the ground.
Seepage water	EWIW that has infiltrated and can further migrate into the ground.
Seismic	Related to earth vibrations produced naturally or artificially.
Semi-Autogenous Grinding (SAG)	A method of grinding rock (ore) into a fine powder using grinding media including both the larger chunks of the ore itself and steel balls.
Separation	Processing methods to separate ore into concentrate and extractive waste from mineral processing.
Shaft	Primary vertical or inclined opening through mine strata used for ventilation or drainage and/or for hoisting of personnel or materials (e.g. ore, waste-rock); connects the surface with underground workings.
Shale	Sedimentary rock consisting of thinly laminated claystone, siltstone or mud stone. Shale is formed from deposits of mud, silt, clay, and organic matter laid down in calm seas or lakes.
Shale gas[(HC)]	Natural gas that remains tightly trapped in shale and consists chiefly of methane, but with ethane, propane, butane and other organic compounds mixed in.
Shale oil[(HC)]	Light oil trapped in low-permeability shale formations.
Shale shaker[(HC)]	Shale shakers are the primary solids separation tool on a rig. After returning to the surface of the well, the used drilling fluid flows directly to the shale shakers where the drilling fluid is separated from the drill cuttings. Once processed by the shale shakers, the drilling fluid is deposited into the mud tanks for reconditioning and re-use. The solids removed by the shale shaker are discharged to a separate holding tank for further treatment or disposal.
Shear strength	The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called cohesion.
Short-term phase	There are no commonly accepted definitions for the short-term phase. According to the literature review, it often refers to the operational phase. For example, the following reference times are provided in the Guidance document for a risk-based preselection protocol for the inventory of closed waste facilities (EC-DG ENV 2011): - short term: from 6 to 12 months; - medium term: from 1 to 10 years.
Siltstone	Rock in which the constituent particles are predominantly silt size.
Site [(a)]	All land at a distinct geographic location under the management control of an operator.
Slurry	A suspension of liquids and solids.
SME	Society for Mining, Metallurgy and Exploration Inc.
Solidification (of waste)	Techniques aiming to reduce the hazard potential of a waste by encapsulating it into a solid of high structural integrity, hence decreasing the solubility, mobility and/or toxicity of the contaminants contained within the waste.
Solubility	Quantity of solute that dissolves in a given volume and type of solvent, at given temperature and pressure, to form a saturated solution. The degree to which compounds are soluble depends on their ability, and that of the other dissolved species, to form ions and aqueous complexes in a particular chemical environment.
Solution mining	Extraction of soluble raw materials from the deposit using a solvent (e.g. water).
SP	Settlement Plates.
Spigotting	Procedure whereby the extractive waste from mineral processing is discharged into the pond through a large number of small outlets or spigots. Spigotting produces a fairly even distribution of extractive waste over the beach that forms the upstream semi-impervious zone of the dam.

Squeeze[(HC)]	Technique where cement is forced under pressure into the annular space between the casing and the wellbore, between two strings of pipe, or into the casing-hole annulus.
SRB	Sulphate-Reducing Bioreactor.
Stage[(HC)]	Isolation of a specific interval of the wellbore and the associated interval of the formation for the purpose of maintaining sufficient fracturing pressure.
Starter dam	Initial dam, which is constructed before the mining operation starts and provides the starting point for construction of the final dam.
STD	Sea Tailings Disposal.
Stimulation[(HC)]	The act of increasing a well's productivity by artificial means such as hydraulic fracturing or acidisation.
Stratum	Sedimentary rock layer, typically referred to as a formation, member or bed.
Stockpile	A pile of excavated *rock* or naturally *non-lithified material* placed in anticipation of later use or rehandling. See also "low-grade ore" and "ore".
STR	Structural limit states
Stripping ratio	The unit amount of waste-rock or overburden that must be removed to gain access to a unit amount of ore, generally expressed in cubic metres of waste-rock/overburden to raw tonnes of ore.
Subaerial deposition	Name commonly used in North America for a method of spigotting which uses spray bars to place thin layers of extractive waste from mineral processing on a previously deposited beach.
Supernatant pond	Pond of supernatant water (also called free or decant water) resulting from separation of solids and water after transport, deposition and settlement/sedimentation of slurried extractive waste. The supernatant pond is contained within the EWF.
Surface casing[(HC)]	Casing extending from the surface through the potable fresh water zone.
Surfactants	Chemical additives that reduce surface tension; or a surface active substance. Detergent added to hydraulic fracturing fluid is a surfactant.
SVOC	Semi-Volatile Organic Compound.
Synthetic-Based drilling Fluid (SBF)[(HC)]	Non-aqueous drilling fluid in which the continuous phase is a synthetic fluid and water or brine is the dispersed phase. See also "non-aqueous drilling fluid".
T	
Tailing [(a)]	The waste solids or slurries that remain after the treatment of minerals by separation processes (e.g. crushing, grinding, size-sorting, flotation and other physico-chemical techniques) to remove the valuable minerals from the less valuable rock.
Tailings, coarse/fine discard	Ore from which as much as feasible of the desired minerals have been removed. Tailings consist mainly of gangue and may include process water, process chemicals and portions of the unrecovered minerals. Note: The UK coal extraction industry uses the terms as follows: ▪ coarse discard: the coarser (and dryer) fraction of the discard, remaining after processing the mass of extracted material to separate the desired product by wet or dry methods. ▪ fine discard: the finer (and wetter) fraction of the discard, produced from the thickened or flocculated suspended solids in the wash water used to process and separate the desired product from the coarse discard by washing or floatation of the extracted material.
TDS	Total Dissolved Solids.
Technically recoverable reserves	The proportion of assessed in-place petroleum that may be recoverable using current recovery technology, without regard to cost.
TE-NORM	Technologically Enhanced NORM. TE-NORM is produced when radionuclides that occur naturally in ores, soils, water or other natural materials are concentrated or exposed to the environment by human activities.
THC	Total HydroCarbons.
Thermal desorption	A thermal desorption system is a non-oxidising process using heat to desorb a substance from a matrix through volatilisation, e.g. to remove oil from oily wastes.
Thickening	Liquid-solid separation process to increase the concentration of a suspension by sedimentation or flotation, accompanied by the formation of a clear liquid.

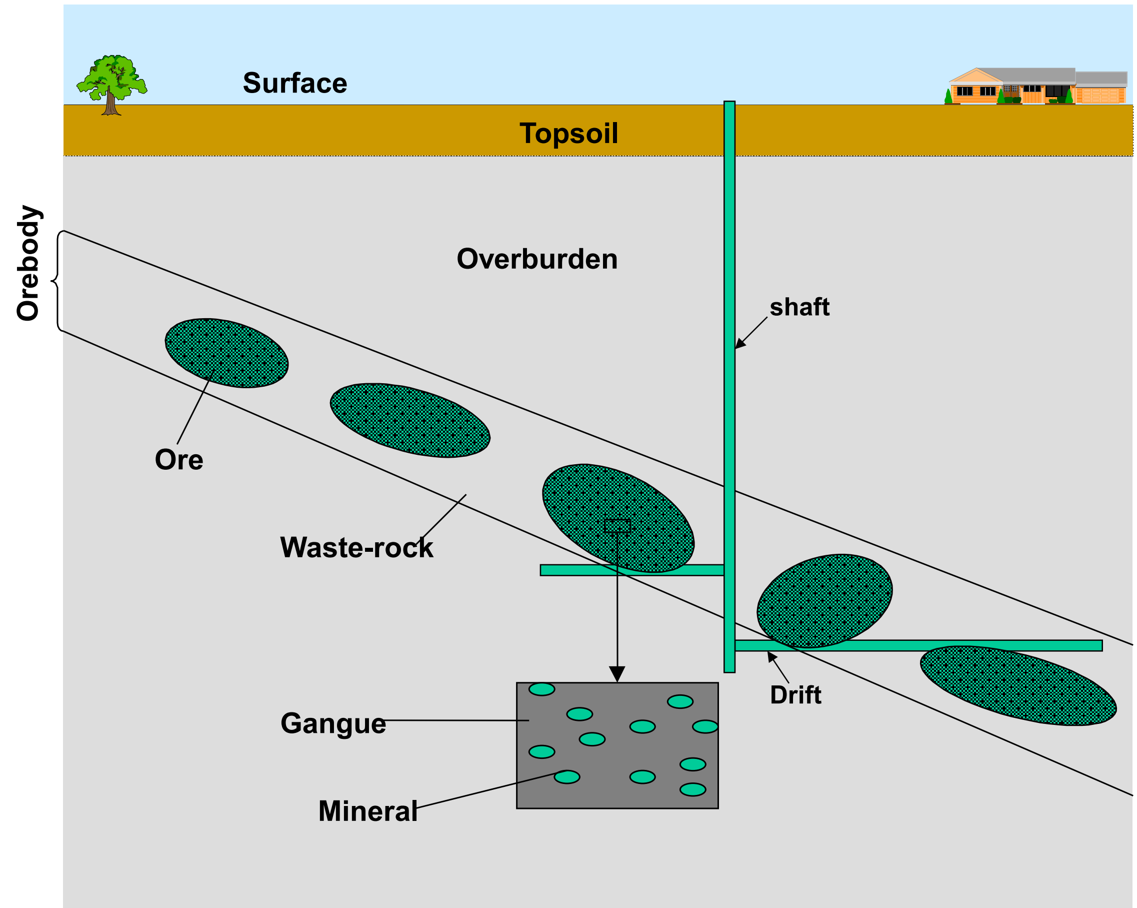
Tight gas[HC]	Natural gas held in sandstone reservoirs that are usually impermeable; it can be extracted by fracturing the rock (tight gas is typically extracted using vertical wells which require less fracturing fluid and so extraction of this gas falls outside the definition of high-volume hydraulic fracturing).
TOC	Total Organic Carbon.
Topsoil	Natural humic layer on top of the orebody, which has to be stripped prior to start-up of extraction (see Figure 8.1).
Total CN	The total of all cyanide existing in the various compounds in aqueous solution [24, British Columbia CN guide, 1992].
TPH	Total Petroleum Hydrocarbon
Treatment [a]	The mechanical, physical, biological, thermal or chemical process or combination of processes carried out on mineral resources, including from the working of quarries, with a view to extracting the mineral, including size change, washing, classification, separation and leaching, and the re-processing of previously discarded waste, but excluding smelting, thermal manufacturing processes (other than the burning of limestone) and metallurgical processes.
TRPH	Total Recoverable Petroleum Hydrocarbon.
TSP	Total Suspended Particles.
Total Suspended Solids (TSS)	The concentration in any liquid, usually water, of suspended particles that are trapped by a filter with a defined pore size.
TWG	Technical Working Group.
U	
Unconformity	The contact between older rocks and younger sedimentary rocks in which at least some erosion has removed some of the older rocks before deposition of the younger. An angular unconformity shows that the older rocks have been deformed and eroded before the younger sedimentary rocks were deposited; there is an angle between the beds of the older and the younger rocks.
Underground extraction	Extraction of the ore takes place under the surface. The orebody is accessed by shafts, ramps and galleries.
Unconventional hydrocarbons[HC]	Oil and gas obtained from geological formations which are typically more difficult to access and which require the use of specific stimulation techniques such as hydraulic fracturing. Shale gas, tight gas and coal-bed methane are examples of unconventional hydrocarbons.
Unconventional gas[HC]	Gas contained in rocks (which may or may not contain natural fractures) which exhibit an *in-situ* gas permeability of less than 1 millidarcy.
Unpolluted soil [a]	Soil that is removed from the upper layer of the ground during extractive activities and that is not deemed to be polluted under the national law of the Member State where the site is located or under Community law.
US-EPA	Environmental Protection Agency of the United States of America.
UV	Ultra Violet.
V	
VCD	Vapour Compression Distillation.
Vein	Thin complex structure of ore accumulations surrounded by gangue.
Venting	Release of gases directly into the atmosphere.
Viscosity	A measure of the degree to which a fluid resists flow under an applied force.
VOC	Volatile Organic Compound.
VWP	Vibrating Wire Piezometer.
W	
WAD CN	See "Weak Acid Dissociable Cyanide" [a].
Waste	Any substance or object which the holder discards or intends or is required to discard according to Article 3(1) of the Waste Framework Directive 2008/98/EC.

Waste facility [(a)]	Any area designated for the accumulation or deposit of extractive waste, whether in a solid or liquid state or in solution or suspension, for the following time periods: • no time period for Category A waste facilities and facilities for waste characterised as hazardous in the waste management plan; • a period of more than six months for facilities for hazardous waste generated unexpectedly; • a period of more than one year for facilities for non-hazardous non-inert waste; • a period of more than three years for facilities for unpolluted soil, non-hazardous prospecting waste, waste resulting from the extraction, treatment and storage of peat and inert waste. Such facilities are deemed to include any dam or other structure serving to contain, retain, confine or otherwise support such a facility, and also to include, but not be limited to, heaps and ponds, but excluding excavation voids into which waste is replaced, after extraction of the mineral, for rehabilitation and construction purposes.
(Extractive) waste management area	Area of the site where extractive waste is handled, treated and/or prepared.
(Extractive) Waste Management Plan [(a)]	Plan for the minimisation, treatment, recovery and disposal of extractive waste, taking account of the principle of sustainable development according to Article 5 of Directive 2006/20/EC.
Waste-rock	The material that extractive operations move during the process of accessing an ore or mineral body, including during the pre-production development stage: part of the orebody, without or with low grades of ore, which cannot be mined and processed profitably (see Figure 8.1).
Water balance	Process whereby all water entering the pond, all water leaving the pond and all water losses are defined and described such that the net gain or loss of water in the pond can be determined.
Water Based drilling Fluid (WBF) or Water Based Mud (WBM)[(HC)]	A drilling fluid in which water or a water-miscible fluid is the continuous phase and the suspending medium for solids, whether or not oil is present.
Water table	Elevation at which the fluid pressure is equal to atmospheric pressure. The surface separating the vadose zone (where water is held under tension) from the saturated zone (where fluid pressures are greater than zero).
Water well	Any residential well used to supply potable water.
Watershed	The region drained by, or contributing water to, a stream, lake, or other body of water.
WBM[(HC)]	Water-Based Mud.
Weak Acid Dissociable cyanide (WAD CN) [(a)]	Cyanide and cyanide compounds that are dissociated with a weak acid at a defined pH.
Weathering	Processes by which particles, rocks and minerals are altered on exposure to surface temperature and pressure, and atmospheric agents such as air, water and biological activity.
Well pad[(HC)]	A site constructed, prepared, levelled and/or cleared in order to perform the activities and stage the equipment and other infrastructure necessary to drill one or more natural gas exploratory or production wells.
Well site[(HC)]	Includes the well pad and access roads, equipment storage and staging areas, vehicle turnarounds, and any other areas directly or indirectly impacted by activities involving a well.
Wellbore[(HC)]	A borehole; the hole drilled by the bit. A wellbore may have casing in it or it may be open (uncased); or part of it may be cased, and part of it may be open.
Wellhead[(HC)]	The equipment installed at the surface of the wellbore. A wellhead includes such equipment as the casing head and tubing head.
Workover[(HC)]	Repair operations on a producing well to restore or increase production. This may involve repeat hydraulic fracturing to restimulate gas flow from the well.
WSO	Water Soluble Organics.
WT BREF	Best available techniques Reference document for Waste Treatment Industries http://eippcb.jrc.ec.europa.eu/reference/wt.html
X	

Y	
Yield	Mass ratio of concentrate to feed, calculated on a dry basis and expressed as a percentage.
Z	

EU legislation references used:

a) Directive 2006/21/EC
b) Directive 2010/75/EC
c) Directive 2000/60/EC



Source: (EC-JRC 2009)

Figure 8.1: Schematic drawing of an orebody

Sources for the glossary (apart from those taken from the existing MTWR BREF (EC-JRC 2009)):

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9 ANNEXES

9.1 Annex 1. Techniques and methods applied for the extraction of mineral resources

Extraction of mineral resources can be divided into two broad categories:
- extraction of liquid and gaseous mineral resources: oil and gas hydrocarbons;
- extraction of solid mineral resources: ores and rocks.

9.1.1 Hydrocarbon extraction: oil and gas

Extraction of oil and gas is carried out by drilling a wellbore to access the underground reservoir/formation containing oil and/or gas, allowing the flow of oil and/or gas to the surface.

Oil and gas extraction can be enhanced by stimulating the formation. These operations aim at improving the flow of oil and/or gas to the surface, and therefore increasing the production of the well.

Information presented in this section is based on the information provided by the operators and the TWG experts during the information exchange process.

9.1.1.1 Wellbore drilling

The main purpose of drilling activities is to create a wellbore in order to reach the underground reservoir/formation containing oil and/or gas. In the oil and gas upstream industry, the objective of this wellbore is to enable extraction of hydrocarbons. This is achieved during the drilling process by:
- perforating the rock;
- removing cuttings to the surface;
- consolidating the wellbore stability;
- isolating the wellbore from non-targeted geological formations such as aquifers;
- constructing the well construction to enable the extraction of hydrocarbons.

Many different drilling methods/techniques were developed to apply and transmit the force to perforate the rock. The different techniques are:
- mechanical drilling: hammer or rotary drilling (the rotary system is the most common drilling technique used in the oil and gas upstream industry);
- jet drilling: erosion and/or abrasion of the rock using a fluid jet;
- thermal drilling: using heat, e.g. from a laser (technology almost never used);
- electro-impulse drilling: high-voltage impulses (technology almost never used).

The most common drilling technique in the oil and gas upstream industry is rotary drilling, where the borehole is created using a rotating bit which crushes the rock while a drilling mud removes the cuttings. The force necessary to drill is transmitted to the bit through the drill pipe/drilling string. The rotation of the bit can be accomplished either from the surface by using, for example, a rotary table/top drive or from underground (bottom-hole rotation) by using hydraulic motors, moved by the drilling mud, which rotate the drill bit directly.

<u>Drilling rig</u>
The equipment used to drill a well is called a drilling rig. The rotary drill rig consists of the following:
- A power source to supply energy for operations (e.g. diesel engine, gas turbines).

- Hoisting equipment to lift up and lower the drilling string into the well, composed of a derrick, a crown block, a travelling block, and a hook.
- Rotating equipment to provide torque force to the bit (e.g. rotary table/top drive).
- Circulation equipment to produce and recycle the drilling muds (water-, oil- and/or synthetic-based muds) used during the drilling process. The drilling mud used to transport drill cuttings to the surface is separated from the cuttings and re-used. The system works usually in a closed loop and is composed of pumps, stand-pipes, hoses, diverters, shale shakers, centrifuges, desanders and desilters and a degasser.
- And safety equipment to prevent accidents. The first preventive measure is to control the hydrostatic pressure created by the mud system using a Pressure Control System composed of a blowout preventer, a stack (rams), a choke manifold and a flare system.

Directional drilling

In recent decades, the use of directional drilling methods and, more particularly, horizontal drilling methods has increased considerably.

Although directional drilling has been practiced since the 1920s, the technique has seen a particular breakthrough in recent decades. Technological advances in materials and equipment have been the predominant driver for this evolution. They include the development of extremely durable synthetic diamond bits (PDC, see Figure 9.1), which allow a considerable reduction in the number of bit trips used while drilling the wellbore, a new generation of mud motors (steerable motors), directional positioning systems and sensors, logging-while-drilling tools, 3D mapping by means of microseismic measurements and dissolvable temporary plugs. As a result, directional drilling technology has become an essential element of modern oil and gas field development. This technology offers the possibility to increase the oil and gas drainage area from one well or a pad of wells, and thus to increase the well productivity. As a consequence, a number of existing hydrocarbon fields which were closed for economic reasons can now be re-exploited using directional drilling.

Source: Site visit, photo by JRC review team, with the kind permission of Seneca Resources

Figure 9.1: Photo of a drill bit with a Polycrystalline Diamond Compact (PDC) cutter

Coil tubing drilling
More recently, coil tubing units have gained a wider acceptance among operators, especially to drill slim-hole rigless wells. The coil tubing is a technique that does not require a rig so a coil of continuous length flexible steel pipe is used instead. The pipe has a smaller diameter than rig pipes, usually from ~ 3 cm to ~ 5 cm, in order to be bent and coiled. The head of the tube is composed of a hydraulically driven injector that makes it possible to regulate the movement and depth of the coil tubing string.

Coil tubing units are usually composed of: a coiled steel pipe, a hydraulic unit, an injector, a stuffing box and a gooseneck. Coil tubing units require specific pump units (triplex pumping unit) in order to perform several types of workover jobs: drilling, acidising, nitrogen lifting, scale cleaning, jetting, running and recovering blanking plugs, opening sleeves, etc.

9.1.1.2 Casing and cementing

The main objectives of casing are:
- to maintain the structural integrity of the borehole;
- to insulate the well (prevent underground contamination from the producing well and vice versa);
- to enable pressure control (blowout preventers are installed on the casing);
- to provide support for the next drilling phase (support and conduct).

Casing the well: steel pipes joined together are put in place in the well to create a mechanical support and prevent formation collapse. Casing is made of metal strings which are hollow steel pipes. Strings are inserted in the well after the drilling and before cementing. When wells are drilled in several stages, casing is performed after each drilling stage, and before cementing. In that case, after each stage, the well is drilled deeper using a smaller drilling and then casing diameter. The number of casing strings (usually from three to six) depends on geological and mechanical parameters.

Typical casings are as follows:
- o The conductor pipe inserted during civil works (site preparation). The conductor is inserted first and is the largest. The diverter and blowout preventer can be installed (sometimes) on the top of the conductor casing in order to protect the initial drilling phase.
- o The surface casing inserted once the large-diameter drilling is concluded. It aims to protect shallow aquifers and/or hydrocarbons. The diverter and blowout preventer are usually installed on the top of the surface casing.
- o The first casing string is inserted in the surface casing string. It aims to protect aquifers and unconsolidated areas (if any), and to provide pressure and structural integrity to the wellbore (structural shoe strength) in order to drill into high-pressure zones. The diverter and blowout preventer are installed on the top.
- o The second casing string (if necessary) is inserted in the first casing string and extends up to the reservoir/formation. This string provides integrity to the system before starting to drill into the reservoir/formation containing hydrocarbons (oil and gas).
- o The formation casing, also called production casing, is set across the reservoir interval after drilling. Sometimes this casing string is connected to the previous casing (first or second casing). In that case, it does not reach the wellhead at the surface and is called liner string.

The main objectives of cementing the well are:
- filling the annulus space (void);
- sealing the casing.

Cementing the well: once the casing is in place, the annulus space (void) between the string and the wellbore is filled with cement. Cement is pumped from the surface down into the well through a the pipe. Once the cement has reached the bottom of the pipe (float shoe), it is pushed out by pumping mud. Surface casing is usually cemented up to the surface. Other casing strings inserted in the well are cemented as much as possible with a minimum overlap of 100 m with the previous string.

9.1.1.3 Well completion works

Once drilling, casing and cementing operations are finished, well completion works are undertaken to transform the drilled well into a producing one. The main objectives of well completion are to enable safe and efficient well production. The completion works correspond essentially to the following main steps:

- Perforation: once drilling, casing and cementing have been finished, perforation is carried out in order to create a connection (pathway) between the formation/reservoir and the well. In order to start the production, small holes are created in the selected zone(s) to allow the hydrocarbons to flow into the well. Perforation can be achieved with explosives or jets. Perforation guns are used for this purpose.
- Tubing: a production tube is placed in the well to control the production and conduct hydrocarbons to the surface.
- Installation of downhole equipment: flow control elements and safety equipment that is required to enable safe and efficient well production are installed in the well.
- Installation of the wellhead: the final step consists of attaching and sealing a tubing hanger device to the production string., A wellhead (also called a Christmas or production tree) is installed on the top of that device. The wellhead is composed of different valves to control the outflow and manage the well production.

9.1.1.4 Well stimulation

In some cases, the well productivity can be enhanced using stimulation techniques in order to increase the flow and/or work complex or unconventional reservoirs/formations.

Five main types of well stimulation techniques can be used to improve the flow of oil and gas through the wellbore to the surface:

- Perforation or well shooting uses explosives to break up the rock and create tunnels through which oil and gas can flow from the reservoir to the well.
- Acidisation or injection of acids to dissolve deposits around the wellbore, sometimes carbonate rocks, and to remove the skin damage created on the rocks during drilling operations in the wellbore area.
- Nitrogen lifting or injection of nitrogen gas to displace well fluids in order to reduce the hydrostatic column and initiate the flow from the reservoir to the surface.
- Swabbing which is done with wire line tools and rubber cupped seals in order to reduce the pressure inside the pipe and initiate the flow from the reservoir to the surface.
- Fracturing which is usually performed by pressure injection of water-based fluids in order to create a net of fractures in the shale formation and enable the flow of hydrocarbons. Along with fluids, proppant (sand) is injected to keep the fractures open. For shale gas formations, high pressures are required to fracture the rock. This requires the use of conventional fracturing or high-volume hydraulic fracturing (HVHF) to stimulate the production. For tight gas or coal-bed methane production, lower pressures are required to fracture the rock than for shale gas or shale oil fracturing. In those cases, no HVHF is required and lower volumes of water-based fluids will be required to fracture the rock.

Perforation or well shooting is used for enhancing the flow. It can be achieved using explosives down the hole. Small explosions will create cracks in the rocks and improve the flow of hydrocarbons to the wellbore.

Acidisation is accomplished by injection of chemicals, usually acids, to dissolve the rock around the wellbore in order to increase the permeability around the well between the formation (usually carbonate rock) and the wellbore.

Acids used to dissolve the rock depend on the type of formation. Usually hydrochloric acid, formic acid, ethanoic acid or hydrofluoric acids are used. Other chemicals such as corrosion inhibitors, surfactants, anti-sludge agents, and friction reducers can also be used (API 2014).

Fracturing was originally used to reduce wellbore skin damage, and now it has expanded to applications such as reservoir/formation stimulation. It is the most common well stimulation technique in the case of shale gas or shale oil production. Two different principal techniques can be used to fracture the rock:

- Hydraulic fracturing using water-based fluids (the most commonly used techniques). Hydraulic fracturing used to be an operation consisting of injection, at low temperature, of a few hundred litres of proppant into low-pressure reservoirs (conventional geologies). High-volume hydraulic fracturing (HVHF) has since developed into a highly engineered and complex procedure used for low-permeability reservoirs/formations (unconventional geologies). Nowadays, high-pressure pumping units, high-strength proppant (sand) and sophisticated fracturing fluids are used to fracture deep, low-permeability, high-temperature reservoirs, in order to fracture the rock. The operation normally starts with the injection of a mixed acid and water, often referred to as a *pre-pad*. This is followed by a mixture of water and a polymer, often referred to as a *pad*. The fracture will initiate during the pumping of the fluids mentioned, and, in order to open the fracture and keep it open, a mixture of proppants and fracturing fluid, referred to as *slurry*, is injected. Other fluids have been tested to replace water-based fluids such as foam-based, oil-based, alcohol-based, emulsion-based or cryogenic fluids, but these are rarely used nowadays for HVHF.
- Pneumatic fracturing using compressed air (rarely used).

Other techniques such as electric fracturing using electric arcs or pulsed arc electrohydraulic discharges, plasma fracturing and/or thermal techniques are implemented more on a research or pilot scale than on an industrial scale.

For further details on different techniques, the JRC Technical Report entitled "An overview of hydraulic fracturing and other formation stimulation technologies for shale gas production" (EC-JRC 2013a) provides a good source of information.

9.1.2 Minerals extraction: ores and rocks

Extraction of solid mineral resources such as metalliferous ores, industrial minerals or construction rocks is carried out by one or a combination (i.e. surface and underground extraction) of the following extraction methods:

- surface extraction;
- underground extraction;
- non-entry extraction.

The choice between surface and underground extraction depends mainly on the depth, type, morphology (vein, veilet, disseminated, massive, etc.), the ore grade (high-grade versus low-grade) and the economics of the deposit.

These methods have been widely described in the literature (EC-JRC 2009; SME 2011). The basic objective of selecting a method to mine a particular orebody is to design an ore extraction system that is most suitable under the existing circumstances. This decision is based upon both technical and non-technical factors (e.g. high productivity, complete extraction of the ore, safe working conditions and/or site rehabilitation).

9.1.2.1 Surface extraction

Further division of surface extraction methods is based on the mechanical properties of the rocks.

For surface extraction, three main types of extractive methods can be applied:
- mechanical surface extraction:
    - for consolidated rocks using sawing, diamond wires or drilling and blasting;
    - for consolidated rocks using diggers/excavators;
- aqueous surface extraction for unconsolidated or permeable rocks.

Finally, the selection of a specific surface extraction method will depend mainly on the shape, dip (slope) and size of the deposit (Carter 2011):
- For mechanical surface extraction of consolidated rocks or drilling and blasting, four methods are usually differentiated:
    - open-pit mining for thick and large deposits;
    - open-cast or strip mining for tabular, low dip, thin and large deposits;
    - quarrying for tabular or massive, thick and moderate deposits;
    - augering for tabular, flat, thin and remnant deposits.
- For aqueous surface extraction of unconsolidated or permeable rocks, two methods are usually differentiated:
    - hydraulicking for tabular, flat, thin and small deposits;
    - dredging for tabular, flat, thick and large deposits.

There are various surface extraction techniques. All have in common the removal of overburden and waste-rock from the surface to reach the deposit usually located near the surface. The surface extraction process can generally be outlined in the following steps:
- excavation by means of drilling and blasting or mechanical excavation methods;
- loading of excavated materials;
- hauling of materials (to the next step);
- rehabilitation.

For surface extraction, the waste-to-ore ratio usually varies from < 0.1:1 to ~ 10:1 depending on local conditions and deposit nature.

<u>Open-pit mining</u>
Open-pit mining refers to mechanical extraction of surface or shallow deposits leading to the creation of an open pit. The overburden and ore are removed in benches. The waste-rock and overburden are transported and disposed of near the extraction pit or crushed and sold if there is a market for the material. The reclamation of the site is performed after completion.

If open-pit mining is the chosen extraction method, it will result in larger amounts of waste-rock in most cases.

Source: site visit, photo by JRC review team

Figure 9.2: Open-pit mining

Open-cast mining/Strip mining/Contour mining

Open-cast mining is a surface extraction method similar to open-pit mining. The main difference is that in open-cast mining the waste-rock and overburden are not transported to waste heap-type facilities but cast back into the previously created excavation pit. As the extraction process progresses the excavation pit is laterally translated. The total amount of waste-rock and overburden is less important than in open-pit mining. The rehabilitation is done simultaneously during the mining process.

Strip mining is similar to open-cast mining but its name refers to the excavation of narrow (50-100 m) and long (~ 1km) strips of overburden.

Strip mining can be divided into two categories:

- area stripping; and
- contour stripping, also called contour mining.

The difference between these techniques is mainly related to the terrain properties: area stripping is more related to flat terrains, whereas contour stripping is more associated with hilly terrain.

Strip mining is generally applied to shallow coal seams or sand and gravel (contour mining).

Quarrying

Quarrying usually refers to the extraction of dimension stones (marble, granite, natural stone, etc.) or aggregates (sand, gravel and/or crushed rocks) from an open pit. The extraction of some industrial minerals may also be included according to the different national/local legislation.

It is generally accepted that quarries are smaller open-pit extraction sites. In many quarries waste-rock and overburden are not transported to waste heap-type facilities but cast back into the previously created excavation pit (placed back into the excavation voids). As the extraction process progresses the excavation pit is laterally translated. The total amount of waste-rock and overburden is less important than for open-pit mining. The rehabilitation is done simultaneously during the extraction process.

In quarries, materials excavation can be performed by:

- drilling and blasting where blasting is carried out by the wedges method or plug-and-feather method (use of a hammer drill);
- mechanical methods such as sawing with diamond wires, excavation above or below the water level (aqueous surface extraction);
- continuous miners/excavators/dredging/hydraulic hoses.

(Priyadarshi and Norman 2012)

In more detail, the different methods generally used for the excavation of dimension stones, aggregates or industrial minerals may be described as follows:

- dimension stones:
  - drilling:
    - line drilling;
    - drilling and blasting (dynamic splitting);
    - drilling and using rock breaker wedges or non-explosive expansive mortars;
    - fracturing by using compressed air/water/flame (such as flame jet, water jet);
  - mechanical methods:
    - channelling and diamond wire sawing machine or chainsaw machine;
- aggregates:
  - drilling and blasting (for crushed stones);
  - mechanical methods:
    - above the water level: excavators, wheel loaders, etc.;
    - below the water level: dragline, hydraulic backhoe excavators, clamshell bucket excavator or suction pump dredger;
- industrial minerals:
  - drilling and blasting;
  - mechanical methods:
    - hydraulic backhoe excavators, ripper, surface miner (e.g. for limestone);
    - excavator, dozer, bucket wheel (e.g. for clay, silica sands or gypsum).

In some countries, the quarry is legally defined as an open-pit mining site in contrast with an underground mine; see also the definition of *quarry* in the Glossary (IQ 2016).

Augering

Auger mining or augering is a low-cost method implemented in coal extraction using auger drills mounted with cutter heads in order to penetrate and fracture the coal seam. The machine is very similar to a drill machine.

Auger mining is usually associated with contour or strip mining.

Hydraulicking

Hydraulicking or hydraulic mining uses high-pressure jets of water to mine the deposit. The technique consists of using water to excavate minerals from placer and/or alluvial deposits and move the targeted sediments in a slurry to the mineral processing stage. This method is not common in Europe.

It is generally used to mine gold.

Dredging

Dredging is an excavation technique. It refers to mechanical excavation of mineral resources under bodies of water. The mineral resources (sediments) are removed from the bottom of surface water bodies.

The management of extractive waste from dredging is not within the scope of this document.

9.1.2.2 Underground extraction

As for surface extraction, further division of underground extraction methods is determined by the geometric characteristics of the deposit, the mechanical properties of the rocks and the ore and grade distribution within the deposit (Carter 2011; Kauppila *et al.* 2013; Okubo and Yamatomi 2009).

The different methods can mostly be divided into two groups depending on the dip of the orebody:
- "steep" orebodies (> 40-50 °);
- "flat" orebodies (< 40-50 °).

In addition, depending on the mechanical properties of the rock, three main classes of extractive methods can be defined based on the degree of support (SME 2011):
- unsupported underground extraction for competent and hard rocks (generally no major artificial support or self-supported with pillars);
- supported underground extraction for incompetent and soft rocks (supported with extractive materials placed back into excavation voids);
- caving for soft rocks that can be largely removed to form a cave.

In contrast with surface extraction, the waste-to-ore ratio is usually less than 1:1, even reaching values as low as 0.1:1 depending on local conditions and the deposit (some underground mines extracting industrial minerals produce very low waste volumes).

Underground mines generally produce 8 to 10 times less extractive waste than open-pit mines. (AtlasCopco 2007)

Underground extraction can generally be outlined in the following steps:
- excavation by means of drilling and blasting or mechanical excavation methods;
- loading of blasted materials;
- haulage of materials;
- underground crushing (primary crusher) and screening;
- conveying (to the surface).

The different extractive methods applied in the underground extraction will also depend on the size of the deposits.

<u>Unsupported underground extraction</u>
For unsupported underground extraction of competent and hard rock, four methods are usually differentiated:
  - room-and-pillar for tabular, flat, thin and large deposits;
  - stope-and-pillar for tabular, flat, thick and large deposits;
  - shrinkage stoping for tabular, steep and thin deposits;
  - sublevel stoping for tabular, steep, thick and large deposits.

<u>Supported underground extraction</u>
For supported underground extraction of incompetent and soft rock, three main techniques are usually mentioned:
  - cut-and-fill stoping for steep and thin deposits;
  - stull stoping for tabular, steep, thin and small deposits;
  - square-set stoping for thick deposits.

Caving:
Finally, for caving, three types of techniques are available:

- longwall mining for tabular, flat, thin and large deposits;
- sublevel caving for tabular or massive, steep, thick and large deposits;
- block caving for massive, steep, thick and large deposits.

Permanent support and long-term stability are generally provided by placing extractive materials back into excavation voids. As the materials used to fill the voids are generated during the extraction process (e.g. waste-rock and/or tailings), the process is usually planned as an integral part of the extraction process. In addition to the safety and stability, placing extractive materials back into excavation voids also has other benefits such as: better recovery of ore, increased mine life, prevention of surface subsidence, and better control of the ventilation flow through the underground mine (AtlasCopco 2007).

9.1.2.3 Non-entry extraction

Non-entry extraction methods are usually used for extraction of hydrocarbons. When it comes to extraction of ores and rocks, non-entry mining methods are used to remove portions of the underground deposit from the surface. Prerequisites for such extraction are that the deposit can be easily accessed from the surface, the permeability of the orebody permits injection and recovery of extraction fluids at the surface and that the mineral resource can be slurried, dissolved, leached or melted in order to allow transfer to the extraction fluid and recovery of the mineral resource. As the applicability of this method is restricted to specific cases, non-entry methods are not commonly used to extract ores and rocks.

Borehole mining
This method is similar to hydraulic mining and consists of two pipes injected into the underground deposit. The first is used to remove the ore, pumping a high-pressure water jet underground, and the other is used to deliver the slurry created back to the surface.

It is generally applied to mine uranium, iron ore, quartz sand, gravel, gold, diamonds, borates, halite and amber (GreatMining 2016).

Solution mining
In-Situ Leaching (ISL), also called *In-Situ* Recovery (ISR) or solution mining, is a method of recovering minerals from deep underground deposits through drilled boreholes. It is very similar to borehole mining. Instead of using high-pressure jets, a leach solution is pumped into the deposit where it circulates through the porous rock and reacts with the ore (usually weak acids). The leach solutions differ from deposit to deposit according to the physico-chemical properties of the deposit.

The solution containing the dissolved minerals, also known as Pregnant Leach Solution (PLS), is then pumped out via a second borehole and processed to recover the minerals. This process permits the extraction of metals and salts from an orebody without the requirement for conventional drill-and-blast, open-cut or underground extraction.

Explosive or hydraulic fracturing may be used to create open pathways in the deposit for the solution to penetrate through.

It is generally applied to mine uranium or copper.
(Spitz and Trudinger 2008)

9.2 Annex 2. Techniques and methods applied in mineral processing

The purpose of the treatment of minerals is to turn the raw ore from the mine into a sellable product. Some processing techniques are common to many extractive industries whereas some are more specific to certain industries such as the Bayer process for refining the alumina from bauxite or the MacArthur-Forrest or cyanide process for extracting gold from ores.

In this section, the most common mineral processes are presented in order to familiarise the reader with the basic concepts of mineral treatment.

As the processing of liquid and gaseous hydrocarbons is not within the scope of this document, refining is not discussed in this subsection. Further information on refining processes can be found in the BREF for the Refining of Mineral Oil and Gas (Barthe *et al.* 2015).

9.2.1 Commonly applied techniques for comminution and beneficiation

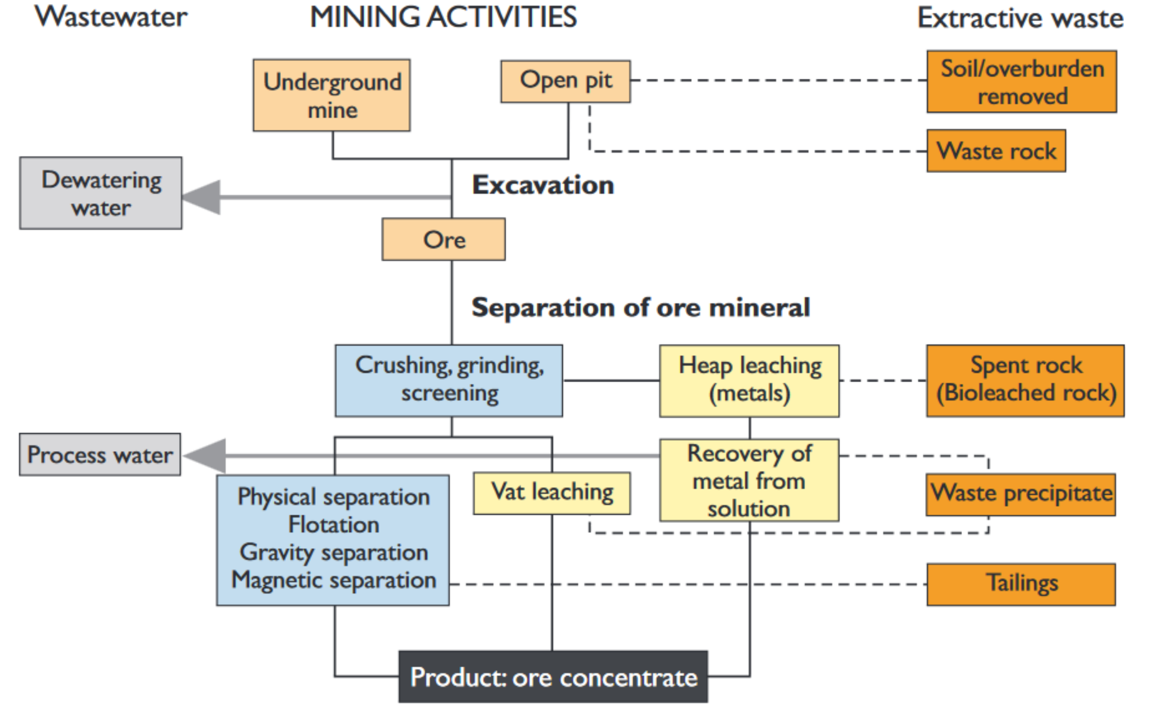
When it comes to the extractive industries, mineral treatment is an important step after extraction, aiming at producing the next product: e.g. the concentrate.

Generally speaking, mineral treatment consists of two main steps (Grewal 2016; Kauppila *et al.* 2013):

- The first step, the comminution, is to reduce the size of the extracted materials and prepare the ore for the next step. Comminution consists of crushing, grinding, screening and classification steps. During that stage of the process, the ore is transformed into a granular material with a specific grain size depending on the mineral. The grain size is selected to allow the liberation of the targeted minerals during the beneficiation stage.
- The second step, the beneficiation, is to separate the valuable mineral resources from the rest of the ore, known as the gangue, in order to concentrate one or more targeted mineral resources in a product, also called concentrate. Beneficiation can be achieved using one or a combination of the following types of processes:
    - sorting;
    - gravity concentration;
    - magnetic separation;
    - electrostatic separation;
    - flotation processes, also called froth flotation;
    - leaching processes, e.g. vat leaching, tank leaching, heap leaching, hot leaching;
    - dewatering.

Other processes based on pyrometallurgy and electrometallurgy, e.g. electrowinning, are not described in this section as these processes are not within the scope of this document.

Figure 9.3 summarises the different mineral processes usually associated with the extraction operations along with the potential extractive waste streams generated.



Source: Best Environmental Practices in Metal Ore Mining 2011 (Kauppila et al. 2013), with the permission of the Finnish Environment Institute

Figure 9.3: General mineral processes and extractive wastes usually associated with the extraction operations

9.2.1.1 Comminution processes

As previously stated, the comminution is an essential element of the mineral treatment. It requires a great deal of expenditure in terms of energy consumption and maintenance. During comminution, the particle size of the ore is gradually reduced. This is necessary for many reasons, e.g.:

- to liberate one or more valuable minerals from the gangue in an ore matrix;
- to achieve the desired size for later processing or handling;
- to expose a large surface area per unit mass of material, thus aiding specific chemical reactions (e.g. leaching);
- to satisfy market requirements relating to particle size specifications.

Comminution encompasses:

- crushing and screening sequences;
- grinding and classification sequences.

9.2.1.1.1 Crushing

Crushing is the first stage in the comminution process. This is usually a dry operation, which involves breaking down the ore by compressing it against rigid surfaces or by impacting it against hard surfaces in a controlled motion flow.

This process step prepares the ore for further size reduction (grinding) or for feeding directly to the classification and/or concentration separation stages. Extractive waste from mineral processing is usually not generated in this process step.

Typical types of crushers are:

- jaw crushers;

- gyratory crushers;
- cone crushers;
- roll crushers;
- impact crushers.

9.2.1.1.2 Screening

Screening can be defined as a mechanical operation which separates particles according to their sizes and their acceptance or rejection by the openings of a screening face. Particles that are bigger than the apertures of the screens are retained, and constitute the oversized fraction. Conversely, those that are smaller pass through the screening surface, forming the undersized fraction. There are many different types of industrial screens, which may be divided into stationary and moving screens. The most important reasons for screening in mineral treatment are:

- to avoid undersize material entering the crushers;
- to avoid oversize material passing to the later stages in the grinding process or in closed-circuit fine crushing;
- to produce material of controlled particle size, e.g. after quarrying.

Rejected particles (oversize) are returned to the crushing process.

Screening is in some cases associated with washing in order to remove fine particles such as clay.

9.2.1.1.3 Grinding

Grinding of ores is necessary in order to liberate the valuable minerals from the ore matrix, i.e. to reduce the size of the particle up to the liberation size. Grinding is almost the final stage in the comminution process and requires the most energy of all the mineral treatment stages. Because of this, the tendency is to first blast (in the mine) or crush the ore to make it as fine as possible to reduce the amount of larger materials sent to grinding, thereby reducing the overall energy consumption in grinding and, hence, comminution. If possible, grinding is performed "wet" as this requires less energy, allowing energy savings of up to 30 % compared to dry grinding. In grinding, the particles are usually reduced by a combination of impact and abrasion of the ore by the free motion of grinding bodies such as steel rods, balls or pebbles in the mill. A Semi-Autogenous Grinding (SAG) mill and Autogenous Grinding (AG) mill can also be used.

The product of grinding is a fine powder with a particle size ranging from 1 µm to 500 µm.

9.2.1.1.4 Classification

Classification may be described as the separation of solid particles into two or more products according to their velocities when falling through a medium. The velocity of the particles depends on their size, density and shape. In mineral treatment, classification is mostly carried out wet, with water being used as the fluid medium. Dry classification, using air as the medium, is used in several applications (e.g. cement, limestone and coal). Classification is normally performed on minerals considered too fine to be separated effectively by screening.

Different classifiers are:

- settling cones and hydraulic classifiers (cones are used for de-sliming whereas hydraulic classifiers are used either to receive final products such as in the sand industry, or to prepare feed into several particle size ranges for subsequent gravity concentration processes);
- hydro-cyclones;
- mechanical classifiers.

9.2.1.2 Beneficiation processes

The comminution process is followed by a beneficiation process, the main goal of which is to separate and concentrate valuable mineral from the gangue. Techniques used to separate and concentrate the valuable minerals can exploit physical, chemical or physico-chemical properties of the minerals.

9.2.1.2.1 Sorting

Sorting is a separation method where valuable minerals are separated from the gangue based on appearance, colour, texture, optical, electrical and/or radioactive properties.

Ore sorting has been carried out since ancient times. Even though "hand sorting" is nowadays not as common as it once was, mainly due to the large quantities of low-grade ore requiring very fine grinding, it is still applied in some developing countries. The mechanised procedures of sorting can be divided into photometric sorting, radiometric sorting (with uranium ores) and electrical sorting (resistance test, metal detectors).

Photometric sorting is a process where the ore is separated into different fractions after an optical examination. The feed particles must be coarse enough, usually greater than ~ 10 mm, for sorting equipment to produce the desired separation at an acceptable rate. Some detectable characteristics, or combination of properties, must be present to allow the discrimination of the valuable material from the non-valuable material. The basis of the photometric sorter is a light source and a sensitive photomultiplier, used in a scanning system to detect light reflected from the surfaces of the feed. An electronic circuit analyses the photomultiplier signal, which varies with the intensity of the reflected light, and produces control signals to activate the appropriate valves of an air-blast rejection device to take away certain particles selected by means of the analysing process.

For that purpose different types of sensors are available, e.g.:
- Induced Radioacivity;
- X-ray transparency;
- X-ray fluorescence;
- ultraviolet reflectance;
- different heating;
- high/low-voltage conductance;
- laser-induced fluorescence;
- laser-induced plasma;
- laser light scattering;
- near-infrared identification;
- specific gravity.

9.2.1.2.2 Gravity concentration

Gravity concentration is a method of separating minerals of different densities by the force of gravity or by other forces, such as centrifugal forces or the resistance to movement offered by a viscous fluid, like water or air. The motion of a particle in a fluid is dependent not only on its specific gravity, but also on its size and shape. Advanced gravity concentration has proven to be an alternative to flotation and leaching, not least because no reagents are required.

Different gravity concentrators are:
- dense media/medium separation, also called heavy media separation;
- jig;
- shaking tables;

- spirals;
- cones.

Generally, gravity separation is chosen when a relatively coarse particle size is required for an adequate degree of mineral liberation, and the difference in density between the valuable mineral and the gauge is big enough for gravity separation. Gravity concentration generally generates more extractive wastes than froth flotation. In some cases however, when the mineral is fine enough, gravity concentration can be as productive as froth flotation.

9.2.1.2.3 Magnetic separation

Magnetic separation is based on the different magnetic properties of minerals. In general, minerals can be divided into two groups according to their magnetic characteristics: diamagnetic, and paramagnetic or ferromagnetic.

Diamagnetic materials are repelled by a magnet. The forces involved are too small to enable diamagnetic materials to be concentrated magnetically.

Paramagnetic and ferromagnetic materials are attracted to a magnet. Paramagnetic materials are attracted weakly to a magnet but can be concentrated in high-intensity magnetic separators. Ferromagnetic materials are attracted to a magnet, and this attraction is much stronger than with paramagnets. Consequently, "low-intensity magnetic separators" are applied to concentrate them.

Different magnetic separators are:
- dry high intensity;
- wet high intensity;
- dry low intensity;
- wet low intensity.

9.2.1.2.4 Electrostatic separation

Electrostatic separation is a method which utilises forces acting on charged or polarised bodies in an electric field to carry out mineral concentration. Different mineral particles, depending on their conductivity, will follow different paths in an electric field, making it possible to separate them. Significant factors in this process include the mechanical and electrical characteristics of the separator and the size, form, specific gravity, surface condition and purity of the mineral particles. Mineral particles have to be entirely dry and the moisture of the surrounding air must be controlled.

Electrostatic separators can be divided into:
- plate electrostatic separators;
- screen electrostatic separators.

9.2.1.2.5 Froth flotation

In flotation, the separation of minerals is accomplished by exploiting the differences in their physico-chemical surface properties. For instance, after conditioning with reagents, some particles become water-repellent or hydrophobic (aerophilic), while other particles remain hydrophilic. In the selective separation process, finely dispersed air bubbles are injected into the pulp, which on their way to the surface will stick to the hydrophobic particles, lifting them to the water surface and forming a stable froth, which is removed. The hydrophilic particles remain within the pulp and are discharged. Flotation processes generally consist of several stages to clean the concentrates again and to scavenge the remaining valuable minerals from the extractive waste from mineral processing.

The reagents used in the flotation process are usually the following:

- Collectors: surfactant added to the pulp and adsorbed onto the mineral surface in order to make the attachment of air bubbles possible. Two main groups of collectors exist:
    - non-ionising (usually hydrocarbons); and
    - ionising.
      Ionising are divided into:
        - cationic (based on pentavalent nitrogen); and
        - anionic collectors.
          Anionic collectors are usually subdivided into:
            - oxyhydryl (carboxylic, sulphates and sulphonates); and
            - sulphydryl (xanthates and dithiophosphates).
- Frothers: heteropolar surface-active reagents added to the pulp to stabilise bubble formation (prevent them from collapsing) and create conditions for froth formation. Frothers usually include in their composition a:
    - hydroxyl group (the most widely used: e.g. pine oil, terpineol, cresol, methyl isobutyl carbinol, polyglycols or polyglycol ethers);
    - carboxyl group;
    - carbonyl group;
    - amino group; and/or
    - sulpho group.
- Regulators or modifying reagents: reagents used to control the interaction of collectors with the minerals in order to make the selective adsorption of collectors on the targeted mineral possible, thus making possible the separation and isolation of different minerals in the flotation process of complex ores. Regulators can either:
    - react with the mineral surface to increase adsorption of collectors (activators: e.g. soluble salts such as copper sulphate); or
    - remove collector coatings from the mineral surface (depressants: e.g. inorganics such as cyanides, ferric chloride and zinc sulphate, or polymeric depressants); or
    - change the pH of the pulp (pH modifiers: e.g. acids such as sulphuric acid or bases such as sodium hydroxide or lime).
- Flocculants, coagulants and dispersants: reagents used in the process in order to promote the agglomeration of particles into flocks. Two main group of flocculants are used:
    - inorganic: e.g. lime, aluminium sulphate, ferrous sulphate or ferric chloride;
    - organic: natural (e.g. guar gum, starch or polysaccharides) or synthetic flocculants (non-ionic polymers such as polyacrylamides, polyelectrolytes such as acrylate-acrylamides and co-polymers).

Flotation machines are divided mainly into two groups:

- pneumatic;
- mechanical.

9.2.1.2.6 Leaching

Leaching is a method where valuable minerals are selectively dissolved from the gangue with a solvent, usually an aqueous solution, resulting in a rich solution with a high concentration of valuable compounds. Afterwards, the valuable mineral needs to be recovered, for instance by precipitation. The valuable mineral or compound can appear in the material being leached in at least three physical forms: as free particles, as multiphase particles in which the valuable mineral is exposed on at least one side to the solvent, and as inaccessible material surrounded by gangue material. In the first two cases, the valuable mineral can be directly leached.

There are several techniques for leaching. These can be grouped into fixed bed procedures, such as percolation leaching, heap leaching, and leaching in a pulp in movement, such as in agitation leaching (tank leaching) and pressure leaching.

Heap leaching: this is a technique where run-of-mine, which can be crushed (generally > 5 mm) and/or agglomerated if necessary, is stacked over an engineered impermeable and lined pad. Under atmospheric conditions, a leaching solution, percolates through the heap, and leaches out valuable minerals. The solution containing the valuable minerals, called pregnant solution, is drained and collected in a storage pond. The valuable minerals are recovered from the pregnant solution, whereas the remaining solution (barren solution) is recycled to produce a new leaching solution. Heap leaching requires longer time periods (weeks to months, even several years in bio-processes) for each pad loading sequence compared to tank leaching (hours to days). Upon completion of heap leaching, the processed ore stack is generally decommissioned in place. In some operations, processing is done on a lined surface that is covered with stabilised surface (on/off pad) to allow removal of the processed ore, usually by loaders or mechanised equipment. The processed ore is moved to a lined facility (spent ore repository) for final closure and reclamation, and the lined surface is re-used. Heap leaching allows the economical processing of low-grade ores.

Tank leaching: this is a technique where crushed/milled ores or flotation concentrates are chemically treated in open tanks under atmospheric pressure conditions to extract valuable minerals from the ore at an accelerated rate. This technique, also called a "semi-closed system", requires the handling and grinding of all run-of-mine ores and disposal of processed materials (tailings) or, if a heap leaching facility is present, the dewatered tailings may be sent to the leach pad for heap leaching. Additional tank leaching can be performed after pressure oxidation or roasting to capture any residual metal.

Pressure leaching: this is a technique where ground ores or flotation concentrates are chemically treated in reactors (autoclaves) under high pressure and temperature, in order to extract valuable minerals from the ore at an accelerated rate. This technique, also called a "closed system", requires the handling and grinding of all run-of-mine ores and disposal of treated materials (tailings).

In-situ leaching: see solution mining (Section 9.1.2.3).

Biological leaching refers to a leaching technique where the bacteria *thiobacillus ferrooxidans* and *thiobacillus thiooxidans* help in the leaching process.

9.2.1.2.7 Dewatering

Dewatering is an important step in mineral treatment. The main objective of dewatering is to remove water from the processed ore as it allows an easier handling and transport of concentrates. In addition, dewatering is also a technique applied for the management of extractive waste from mineral processing. The main benefit of dewatering is to enable the recycling of water extracted from the ore. Costs for dewatering depend considerably on the technique applied.

The different dewatering techniques are:
- thickening;
- filtration;
- centrifuging;
- thermal drying.

Thickening
Thickening is extensively applied in pre-dewatering of concentrates and in dewatering of extractive waste from mineral processing for water recovery, due to its comparatively low cost

and high capacities compared to filtration. Intermediate thickening is also applied in several mineral treatment techniques.

Thickening is a sedimentation process that results in a large increase in the concentration of the suspension and in the formation of a clear liquid. Thickeners are tanks from which the settled and thickened solids are removed at the bottom as an underflow and the clear liquid flows to an overflow point or launder system at the top. They may be batch units, such as the baffle-plate thickener, or continuous units. Continuous thickeners are normally constructed of a cylindrical tank made of steel (usually less than 30 m in diameter), concrete or a combination of both with the depth ranging from approximately 1 m to 7 m and the diameter from approximately 2 m to 200 m. In the tank, there will be one or more rotating radial arms, each possessing a series of blades. These blades rake or scrape the settled solids towards the underflow withdrawal point. There are several types of continuous thickeners, for instance bridge thickeners, centre pie thickeners, traction thickeners, tray thickeners and high-capacity thickeners.

Source: (EC-JRC 2009)

Figure 9.4: Continuous thickeners

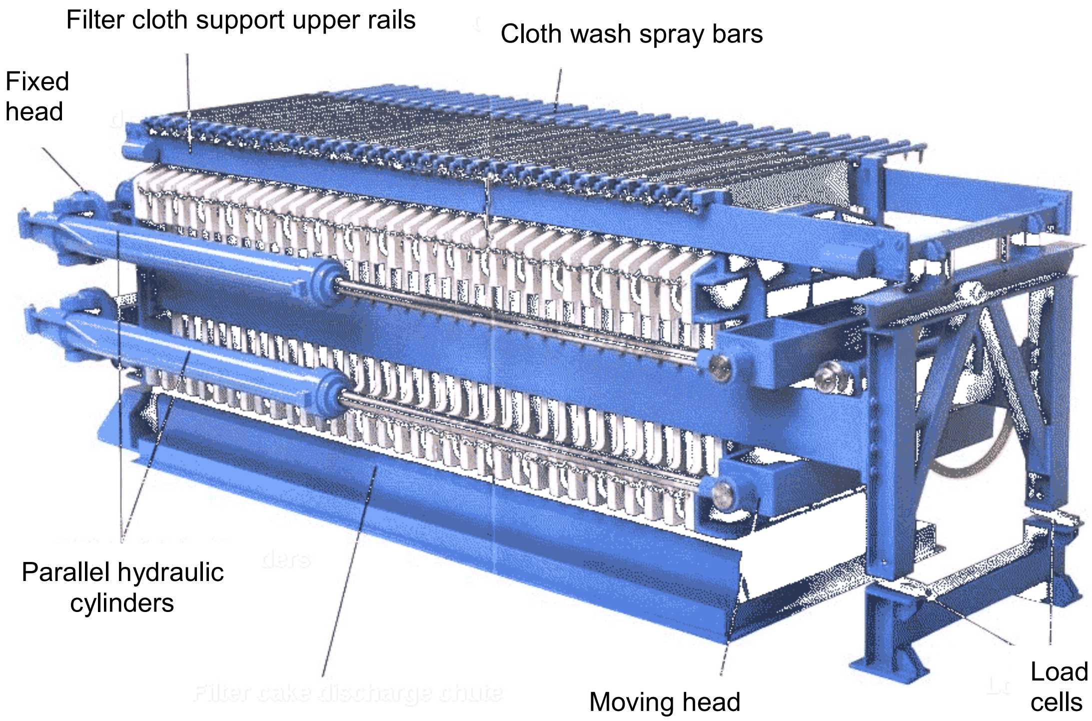
Filtration

Filtration is used for dewatering of flotation concentrate, magnetic concentrates and several non-metallic minerals; removing pregnant solution from the leached solid in the cyanide process; washing the dewatered filter cake; clarifying decanted pregnant solution and in collecting precipitate.

Filtration can be regarded as the process of separating solids from a liquid by means of a permeable septum, which holds the solid but allows the passage of liquid. Filtration often follows thickening, whereby the thickened pulp may be fed to storage agitators where flocculants are sometimes added and from where it is drawn off at a uniform rate to the filters. The most common types of filters employed in mineral treatment are cake filters in which the principal requirement is the recovery of large solid amounts from relatively concentrated slurries. Cake filters are essentially classed as vacuum filters and pressure filters, depending on the means employed to provide the required pressure difference on the two sides of the porous medium. They may also be batch or continuous types.

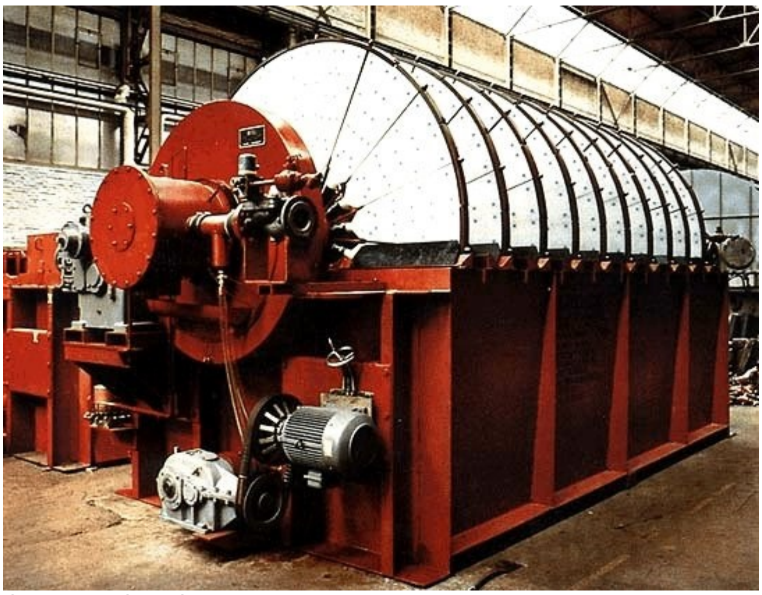
The most frequently utilised types of pressure filters are filter presses, which are constructed in two main forms: the plate-and-frame filter press and the chamber press. The operating pressure in the plate-and-frame press can reach 25 bars.

On the other hand, there are several types of vacuum filters, such as continuous drum filters (made in a wide variety of designs), continuous disk filters and horizontal belt filters.



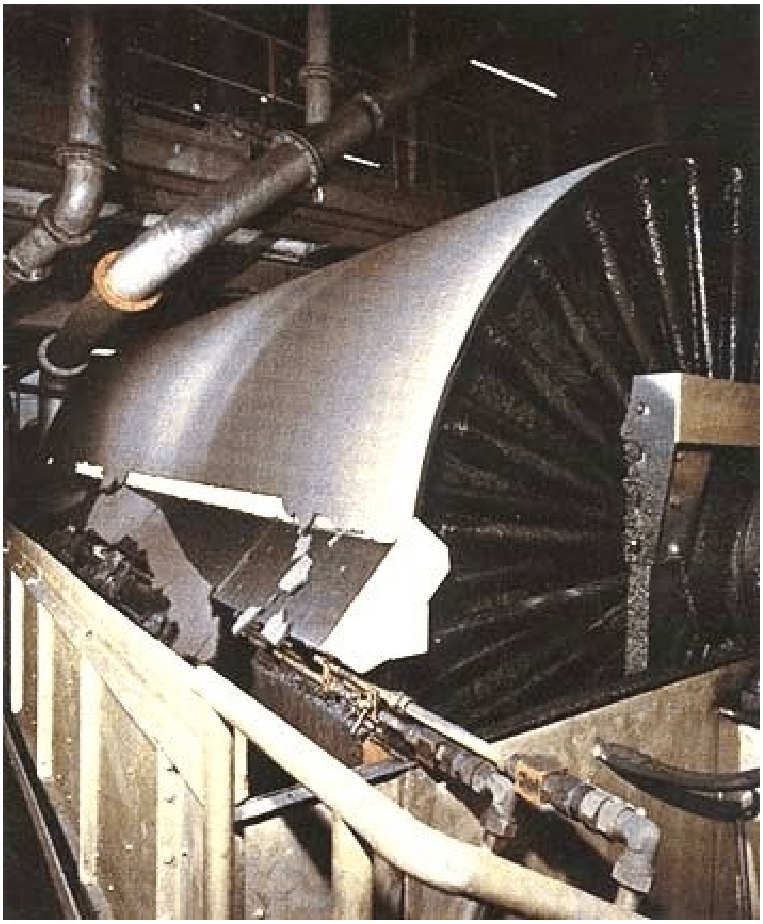
Source: (EC-JRC 2009)

Figure 9.5: Plate-and-frame filter press



Source: (EC-JRC 2009)

Figure 9.6: Drum filter



Source: (EC-JRC 2009)

Figure 9.7: Disk filter

Centrifuging

As an alternative to plate-and-frame filter presses, solid bowl centrifuges are used for dewatering.

Dewatering by means of centrifuges results in a lower solids content compared to plate-and-frame filter presses. Therefore, the dewatered material behaves more like a jelly than a cake. Flocculants have to be added for optimal results.

9.2.2 Other specific techniques and processes

9.2.2.1.1 Production of aggregates

As previously stated, quarries are usually surface mines for extraction of dimension stones and aggregates. Dimension stones are excavated and cut into the required dimensions whereas the materials extracted to produce aggregates are processed with crushers, e.g. jaw crushers, gyratory crushers, cone crushers, impact crushers, roll crushers, in order to reach the targeted particle size. The crushing process is followed by a screening process which aims at separating and classifying the crushed materials into different classes of aggregates, i.e. different particle sizes, from coarse to fine. The crushing and screening processes are the same as the ones described in Section 9.2.1.1 on comminution processes. In quarries, these processes can be carried out directly after excavation in the quarry itself.

The crushing and screening processes can be followed, when necessary, by a washing process. In some cases, production of aggregates, sand and gravel will require a washing step to remove deleterious materials such as clay and silt.

The washing is usually performed on a washing screen where the aggregates are sprayed with water. If additional washing is necessary, washing trommels or scrubbing barrels can be used. In the case of materials that are particularly difficult to wash, log washers can be used. Log washers are made of two counter-rotating steel logs/shafts fitted with blades in order to agitate and scrub the aggregates.

Sand is produced by separation of sand from silt and clay. This is achieved using classifiers such as the ones used for comminution processes in mines or dry screens (see Section 9.2.1.1).

Typical classifiers used in the quarrying processes are:
- free-settling classifiers;
- horizontal current classifiers;
- hindered settling classifiers;
- elutriators;
- hydro-cyclones;

In some cases, if the sand contains organic matter such as lignite, a washing step will be necessary to remove the lignite.

The extractive waste generated during the quarrying processes is usually the suspension of silt and clay in the process water used for the washing steps.

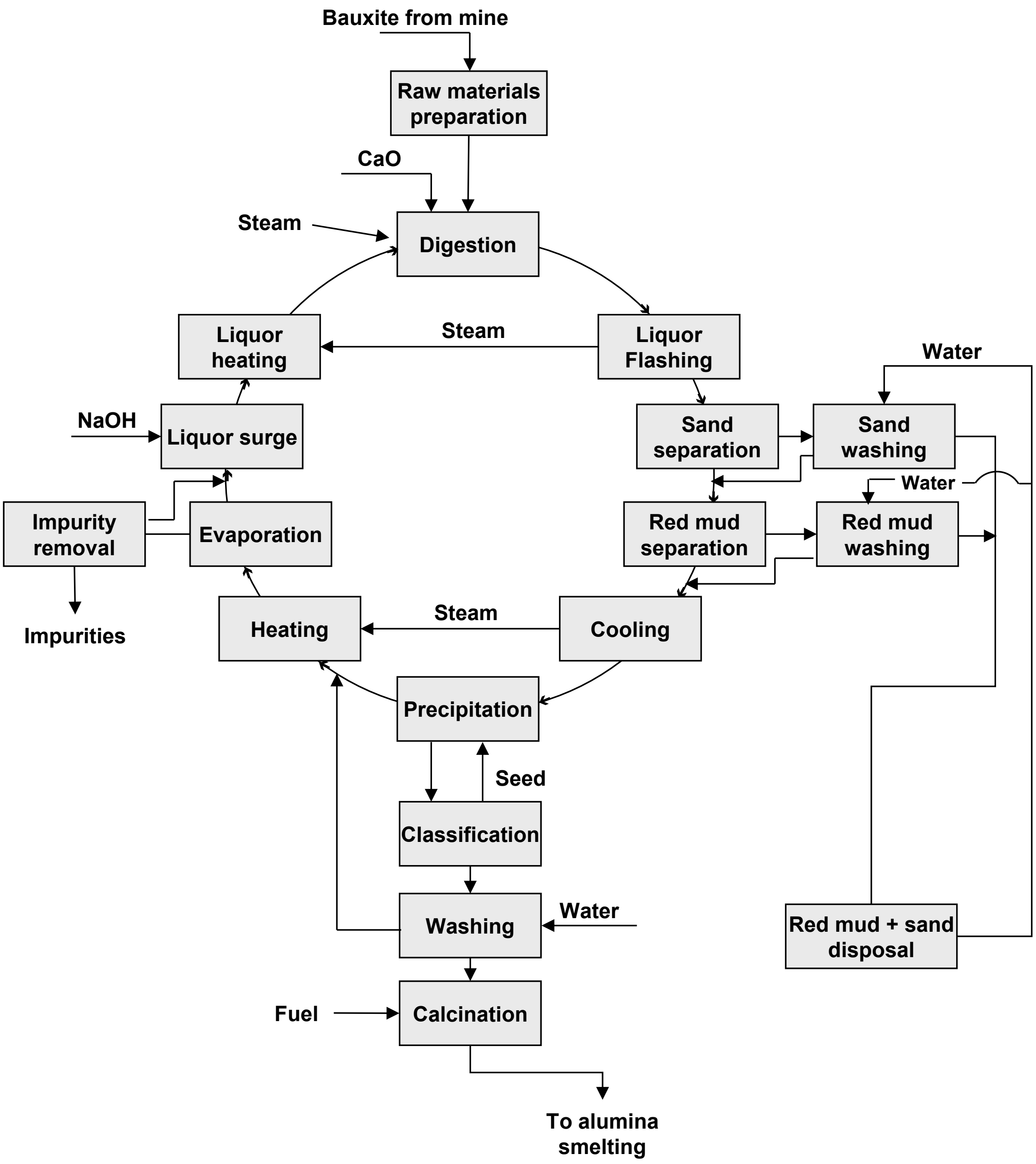
When needed, dewatering techniques, mainly silt lagoons and settlement ponds but also techniques described in Section 9.2.1.2.7 can be used in quarrying processes to clarify and recycle water, and to separate the solid fraction to reduce the volume of materials to be handled.

9.2.2.1.2 Alumina refining

Alumina refining is the process that uses bauxite as a raw material to produce alumina. Alumina is a white granular material and is properly called aluminium oxide. The Bayer refining process used by alumina refineries worldwide involves four steps - digestion, clarification, precipitation and calcination.

Alumina is converted into aluminium via smelting, and these techniques are described in the BREF on Non-ferrous Metals Industries (Cusano *et al.* 2017).

The digestion (dissolution) of aluminium "hydrate" (e.g. $Al_2O_3 \cdot 3H_2O$) from the bauxite is carried out under pressure in high-temperature (around 250 ºC) sodium hydroxide. The insoluble particles, sand and red mud, are separated by cycloning, decantation, and, after washing and filtration, are deposited in the extractive waste deposition area (including the EWF). The aluminium hydrate is precipitated as a white slurry and dried to produce alumina (Al_2O_3), a white crystalline product in particles of ~ 90 µm size. Four to six tonnes of bauxite are needed to produce two tonnes of alumina and subsequently one tonne of aluminium (EC-JRC 2009).



Source: (EC-JRC 2009)

Figure 9.8: Typical flowsheet of the Bayer process

This process is normally carried out close to the mine site but there are sites in Europe where bauxite is converted to alumina at the same site as the aluminium smelter or at stand-alone alumina refineries.

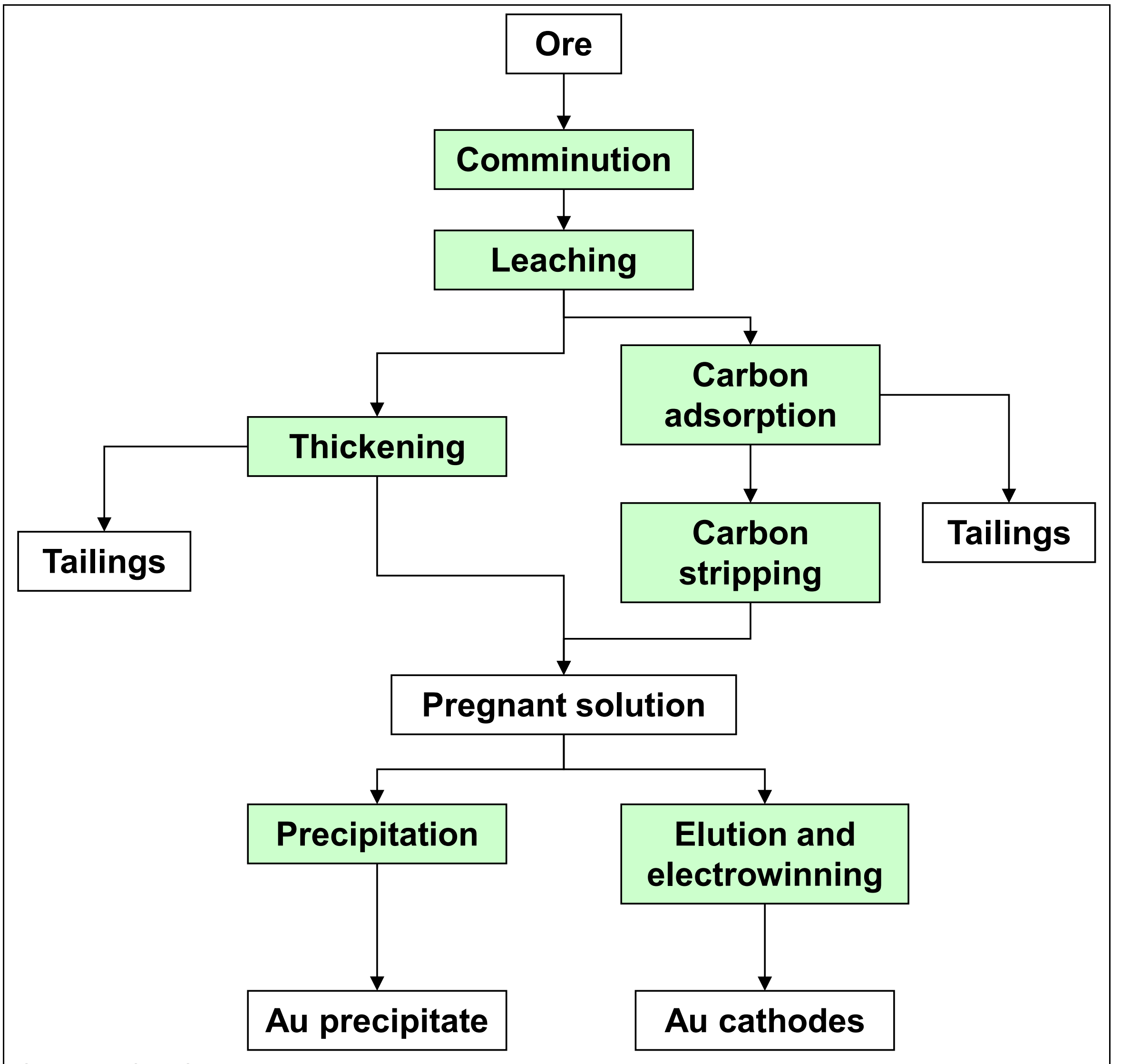
More information about alumina refining is available at:
http://bauxite.world-aluminium.org/refining/process.html

9.2.2.1.3 Gold leaching with cyanide

Gold leaching is applied to run-of-mine ore or is integrated into the other mineral treatment steps, e.g. after comminution and gravity separation or flotation. Therefore leaching is generally considered to be part of mineral treatment. Other minerals may be leached and other leaching solutions besides cyanide can be used, e.g. salt can be leached or dissolved with water, or copper may be leached with sulphuric acid. Nonetheless, due to the high toxicity of cyanide and public concern about its use in the extractive industry, this section focuses on the use of cyanide in the leaching of gold. It should also be noted that, depending on the gold deposit, cyanide may not be used.

Use of cyanide in the gold industry

Gold typically occurs at very low concentrations in ores, i.e. less than 10 g/t or 0.001 %. At these concentrations, the use of hydrometallurgical extraction processes, i.e. based on aqueous chemistry, are the only economically viable methods of extracting the gold from the ore. Typically hydrometallurgical gold recovery involves a leaching step during which the gold is dissolved in an aqueous medium, followed by separation of the gold-bearing solution from the residues or adsorption of the gold onto activated carbon and finally gold recovery either by precipitation or elution and electrowinning (see the following figure).



Source: (EC-JRC 2009)

Figure 9.9: The principles of gold recovery by leaching

Often a gravity separation circuit is incorporated into this process after comminution to recover the sufficiently coarse gold particles (> 30 µm) prior to leaching. The use of gravity separation in the field of gold recovery is rapidly advancing into ever smaller particle sizes.

Gold is one of the noble metals and, as such, is not soluble in water. The presence of a complexing agent, such as cyanide, which stabilises the gold species in solution, and an oxidant, such as oxygen, are required to dissolve gold. The amount of cyanide in solution required for dissolution may be as low as 350 mg/l or 0.035 % (as 100 % NaCN).

Alternative complexing agents for gold, such as chloride, bromide, thiourea, and thiosulphate are available but form less stable complexes and, thus, require more aggressive conditions to dissolve the gold. These reagents are often more expensive to use and/or also present risks to health and the environment. This explains the continued dominance of cyanide as the primary reagent for the leaching of gold from ores.

Ore preparation

The aim of ore preparation is to ensure optimum economic recovery of the gold in the presence of the leaching solution (the aqueous cyanide solution). The first step in ore preparation is crushing and grinding, which reduces the particle size of the ore and liberates the gold for recovery.

Ore that contains free gold may not yield a sufficiently high recovery by means of cyanide leaching only, and may require a gravity recovery process where the free gold is recovered before the remainder of the gold is subject to cyanide leaching.

Gold-bearing ores that contain gold associated with sulphide or carbonaceous minerals require additional treatment, besides size reduction, prior to gold recovery. Gold recovery from sulphide ore is poor because the cyanide preferentially leaches the sulphide minerals rather than the gold, and cyanide is consumed by the formation of thiocyanate. These ores are subject to a concentration process, such as flotation, followed by a secondary process to oxidise the sulphides, thus limiting their interaction with the cyanide during the gold leach. Carbonaceous minerals adsorb the gold after it has been dissolved. This is prevented by oxidising the ore prior to leaching. The leaching process may also be modified to counter this effect, by the addition of activated carbon to preferentially adsorb the gold.

Leaching with aqueous cyanide solutions

Gold is leached in aqueous cyanide by oxidising it with an oxidant such as DO and complexing it with cyanide to form a gold-cyanide complex. This complex is very stable and the cyanide required is only slightly in excess of the stoichiometric requirement. However, in practice, the amount of cyanide used in leach solutions is dictated by the presence of other cyanide consumers and the need to increase the rate of leaching to acceptable levels.

In practice, the typical cyanide concentrations used range from 300 mg/l to 500 mg/l (0.03 % to 0.05 % as NaCN), depending on the mineralogy of the ore. The gold is recovered by means of either heap leaching or agitated pulp leaching.

With heap leaching, the ore or agglomerated fine ore is stacked in heaps on a pad lined with an impermeable membrane. The term "dump leaching" is sometimes applied to heap leaching of uncrushed ore. Cyanide solution is introduced to the heap by sprinklers or a drip irrigation system, the solution percolates through the heap, leaching the gold from the ore. The gold-bearing solution is collected on the impermeable membrane and channelled to storage facilities for further processing. Heap leaching is attractive due to the low capital cost involved, but is a slow process and the gold extraction efficiency is also relatively low.

In a conventional milling and agitated leaching circuit, the ore is milled in semi-autogenous ball or rod mills to the consistency of sand or powder. The milled ore is conveyed as slurry to a series of leach tanks. The slurry is agitated in the leach tanks, either mechanically or by means of air injection, to increase the contact of cyanide and oxygen with the gold and to enhance the efficiency of the leach process. As mentioned earlier, the cyanide dissolves gold from the ore and forms a stable gold-cyanide complex.

The pH of the slurry is raised to pH 10-11 using lime, at the head of the leach circuit to ensure that when cyanide is added hydrogen cyanide gas is not generated and the cyanide remains in solution and hence available to dissolve the gold. The slurry may also be subject to other preconditioning, such as pre-oxidation at the head of the circuit, before cyanide is added.

Where oxygen instead of air is used as the oxidant, it has the advantage of increasing the leach rate and also decreasing cyanide consumption due to the inactivation of some of the cyanide-consuming species present in the slurry.

Where carbon is used to recover the dissolved gold, highly activated carbon is introduced into the process, either directly into the leach tanks (referred to as Carbon-in-Leach (CIL)) or in separate tanks after leaching (referred to as Carbon-in-Pulp (CIP)). The activated carbon adsorbs the dissolved gold from the solution component of the leach slurry, thereby concentrating it onto a smaller mass of solids. The carbon is then separated from the slurry by screening and subjected to further treatment to recover the adsorbed gold, as described below.

Where carbon is not used to adsorb the dissolved gold in the leach slurry, the gold-bearing solution must be separated from the solids component of the slurry, utilising filtration or thickening units. The resultant solution, referred to as pregnant solution, is subjected to further treatment (other than by carbon absorption) to recover the dissolved gold, as discussed under gold recovery.

The material from which the gold has been removed by adsorption or liquid/solid separation is referred to as extractive waste from mineral processing. The extractive waste from mineral processing is either dewatered to recover the water and residual cyanide reagent, treated to either neutralise or recover cyanide, or sent directly to the extractive waste deposition area (including the EWF).

<u>Recovery of dissolved gold</u>
The gold is recovered from the solution by using cementation on zinc powder (the so-called Merrill-Crowe process) or by first concentrating the gold using adsorption on activated carbon, followed by elution and either cementation with zinc or electrowinning. For efficient cementation, a clear solution is required, which is typically prepared by filtration or countercurrent decantation. These are capital-intensive processes and have been superseded by processes using adsorption of the dissolved gold onto activated carbon. Adsorption is achieved by contacting the activated carbon with the agitated pulp. This can be done while the gold is still being leached with the Carbon-in-Leach or CIL process, or following leaching with the Carbon-in-Pulp or CIP process. Activated carbon in contact with a gold-containing pulp can typically recover more than 99.5 % of the gold in the solution in 8 to 24 hours. The loaded carbon is then separated from the pulp using screens that are air or hydro-dynamically swept to prevent blinding by the near-sized carbon particles. This separation of ore particles (typically < 100 μm) from the coarser carbon particles (> 500 μm) is a lot less capital-intensive than the filtration needed when using the Merrill-Crowe technique).

The fine barren ore, i.e. the extractive waste from mineral processing, is then either thickened to separate the cyanide-containing solution for recovery or destruction of the cyanide, or sent directly to the extractive waste deposition area (including the EWF), where the cyanide-containing solution is often recycled to the leach plant.

The gold adsorbed on the activated carbon is recovered from the carbon by elution, typically with a hot caustic aqueous cyanide solution. The carbon is then regenerated and returned to the adsorption circuit while the gold is recovered from the eluate using either zinc cementation or electrowinning. This gold concentrate is then calcined, if it contains significant amounts of base metals, or directly smelted and refined to gold bullion that typically contains ~ 70-90 % gold. The bullion is then further refined to either 99.99 % or 99.999 % fineness, using chlorination, smelting and electrorefining. Recently developed processes utilise solvent extraction to produce high-purity gold directly from activated carbon eluates, or following intensive leaching of gravity concentrates.

<u>Process operation and the environment</u>
The following are sources of cyanide emissions to the environment:

- CN to air as HCN;
- seepage from ponds containing extractive waste from mineral processing;
- pond discharges required to manage the overall water balance.

It is part of normal operation to attempt to optimise process economics. This coincides with the objective of minimising the impact of cyanide on the environment and cyanide consumption. Process economics are sensitive to the amount of cyanide consumed in the process. Increased cyanide addition may have a "double-barrelled" effect, meaning the operating costs increase through the extra amounts of cyanide that have to be purchased as well as because of the higher amounts of cyanides that will have to be destroyed or recycled prior to EWIW discharge. Cyanide classified as "consumed" from a process point of view may still be active from an environmental perspective, for instance as may be the case with copper cyanide complexes.

9.3 Annex 3. Illustrative case study: BAT proposal for minimum-impact mineral processing concentrator

1. Description

The aim of this case study has been to improve the understanding of the full operational risk of a new copper concentrator during an estimated 15-year mine lifetime. Operational risk was focused on decreasing water stress, environmental hazards, and possible dam break-up. In this example, the main focus has been on conceptual study on simulating and calculating the economics of four different methods to manage extractive waste from mineral processing and their impact on the site water balance. The method selected was found to be the main process to achieve low operational risks and low fresh water demand.

The selected tailings treatment flowsheets that form the basis of this study are

- Case 1: conventional (unthickened, slurried extractive waste see Section 4.2.2.1.1.2);
- Case 2: thickened extractive waste, (see Section 4.2.2.1.1.3);
- Case 3: paste extractive waste and (see Section 4.2.2.1.1.3);
- Case 4: filtered extractive waste (see Section 4.2.2.1.1.4).

All results are applicable to other mineral processing plants with small variations.

2. Technical description

Mineral processing concentrators are increasingly facing large challenges with fresh water availability and quality, as well as new environmental limitations both from the old traditional EWFs as well as the volume and quality of the discharge. The trend of lower grades in mineral deposits is also enlarging EWFs' size and the water consumption. In addition, climate change is having an effect on water supply (IPCC 2014).

This study follows a similar approach to that of van Schaik (Van Schaik *et al.* 2010) in that simulation basis was used to map compounds and total flows with the objective then to perform an environmental analysis to determine the optimal economic solution but also considering the environmental impact (Reuter *et al.* 2015). A comprehensive sustainability indicator framework has recently been developed that combines numerous impacts into one simple result, while comparing it to a benchmark (Rönnlund *et al.* 2016). Water, energy and materials are thence combined and evaluated at the same time.

In summary, the objective of this study is to clarify the difference between the whole mineral process' operational cost during its lifetime with different layouts and extractive waste treatment. The focus was set on environmentally friendly solutions, with minimum fresh water usage, effluent volumes and processes without a dam. This annex develops further the concepts presented by Jansson (Jansson *et al.* 2014).

As the calculation basis, an imaginary 20 Mt/year capacity copper concentrator (porphyry Cu) was set up with an estimated 15-year lifetime. As a turnkey cost basis, we used Finnish cost calculations and the estimated calculation level accuracy is around ±30 % as net present costs. The concentrator plant is equipped with one SAG mill, two ball mills, two lines with eight flotation cells each, one regrinding HIG mill, one concentrate thickener as well as two PF concentrate filters with a storage system.

For the site conditions, the concentrator was placed on flat area in temperate climatic conditions. Fresh water intake was determined to be ~ 10 km away from the concentrator with a 25 m static head. The extractive waste area was also located 10 km away from the concentrator with a 25 m static head.

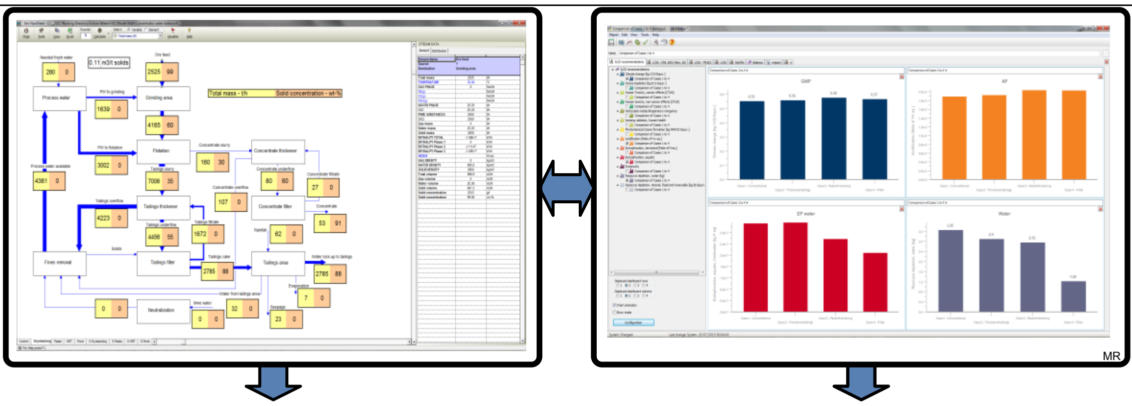
A study limitation is that no mine water, freezing conditions, dust control (wind), AMD generated water or earthquakes were taken into account.

For operational costs, a fresh water price of EUR 0.001/m^3 was used, electrical price EUR 100/MWh and labour cost EUR 2 960/month.

3. Achieved environmental benefits

The basic water and material balances were calculated for four different mineral process schemes: Case 1: Conventional extractive waste management; Case 2: Thickened extractive waste management; Case 3: Paste extractive waste management; and Case 4: Filtered extractive waste management following the approach discussed by Reuter and co-authors (Reuter *et al.* 2015).

In all mass balance calculations, the fresh water intake was analysed to estimate the amount needed in the process and thus estimate the fresh (blue) water footprint (WFN 2016). The climatic conditions for the selected site were gathered from (World Climate Guide 2016). The soil seepage capacity was estimated from data collected from mines near the imaginary location for this mineral processing site. All data were put into the Outotec HSC simulation tool to calculate the average flows as shown in Figure 9.10. The simulation tool is a steady-state simulator and it calculates the situation where all material put into the process also leaves the process and does not take into account the normal process variation. These flows were then used as a basis for the cost calculations and also to produce the data used in the environmental footprint software GaBi (Thinkstep 2015) - see internet information for details (Reuter *et al.* 2015).



BAT, Flow Sheets & Recycling System Maximizing Resource Efficiency – Benchmarks

$US / t Product (CAPEX & OPEX)
Recyclability Index (based on system simulation of whole cycle)
Energy: GJ & MWh / t Product (source specific)
Exergy: GJ & MWh / t
kg CO_2 / t Product
kg SO_x / t Product
g NO_x / t Product
m^3 Water / t Product *(including ions in solution)*
kg Residue / t Product *(including composition)*
kg Fugitive Emissions / t Product
kg Particulate Emissions / t Product
Etc.

Environmental Indicators based on BAT Driving Benchmarks of Industry

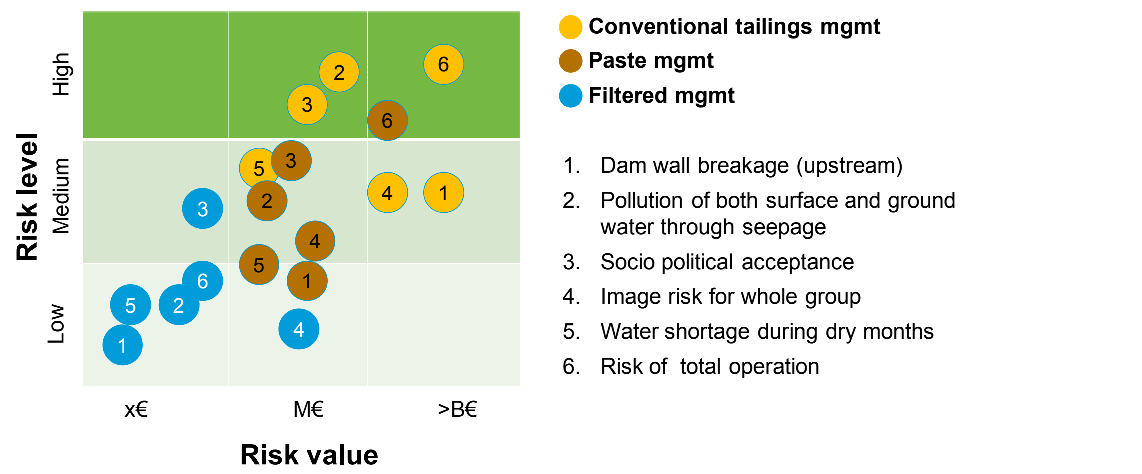
ReCiPe (and similar) – Endpoint estimation
Global Warming Potential (GWP)
Acidification Potential (AP)
Eutrification Potential (EP)
Human Toxicity Potential (HTP)
Ozone Layer Depletion Potential (ODP)
Photochemical Ozone Creation Potential (POCP)
Aquatic Ecotoxicity Potential (AETP)
Abiotic Depletion (ADP)
Water footprint (Green, Blue, Grey)
Etc...

NB: (Left) the HSC simulation of the water system for the four cases and (right) the environmental footprint calculation produced from the simulation results by GaBi
Sources: (Outotec 2016; Reuter et al. 2015; Thinkstep 2015)

Figure 9.10: A summary of the methodology

<u>Risk matrix</u>

For the estimation of the risks allocated to the studied mineral processes, a simple risk matrix, with the risk value in EUR versus the potential risk level was set up with the basic operational risks today in any typical mineral process. Figure 9.11 depicts various scenarios for three solution types and shows their respective risk value and level. In Figure 9.11, the yellow colour indicates conventional extractive waste management, brown for paste and blue for filtered extractive waste. As seen from this evaluation, the highest operational risks are allocated to conventional extractive waste management, and the lowest to the filtered extractive waste.



Source: provided by the TWG

Figure 9.11: Simple risk matrix for estimation of operational risks associated with different extractive waste process

<u>Risks related to the dam wall and its constructions</u>

In order to estimate the costs related to dam construction for conventional, thickened/paste extractive waste, the following dam design constructions were estimated. It should be pointed out that the estimation was made for a completely flat surface (the high end price). It would be of benefit if there were "bowl"-shaped earth structures available, which would lower the estimation towards zero. A naturally formed lake or "bowl" is the cheapest option but typically it is not among the options due to strict environmental legislation. For this study the following could be roughly estimated for the most common dam types:

- Upstream: this option has the highest risk associated to dam wall breaking with the lowest initial costs, making it the most popular one. (See Section 4.2.1.3.3.1.2.1.)
- Downstream: this option has the lowest risk of dam wall breaking, thus the price is the highest due to the biggest amount of material needed for its construction. (See Section 4.2.1.3.3.1.2.2.)
- Centreline as the first modification of the previous ones to achieve a more stable construction than with the upstream model, but with lower investments than the downstream model. (See Section 4.2.1.3.3.1.2.3.)
- Modified centreline as one more modification to achieve a stable construction with lesser investments than for the centreline.

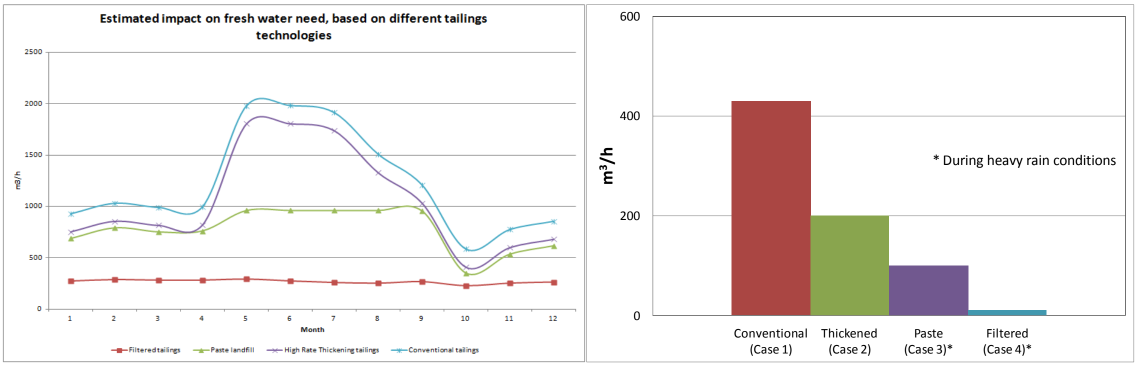
For the calculations in this study, the downstream model was selected to reflect the environmentally sound and sustainable option.

<u>Risks related to the climatic conditions and seepages from EWFs</u>

EWF seepage is considered as a water consumer. As stated before, the concentrator was located in the temperate zone where summers are relatively hot and dry and autumn to spring is wet with lots of rain. The rainfall, evaporation, water locked in to the extractive waste as well as the type of soil under the EWF were used as input for the calculations.

Two different graphs could be produced, showing the average sum of these. Figure 9.12 shows the estimated seepage amount of these four different EWFs, where the highest seepage is related to conventional and thickened ones due to wet conditions. As paste and filtered extractive waste have their water in sand as locked in by capillary forces, then the only accountable and partly recoverable drainage comes during heavy rainfall.

On the basis of Figure 9.12 data, the climate impact on average fresh water demand could be estimated. It can be seen that highest need for water is for the traditional extractive waste management and the paste disposal processes. On the other hand, the filtered extractive waste squeezed most of the water out the extractive waste and therefore has the highest capacity for re-using and conserving the water. The physical appearance is like wet sand.



(a) (b)

(a) seasonal variation and (b) estimated total extractive waste seepage for a 20 Mt/a copper concentrator
Source: provided by the TWG

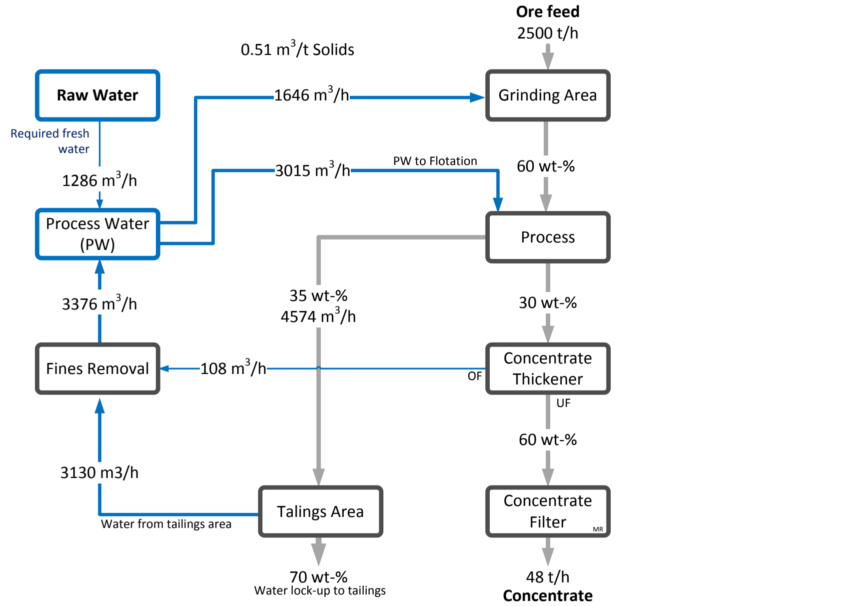
Figure 9.12: Risk related to seepages from EWFs and impact of evaporation and seepage during summer months

The trade-off study simulations and calculations

As the basis for the full operational costs calculation, water and material balances had to be fixed and estimated. Four different estimation were made for conventional, thickened, paste and filtered extractive waste. It should be noted that rainfall, evaporation and seepages are not shown in these simplified process calculations, due to reading clarity reasons (Jansson *et al.* 2014).

Case 1: The simulation results with conventional extractive waste management effects on fresh water usage

Figure 9.13 provides a specific simulation for the conventional option as shown.



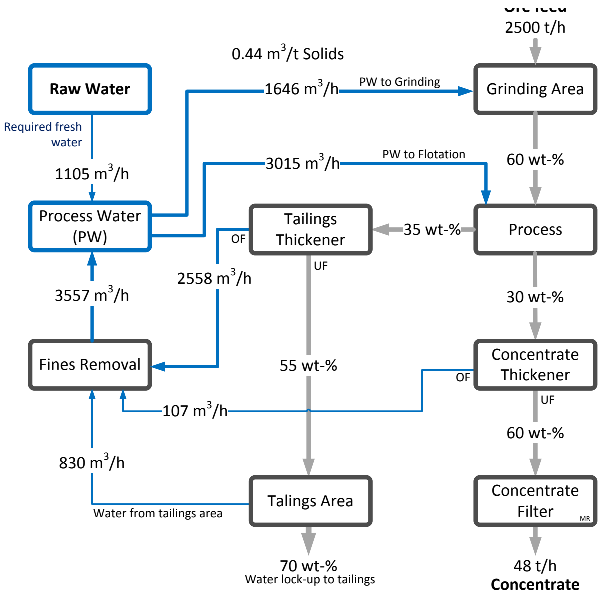
NB: it should be noted that the dam gives the biggest source of variation to the process, both by rainfall, evaporation and filtration and lock-up
Source: provided by the TWG

Figure 9.13: Simplified water balance calculations for conventional extractive waste management

Using the simulation for sensitivity analysis, one can estimate that the average need for fresh water is around 0.6-0.9 m^3/t ore or 1 400 m^3/h with a typical 15 %, for example, addition to the calculation. Thus one has to recognise that during the dry season the fresh water need is doubled. Operational risks in the conventional extractive waste are related to the dam risks, seepages, high water usages, negative/positive water balances which are drivers for sociopolitical risks.

<u>Case 2:</u> The simulation results with thickened extractive waste management effects on fresh water usage

Figure 9.14 shows the impact of thickened extractive waste. A sensitivity analysis with the simulation model showed that the thickened extractive waste method did not decrease the fresh water usage more than ~ 200 m^3/h to a level of 1 200 m^3/h. This means an average fresh water usage of 0.5-0.8 m^3/t ore. From the risk management point of view, the same risks remain as with conventional extractive waste management.

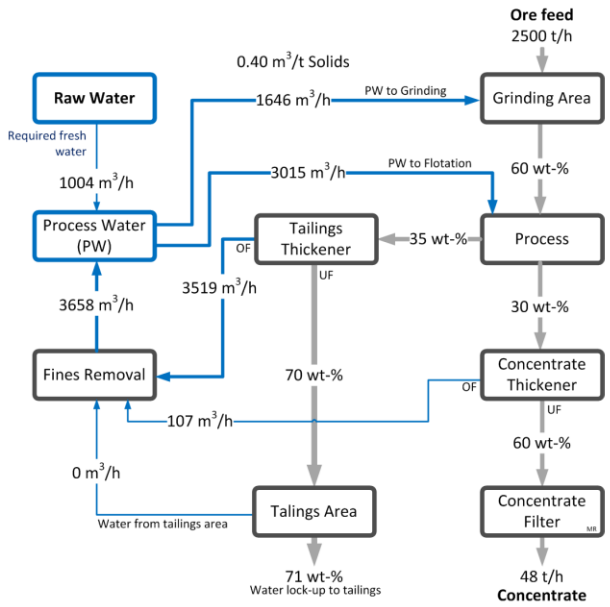


Source: provided by the TWG

Figure 9.14: Simplified water balance calculations for thickened extractive waste management

<u>Case 3:</u> The simulation results with paste extractive waste management effects on fresh water usage

Figure 9.15 shows the effect of a thickened paste option.



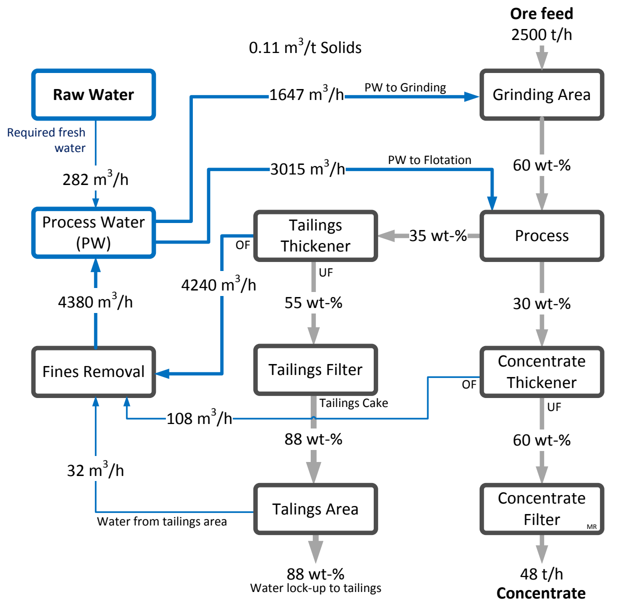
Source: provided by the TWG

Figure 9.15: Water balance calculations for paste thickening.

As the paste thickener underflow is estimated to be near 70 % and the sand lock-in capability 30 %, a very small or no effluent treatment is needed. The fresh water usage is still in the range of 0.45-0.7 m^3/h, and the average need around 1 100 m^3/h including the +15 % needed for the process capacity.

Regarding risk management, many of the same risks as with conventional and thickened waste exist, although they may not be as high. If the possibility of placing back materials into excavation voids exists then the operational risks are very low except for the water-related issues.

<u>Case 4:</u> The simulation results with filtered extractive waste management effects on fresh water usage
Figure 9.16 depicts the significant effect filtration has on the decrease of the use of fresh water.

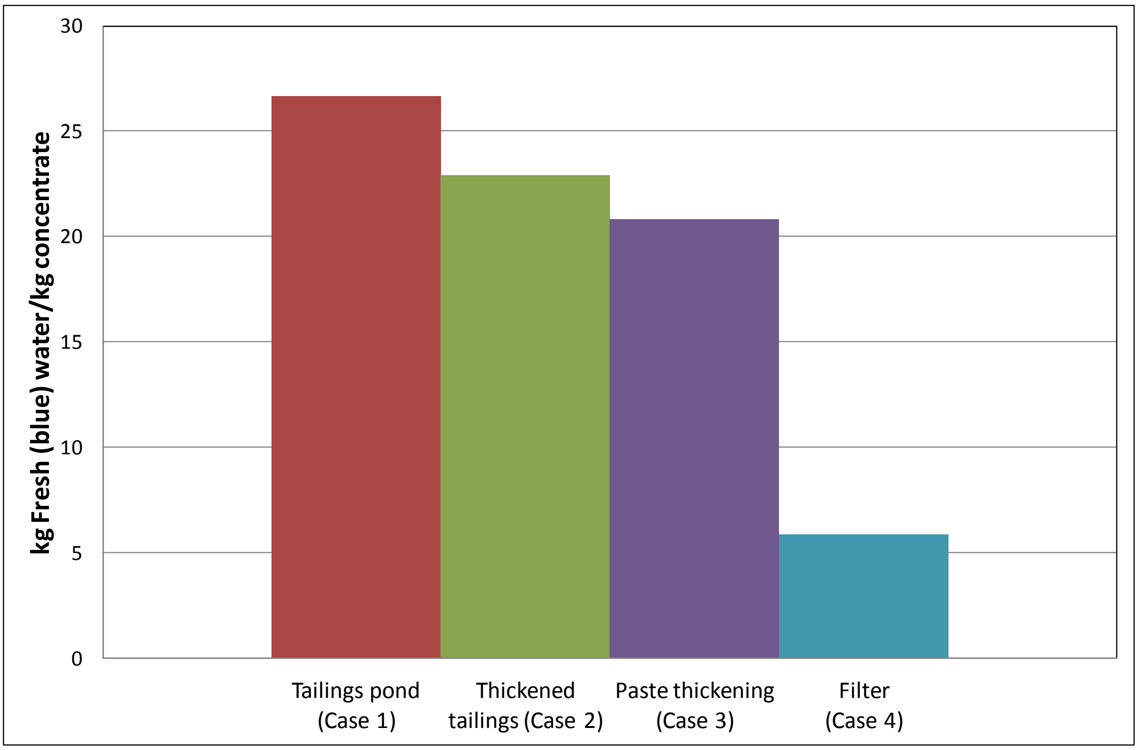


Source: provided by the TWG

Figure 9.16: Simplified water balance calculations for filtered extractive waste

This example shows that the big opportunity for lowering the required fresh water amount comes from the removal of wet extractive waste. In addition, this approach also minimises seepage issues and risk through contaminating groundwater, evaporation losses are minimised, and rainfall does not impact the dry stacking option in the same ways as in the previous three cases. Thus there will be lower operational risks than with the other options. Under optimal conditions, the fresh water usage is estimated to be around 0.1-0.15 m^3/t ore and the fresh water flow around 310 m^3/h including the +15 % as before.

The disadvantage of the filtered extractive waste options comes with the need for "new" and more equipment and technology. Thus a significant result of this study shows that the water (blue) footprint is significantly lower for Case 4 (the filtering option) as shown by Figure 9.17, while not impacting significantly on the carbon footprint, which will become evident from the next section.

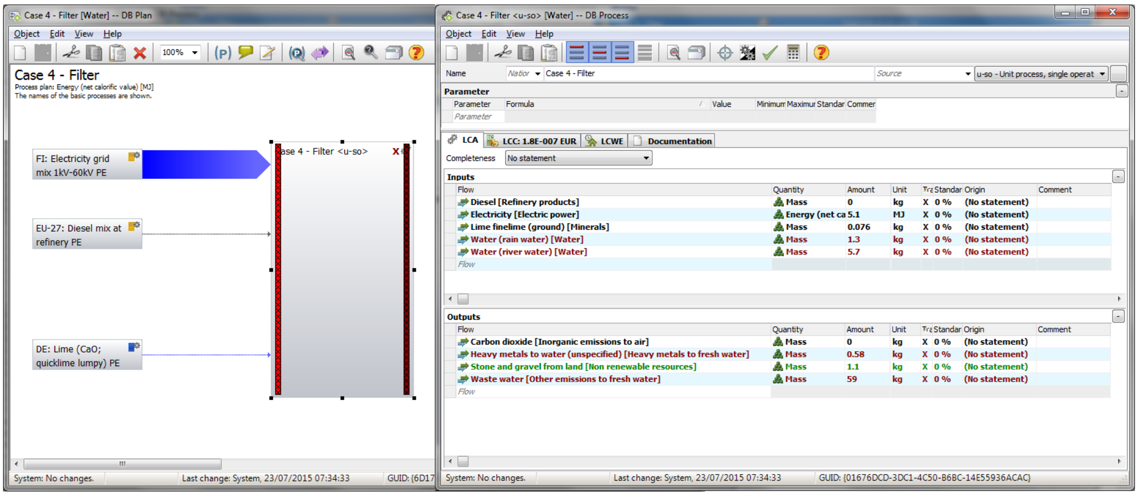


Source: provided by the TWG

Figure 9.17: A comparison of the fresh water footprint of the four cases based on kg output concentrate

4. Environmental performance and operational data

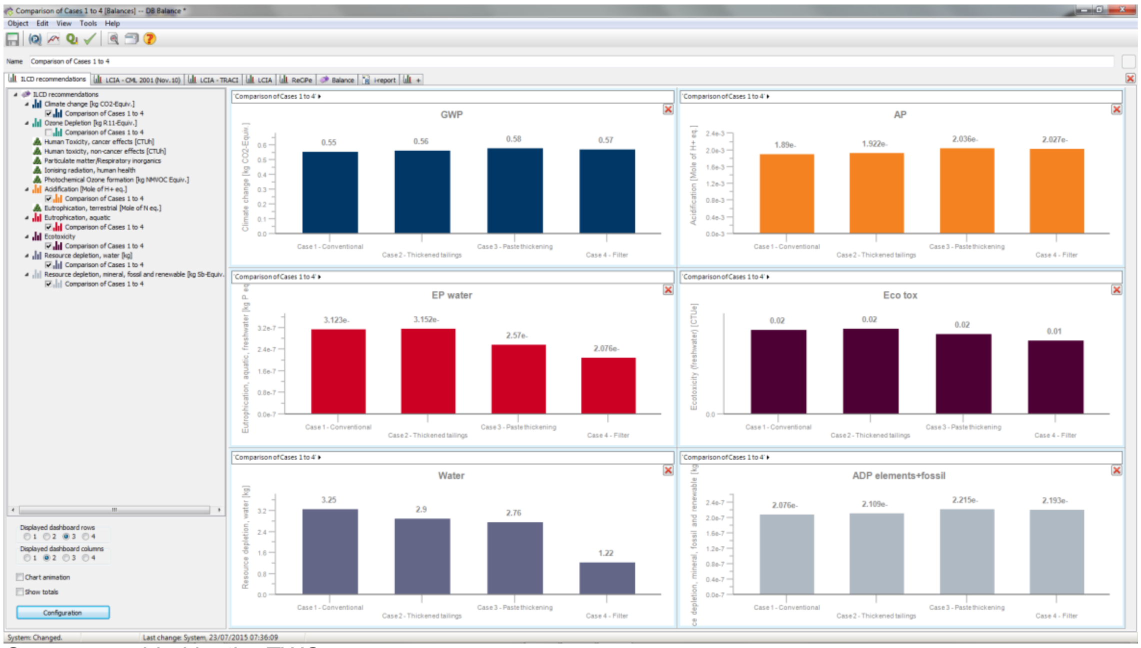
Figure 9.18 shows the data that were applied and the flows included in the analysis. The data have been derived from the simulation models that have been used to generate Figures 9.13 to 9.16.



Source: provided by the TWG

Figure 9.18: The data used for the Case 4 filter option to perform the GaBi analysis

Figure 9.19 shows that there is little difference in the global warming and acidification potential between the four options. However, it is clear that Case 4, due to its lower water usage, has a significantly lower water footprint and also lower impact on water quality as shown by the eutrophication potential and ecotoxicity, noting that the toxicity and eutrophication originate through the various in- and outflows through the system boundaries (e.g. power, diesel, lime).



Source: provided by the TWG

Figure 9.19: The environmental impact analysis for each of the four cases, showing global warming potential (GWP), acidification potential (AP), eutrophication potential (EP-water), ecotoxicity, abiotic depletion (ADP) per kilogram of concentrate

5. Cross-media effects

- Cross media effects were not studied during the assessment.

6. Technical considerations relevant to applicability

Less than 1 % of mining users are applying paste extractive waste landfill or dry stacking in their operations. In general, large-volume dewatering equipment and technologies were not available until 2010. It has impacted conventional methods dominating in the mining business.

Applicability limitations were not found during the study. In some cases, dusting by wind needs to be addressed and scenic value can be preserved by reducing the stacking height.

7. Economics

The cost of water per m^3 or its availability is dictating the selection of new concentrator plants. Based on rough calculations on EPC project costs and operational costs for plants, there is only a minor shift towards a higher CAPEX cost of paste or dry stacking plants with significant savings on OPEX in the long run.

	Total costs €/t-ore in 15 years period				
	CAPEX	OPEX €/t-ore	Total (capex+opex) €/t-ore	Operational Risk	Note
CONCENTRATOR	**254 539**	**3,32**	**4,18**		
CONVENTIONAL					
Tailings handling	3 145	0,05	1,94	HIGHEST	DownStream model
Tailings dam	50 697	1,35			
Water Treatment	39 502	0,15			After use rehability costs excluded
Total w/concentrator	**347 883**	**4,88**	**6,13**		
THICKENED TAILINGS					
Tailings handling	17 845	0,14	2,12	HIGHEST	DownStream model
Tailings dam	50 697	1,35			
Water Treatment	49 024	0,12			After use rehability costs excluded
Total w/concentrator	**372 105**	**4,94**	**6,30**		
PASTE TAILINGS					
Tailings handling	34 631	0,25	1,30	MEDIUM	DownStream model
Tailings dam	25 019	0,45			
Water Treatment	30 591	0,11			After use rehability costs excluded
Total w/concentrator	**344 780**	**4,14**	**5,48**		
FILTERED TAILINGS					
Tailings handling	94 436	0,58	1,25	LOWEST	
Tailings storage	8 448	0,06			
Water Treatment	16 982	0,09			Progressive rehabilitation
Total w/concentrator	**374 405**	**4,05**	**5,43**		

Source: provided by the TWG

Figure 9.20: The economic impact analysis for each of the four cases based on conceptual plant equipment arrangement

8. Driving force for implementation

- The estimated calculation shows that the lowest total operational cost is achieved with the filtered extractive waste. If the paste processes and placing back materials into excavation voids option exist simultaneously, then it will have the lowest cost. It should be noted that in these calculations a fresh water price of EUR 0.001/m^3 was applied. If the water price is higher, then the difference of the filtered extractive waste compared to the other ones is also increased. It should be clear that that the usage of either paste or filtered extractive waste technology decreases the effluent generation to levels of nearly zero.
- Today new environmental challenges are emerging for mineral processing. Risks related to poor fresh water quality and scarcity, wet extractive waste dams and new effluent limitations are growing worldwide. All of these are resulting in new guidelines towards minimum-impact concentrators. Rich mineral deposits are diminishing, and large, low-grade deposits are dominating the greenfield mine projects. From this work it can be concluded that:
    - the future of water management is in more closed water loops and also smaller volumes to overcome higher operational risks;
    - for conventional and thickened extractive waste management the selected EWFs have a huge impact on the total operational risk;
    - paste thickening is a very good alternative with low operational risk if the possibility of placing materials back into excavation voids exists, but it does not solve the water management issues;
    - filtered extractive waste in this study gave the lowest operational risk, with the closest neutral water balance of the four studied;
    - large, low-grade deposits have challenges in fresh water intake, and the ultimate level of recycling of process water becomes standard design of new greenfield plants;
    - the filtering option (Case 4) shows a significantly lower water footprint and impact, while the carbon footprints of the other cases are more or less similar;

- the filtering option with dry stacked extractive waste cake (Case 4) shows a significantly lower land footprint and impact, while the carbon footprints of the other cases are more or less similar.

9. Example sites

- Several example sites exist. Outotec has supplied several references of technologies for dry stacking plants outside the EU, e.g. Australia and Mexico, for iron and gold concentrators respectively.
- For non-ferrous concentrators there are filtered extractive waste and dry stacking plants existing in Alaska, the US and Chile. These are just few examples of the implementation of filtered extractive waste plants.
- Implementation of mineral concentrator plants for paste extractive waste can be found in Australia and Chile. Recently, Outotec has agreed the delivery of one paste extractive waste landfill to a Nordic country.

10. Reference literature

(EC-JRC 2013c)
(Fagan *et al.* 2010)
(Hoekstra *et al.* 2011)
(IPCC 2014)
(Jansson *et al.* 2014)
(Loubet *et al.* 2014)
(Mekonnen and Hoekstra 2012)
(Nair *et al.* 2014)
(Reuter *et al.* 2015; Reuters 2016)
(Rönnlund *et al.* 2016)
(Outotec 2016)
(Van Schaik *et al.* 2010)
(Thinkstep 2015)
(WFN 2016)
(World Climate Guide 2016)

9.4 Annex 4. Illustrative example of final design of heaps in the Ruhr area

Summary

Surrounding rock accrues during the hard coal extraction process. Once the coal has been removed these so-called heaps are transported to slag heaps. At the same time, the design of the slag heaps was historically subject to change. Various demands on the subsequent use also result in various requirements regarding the final design. To accommodate these demands as far as possible is partly beyond the tasks of mining law management procedures and is subject to coordination between the relevant parties.

Introduction

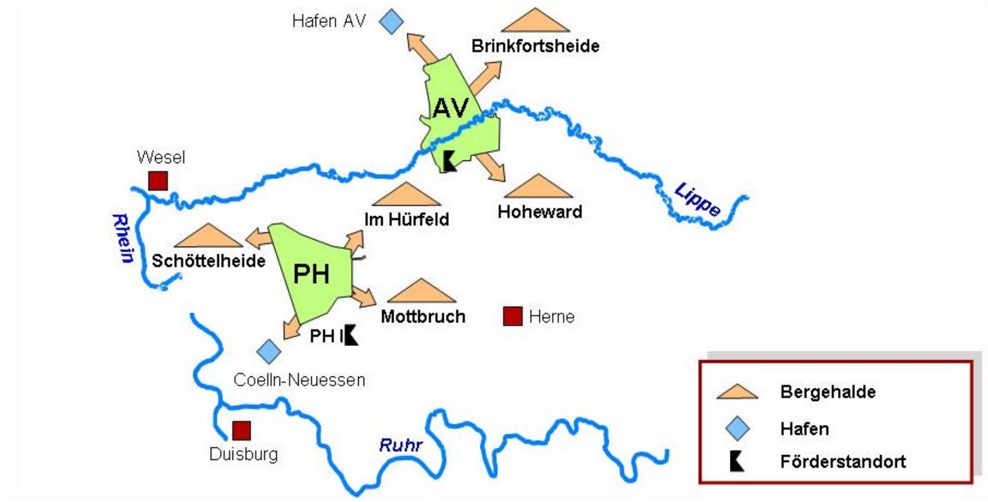
The RAG AG and its legal predecessors have been operating hard coal mines in the Ruhr area for over one hundred years. Surrounding rock accrues during the extraction process of hard coal below ground. The surrounding rock, which is excavated together with the bulk output, is today separated from the hard coal during the coal washing process and accrued as chunky washery dirt or superfine-grained flotation extractive waste.

So-called stowing techniques, i.e. the re-introduction of barren surrounding rock, was already implemented in the early underground engineering. The purely manual excavation required the *in-situ* separation of barren rock which was excavated together with the coal. Here, by pre-sorting the rock, the efforts were focused on leaving the rock *in situ*, in order to save unnecessary transport energy which as a rule meant human muscle power. A further effect was that the chunky rock in connection with the timber provided the protective support for the miners in the coalface. In the course of continuing development, like for example the introduction of the plough as an extraction medium, the mined bulk output became increasingly less chunky so that it was no longer suitable for manual stowing. In areas of inclined or steep formation the dirt material separated above ground was then placed back into excavation voids. For this, gravity was used so that the material could be introduced into the caved areas without any additional energy input.

With an advanced degree of mechanisation, the mining activities moved from level to moderately inclined coal seams. Only by using pressurised air could stowing be introduced into these coal seams. Pneumatic stowing was used in the German hard coal mining industry until the beginning of the 1990s. Since then, dirt material has been transported to slag heaps due to technical reasons.

Active slag heap management in the Ruhr area

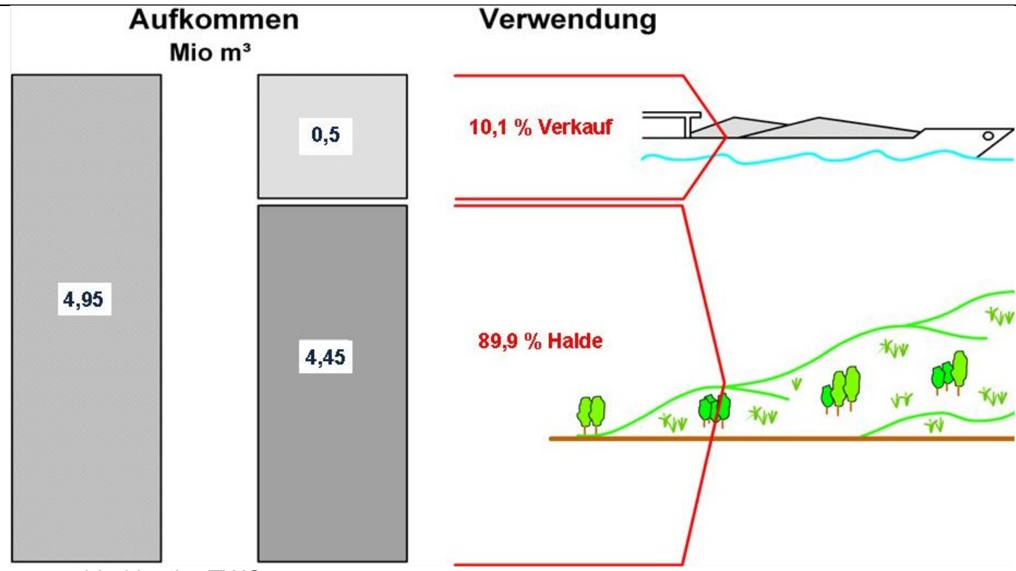
The RAG is operating two active coal mines with three active slag heaps (Figure 9.21). Prosper-Haniel Mine supplies "Schöttelheide" slag heap and "Im Hürfeld" and Auguste Victoria Mine supplies "Brinkfortsheide" slag heap or the "Brinkfortsheide" extension.



Source: provided by the TWG

Figure 9.21: RAG active coal mines with three active slag heaps

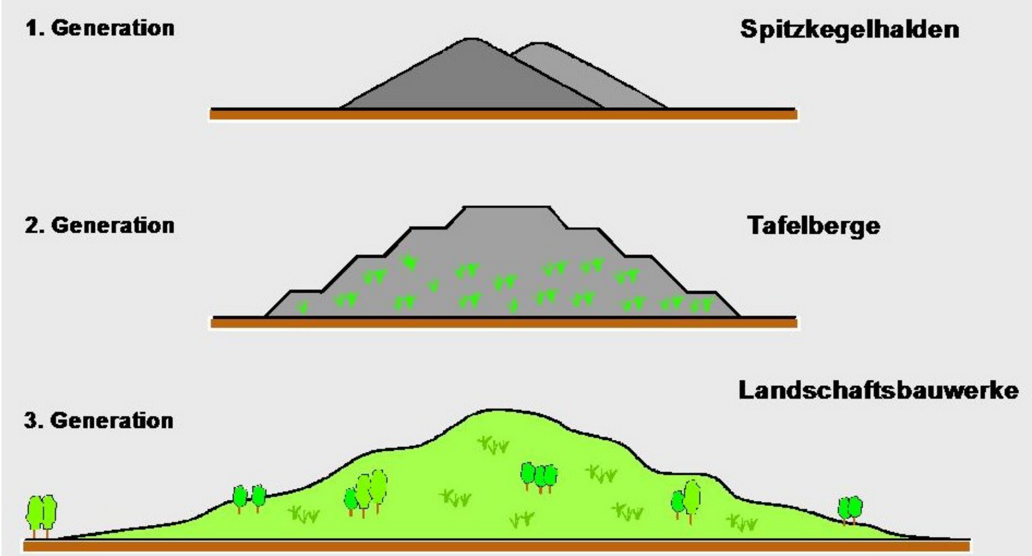
The filling of "Hoheward" and "Mottbruch" slag heaps was terminated in 2012 and 2013 respectively. In 2013 RAG's slag quantity amounted to approximately 4 million tons, although a small amount of slag is realised by so-called third-party stowing. (Figure 9.22).



Source: provided by the TWG

Figure 9.22: Alternative use of extractive residues

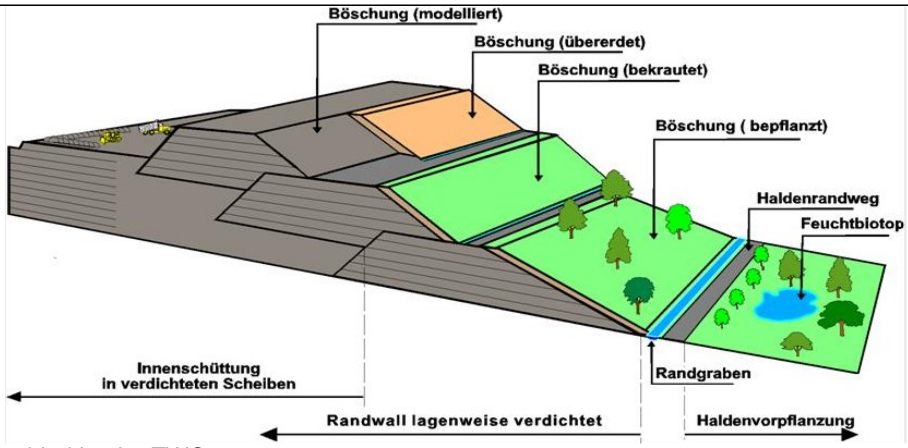
Transport is by ship using the harbours of Auguste Victoria (AV) and Coelln-Neussen (see Figure 9.21). The material is, for example, used as material for land reclamation in the Netherlands. The main part of slag material is heaped on slag heaps. In the past, the design of slag heaps has undergone a change. Whereas initially the slag material was heaped in the form of pointed cones and later on, due to reasons of stability, as table mountains, today's slag heaps are designed as so-called landscape structures. (Figure 9.23)



Source: provided by the TWG

Figure 9.23: Schematic illustration of the heap closure design evolution

The procedure for the filling is as follows: first the area and a slag heap wall are prepared and finally the inside area is filled. Figure 9.24 shows the layers of the slag heap wall, the soil cover of modelled slopes and the herbs and plants covering the slopes.



Source: provided by the TWG

Figure 9.24: Landscaped heap design

The filling of RAG Aktiengesellschaft's slag heaps is subject to management plan obligations according to the Federal Mining Act. The required management plans were prepared by the RAG or its legal predecessors. In general, the application documents that come with the management plans include plans which show the intended final design. In the course of the participation in the management procedure to be carried out, this final design formed an elementary component. Following a mining law permission, the site of a slag heap being filled is under mining supervision and falls within RAG's area of responsibility.

Special Management Plan Recultivation

The successive recultivation during the filling of slag heaps is handled separately.

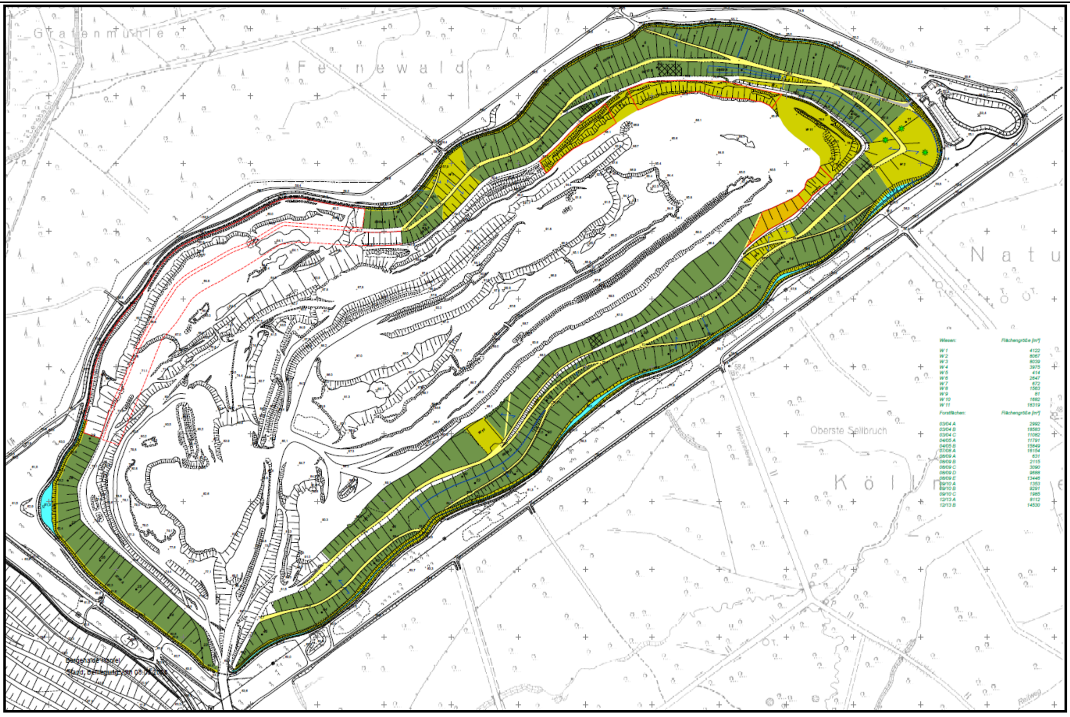
Each year, a special management plan in accordance with the guidelines of the former regional mining inspectorate of North Rhine-Westphalia is to be submitted to the mining authorities for each active slag heap by 1 November for the permission of slag heaps in areas subject to mining supervision dated 13 July 1984 including the principles for the creation and rehabilitation of slag heaps from hard coal mining in the revised version dated 22 July 1991.

This special management plan recultivation introduces the mining authorities to the recultivation plans of the coming planting period. As a rule, pictures of the slag heaps being filled are taken during a yearly photo flight which is conducted in spring in order to prepare this special management plan. On this occasion a orthophotomosaic is generated (Figure 9.25). A layout with an exact topography of the slag heaps is derived from the photogrammetric evaluation.

Source: provided by the TWG

Figure 9.25: Aerial view of "Schöttelheide" slag heap in Bottrop

Based on these layouts, RAG carries out its yearly recultivation planning which is then submitted to the mining authorities as a special management plan. The graphic illustration of the new plan and already existing, recultivated areas of a slag heap is realised in the shape of a recultivation plan (Figure 9.26). A yearly inspection of slag heaps is carried out as part of the coordination of this recultivation plan.



Source: provided by the TWG

Figure 9.26: Recultivation plan for "Schöttelheide" slag heap in Bottrop

Upon completion of the filling and recultivation of a slag heap, the final management procedure for the release from the mining authorities is prepared and introduced by RAG.

Early termination of a fill

Continued reduction of hard coal mining and the connected closures of mines in the past have also led to the premature closure of locations for slag heaps in advance of completion according to the original plan.

The political decision to terminate the German hard coal mining industry at the end of 2018 made things worse and, as a consequence, RAG made an adjustment of their mining-based planning. The adjustment of production also resulted in an adjustment of the slag heaps to be designed. Basically, for all these locations the question of the final design arises. This has produced an area of tension between the pure rehabilitation according to the Federal Mining Act and demands on the design from a landscape planning point of view. Furthermore, slag heap locations are also suitable for further technical use. Particularly noteworthy is the erection of wind turbine installations. Two wind turbines were erected in 2010 on "Scholven" slag heap which was filled until 1987 and RAG Montan Immobilien is erecting an expected three wind turbine installations at the location of "Brinkfortsheide" slag heap which is still being filled. In the course of recultivation it is necessary to integrate earth mass into the layer providing the contour and into the recultivation layer. In addition, the slag heap locations are technically also suitable for depositing external earth masses. This results in a requirements profile within the framework of the final design for the relevant locations. Manifold interests lead to the necessity to coordinate these interests and, ideally, adhere to them as far as possible. This results in requirements from an environmental point of view, from the utilisation potential and the design guidelines. However, there should be a differentiation between mandatory requirements and optional parts of the design. In relation to this, the financing of such design elements should be mentioned which can, in principle, not be part of the rehabilitation.

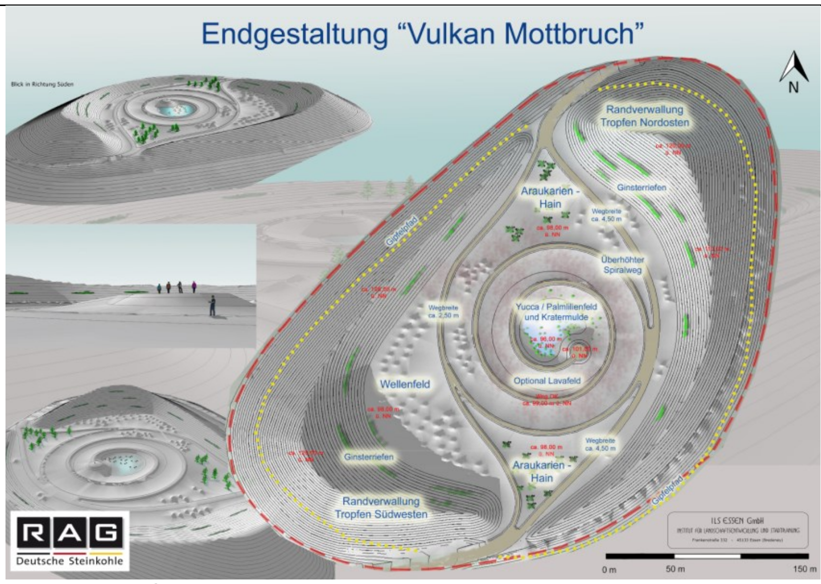
Final design using the example of "Mottbruch" slag heap

In 1996, the former Ruhrkohle Bergbau AG started the filling of "Mottbruch" slag heap in the vicinity of the city of Gladbeck. In this instance, several slag heaps that already existed at the location were connected. The filling continued until 2013 and most recently by Prosper-Haniel Mine. The design was in the form of a "volcano" with a "crater" at the top of the slag heap (Figure 9.27). The precise design of this slag heap was left out of the original plan and the final design was made dependent on the subsequent use which was still to be agreed upon.

Source: provided by the TWG

Figure 9.27: Aerial view of the "Mottbruch" heap

Regarding the design of the slag heap top, RAG Aktiengesellschaft made suggestions, building on previous meetings which had been held with the city of Gladbeck (Figure 9.28).



Source: provided by the TWG

Figure 9.28: Suggested reclamation

RAG Aktiengesellschaft is in discussion with the city of Gladbeck in order to coordinate and integrate their interests into the still not finalised plan of the final design of the top area. For this reason, the city of Gladbeck invited RAG Aktiengesellschaft together with the regional association to a one-day information event on the slag heap. Interested citizens were able to make suggestions regarding the design of the slag heap. Once this event has been evaluated it was planned to introduce a planning workshop at the beginning of 2015 in order to take up those suggestions. An important aspect is the question of financing the design as far as it goes beyond a pure rehabilitation. According to mining law permission, the results of these talks regarding the design and subsequent use of the slag heap top will be included in the documents to be submitted.

Conclusion

The design of slag heaps in the Ruhr area has historically been subject to change. The design of the recently filled slag heaps follows the so-called concept of landscape structures. Numerous demands are made on the design with regard to the rehabilitation and subsequent use. In principle, this can cause tension between the different interests. Here, an important factor is the ability to finance the special design suggestions. Acceptable solutions are the result of extensive coordination between the different parties.

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