Study supporting the elaboration of guidance on best practices in the Extractive Waste Management Plans

Final Report

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in collaboration with WEFalck, Pöyry Finland Oy, Botond Kertész & CRS Ingenería

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Abstract

The Directive 2006/21/EC on the management of waste from the extractive industries (EWD) provides measures, procedures and guidance to prevent or reduce as far as possible any adverse effects on the environment and any resultant risks on human health from the management of extractive waste. According to Article 5 of the EWD operators have to submit an extractive waste management plan (EWMP) as part of their permit applications.

The present study uses a wide range of information provided by Member States and the extractive industries, reflecting many years of experience with EWMPs, to identify best practices, as well as to outline a methodology to develop EWMPs.

The focus is on (a) the prevention or reduction of extractive waste generation and of its harmfulness, (b) the recovery of extractive waste (by recycling, re-use or reclaiming), as well as (c) the assurance of short- and long-term safe disposal of extractive waste.

The study comprises two guidance documents, which were developed based on risk assessment principles, focusing on the objectives of (a) achieving a Circular Economy throughout the whole life-cycle of an extractive operation, and (b) the safety of the extractive waste at each stage of the life-cycle of an extractive waste facility.

Résumé

La Directive 2006/21/CE sur la gestion des déchets de l’industrie extractive (ci-après ‘la directive’) prévoit des mesures, procédures et orientations visant à prévenir ou réduire les effets néfastes sur l'environnement et les risques pour la santé résultant de la gestion des déchets des industries extractives.

En conformité avec l’article 5 de la directive sur les déchets extractifs, pour l'octroi de l’autorisation, les exploitants doivent soumettre un plan de gestion des déchets.

Ce rapport utilise un large éventail d’informations fournies par les États membres et par les industries extractives, reflétant de nombreuses années d'expérience dans la planification et la gestion des déchets, afin d’identifier des exemples de meilleures pratiques, tout en incluant une méthodologie pour développer ces plans de gestion des déchets d'extraction (PGDE).

L'accent est mis sur (a) la prévention ou réduction de la production des déchets d'extraction et des effets nocifs qui en résultent, (b) l’encouragement de la valorisation des déchets d'extraction (la réutilisation et le recyclage), (c) la certitude de l'élimination correcte à court et à long terme des déchets d'extraction.

Ce rapport comprend deux documents d'orientation destinés à aider (a) à réaliser une économie circulaire tout au long de la vie d’une opération d’extraction et (b) à assurer l'élimination sûre des déchets d'extraction dans les installations de gestion de déchets tout au long de leur cycle de vie.

Pour établir ces guides, les informations sont analysées sur la base de ces principes d’évaluation des risques.

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1. Executive summary

The present report constitutes the final output from a Study commissioned by DG Environment under Contract No. 070201/2017/768854/ETU/ENV.B.3 with a view to support the elaboration of guidance on best practices in the Extractive Waste Management Plans (EWMPs) according to Directive 2006/21/C on Extractive Waste (EWD). The study was performed by Eco-Efficiency Consulting and Engineering Ltd. in collaboration with the following subcontractors: WEFalck, Pöyry Finland Oy, Botond Kertész, and CRS Ingenería. The study resulted in two guidance documents: (1) Best Practices in Extractive Waste Management Plans (EWMPs) with regard to the provisions of the Circular Economy Action Plan, and (2) Best Practices for the safe disposal of extractive waste. The present report includes (a) this Executive Summary, (b) the consolidated guidance document on Best Practices in EWMPs supporting the circular economy paradigm, which considers Member States' and stakeholders' comments received during a technical workshop held in Brussels on 12 of September 2018 (Ch. 3), and (c) a consolidated document on Best Practices implementation concerning the provisions set out in Articles 5(2)(c) and 5(3) of the EWD), which includes comments received from DG ENV (Ch. 4).

The work undertaken included:

- Data collection and evaluation of the data provided by the European Commission, that resulted from a call for input, asking Member States to provide one or more of the following items: (a) their guidelines on how to develop extractive waste management plans, (b) extractive waste management plans (EWMPs) submitted to the competent national authorities, (c) pre-selected EWMPs comprising candidate best practices, and (d) candidate best practices related to the Circular Economy paradigm.
- Assessment of the information provided and of further data collated by the contractors, enriched through country visits to France, Greece, Hungary, Spain, and Sweden, as well as bibliographic research in order to propose a methodology to develop EWMP, under the principles of risk analysis, risk evaluation and risk treatment.
- Identification of Best Practices in Extractive Waste Management Plans in view of:
    - Article 5(2)(a) of the EWD: the prevention or reduction of extractive waste generation and of its harmfulness
    - Article 5(2)(b) of the EWD: the recovery of extractive waste by means of recycling, re-using or reclaiming such waste.
    - Article 5(2)(c) and Article 5(3) of the EWD: Ensuring the short- and long-term safety of the extractive waste, in particular by considering as part of the design phase, the management during the operation and after closure of a waste facility
- A stakeholder workshop on the results that arose from the first phase of the project concerning the best practices that contribute to Circular Economy aspects in the EWMPs.

These two guidance documents are intended as legally non-binding. They target competent authorities and extractive industry operators, aiming to integrate the Circular

Economy principles and key elements of short- and long-term safe waste management into EWMPs. The project covers all extractive industries (energy minerals, metal ores, industrial and construction minerals). The undertaking was independent of and complementary to the work on the Best Available Techniques reference document on the management of waste from extractive industries (MWEI BREF, 2018[1]).

1.1 The Circular Economy Action

The Communication "Closing the loop - An EU action plan for the Circular Economy"[2] describes the 'Circular Economy' as an economy wherein the value of products, materials and resources is maintained for as long as possible, and the generation of waste minimised. The circular economy aspects, such as prevention or reduction of waste generation and of the harmfulness of wastes, as well as recovery of extractive waste by ways of recycling, re-use or reclaiming such waste are stipulated in Article 5 "Waste Management Plan" of the EWD. The first deliverable of the present study was focused on the provisions of Articles 5(2)(a) and 5(2)(b) of the EWD.

The EWMPs from extractive industries across collated were reviewed with respect to the criteria set out in the Circular Economy Action Plan. It should be highlighted that the EWD and in particular its Article 5 reflected already in 2006 what is in essence a Circular Economy perspective.

Extractive waste management planning can be a complex process and is influenced by the geological, geochemical, climatological, and social conditions of the location of each deposit. For this reason, in the present study a systemic life-cycle approach was chosen. Specifically, the proposed practices in the field of recycling and recovery of extractive waste (potential use) may be applied to the first five basic phases in a mining life-cycle (exploration, design, construction, extraction, and processing), and which have direct consequences on the generation and management of the extractive wastes. The study highlights that effective extractive material management begins with the design phase of a mine, since extractive waste generation can be reduced by optimising mineral extraction and processing. Depending on the formation that is mined, an optimisation of the mineral extraction and processing can be achieved by strengthening the role of the two first steps of the mining life-cycle (exploration and design). Developing new strategies and technologies that address how to increase recycling of waste will further reduce the amount of such waste to be disposed.
A total of 75 Fact-Sheets were prepared, based on the EWMPs collected and through the country visits. The majority of the information available pertained to metal ores and construction or industrial minerals. The results from the data collection process demonstrated that the extractive industry actively searches for strategies to maximise resource use and waste minimisation. In general, if there is market, excavated 'waste' materials are sold off. The practices mostly concern:

[1] Garbarino, E., Orveillon, G., Saveyn, H.G.M., Barthe, P., Eder, P. (2018): Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries in accordance with Directive 2006/21/EC.- JRC Science for Policy Report, EUR 28963 EN: 722 p., http://publications.jrc.ec.europa.eu/repository/handle/JRC109657
[2] European Commission. (2015): Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions. Closing the loop - An EU action plan for the Circular Economy.- COM(2015) 614 final. Brussels. https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF.

- considerations of extractive waste generation and its management at the design phase
- filling excavation voids with extractive material (Note: in some MSs these excavated materials are considered as waste and in some others as secondary raw material; the scope of the present guidance is only to present techniques that strengthen the role of the Circular Economy and not to discuss what is waste and what not)
- utilising waste rock in different kinds of earthworks on site during active mining operations, as landscaping material during rehabilitation
- marketing waste rock as aggregate, for general civil engineering applications, or to the chemical industry
- recycling or re-using of historical extractive waste
- recycling of waste water
- segregation and re-use of topsoil, either for rehabilitation or as marketable product

The assessed information was cast into a Background Document that was sent for review to a wide range of stakeholders, such as competent authorities, the extractive industry, the Expert Group on Waste, the Raw Materials Supply Group, the Technical Working Group on the Best Available Techniques Reference document on the management of waste from extractive industries, academia and NGOs, in order to be commented on and to solicit additional practices. These experts were also invited to a Workshop on ‘Best Practices of Extractive Waste Management Plans’, that was held on 12 September 2018 in Brussels.

The revised guidance that includes the comments received forms Chapter 3 of this report.

The Guidance does not undertake to interpret EU waste legislation, including Article 5 of the EWD, but aims to link the relevant provisions of Article 5 with the objectives of the Circular Economy Action Plan, covering all facets of the extractive sectors. The ‘practices’ illustrated are more generic and focus on resource management aspects in the extractive sector that can play a central role in the Circular Economy.

The guidance combines comprehensive risk-based considerations for the selection of appropriate waste management options with the principles of Circular Economy. Risk based considerations contribute to setting priorities for environmental and societal protection in an objective and scientific way. The combination of information on risks and impacts is helpful to develop workable solutions for the specific context of a country and an extractive operation. Hence, a risk-based methodology to develop EWMPs is proposed, by providing a selection of examples and details from already submitted EWMPs from different extractive industries that are operating in Europe.

1.2 Short- and long-term safe disposal of extractive waste

EWMPs should reflect in a structured way the planning of waste management options with a view to meet the objectives of Article 5 of the EWD. The key to environmentally safe and responsible management of tailings is an effective management framework throughout the full life-cycle of an extractive waste facility. Objectives such as (a) protection of public health & safety, (b) mitigation of negative environmental impacts, and (c) safe after-closure procedures are the key concepts that have to be incorporated into the EWMPs. This guidance document outlines the conceptual approaches to develop EWMPs with respect to the criteria set out in Articles 5(2)c and 5(3) of the EWD, and it provide examples of best practices that have been identified in the reviewed EWMPs.

This guidance document forms Chapter 4 of this report.

Ensuring short-term operational safety not only encompasses technical measures and designs, but also management measures. The EWMPs reviewed cover predominantly the operational aspects and are concerned with compliance with applicable rules and regulations. However, the dimension of time in the sense of long-term stability of the chosen management solutions for EW and EWFs mostly is not mentioned explicitly. Hence, the guidance is particularly concerned with the dimension of time of the EWMPs, namely with the long-term safety and stability of the selected EWM solutions. The long-term manageability of mining residues depends *inter alia* on their nature and quantity, which in turn depend on the host geology, as well as the mining and processing methods.

This exercise is independent of and complementary to the work on the revised Best Available Techniques reference for the Management of Waste from Extractive Industries in accordance with the EWD, which is focusing on ensuring geotechnical, environmental and human health & safety of EWFs (short-term). Therefore, the guidance focuses explicitly on the differences between operational and long-term safety features and provisions. A continuum of geotechnical and environmental safety has to be assured during the transition from the operational to the post-closure phase. A life-cycle perspective during planning ensures a smooth transition and an efficient use of resources by considering the requirements of the post-closure phase already during the operational phase. Such an approach also has the advantage that the closure of extractive waste facilities is not left until the mining operation ceases, which reduces the phenomenon of abandoned extractive waste facilities.

The EWD requires the establishment of post-closure monitoring procedures. The monitoring provides assurance that the EWF functions as designed and complements the records produced during the exploratory and operational phases. The respective records will also facilitate maintenance and repair during long-term management.

Recent events, such as the tailings dam accidents in Brazil, have highlighted the importance of comprehensive risk management, including adequate risk identification, risk analysis, risk evaluation and risk mitigation. Risk and its management are major drivers behind extractive waste management concepts and solutions. Risk-based decision-finding helps to focus the EWMP on the essential aspects and, hence, to use resources efficiently, while maximising the levels of protection of the environment and human health.

One issue that became apparent during the evaluation of the EWMPs was (potential) conflicts between the objectives for the safe disposal of extractive waste and the circular economy policies. Decisions to declare some extracted materials as waste and to proceed to disposal are made, when no beneficial use for the waste can be found, which in turn often depends on the economic context at the time. In consequence, such wastes may still contain components that could become valuable at some later point in time. Whether these materials can be recovered later depends on the chosen disposal method.

Near-surface repositories, such as waste-rock dumps or tailings ponds may be relatively easily accessed and reworked. The situation is different for materials placed into deep mines, where re-entering after closure is difficult and can be dangerous. This dilemma between long-term safe extractive waste management solutions and maintaining access to potentially valuable resources needs to be carefully weighed, during the development of an EWMP.

Although radiation protection aspects are not subject of the EWD, the guidance tries to shed a light on the issue of Naturally-Occurring Radioactive Materials (NORM), by providing a comprehensive overview according to Directive 2013/59/EURATOM[3], also known as the EU Basic Safety Standards for Radiation Protection (BSS).

It was noted that long-term stability as postulated in the EWD has not been reflected in the EWMPs that could be evaluated for the purposes of this project. For this reason, the proposed Best Practices mainly concern rehabilitation examples. The perceived gaps were filled by referring to information and a wide range of guidance documents produced by the industry itself, its associations, and international bodies.

1.3 Workshop with Member States and stakeholders

To promote the exchange of information on best practices a Workshop on 'Best Practices in Extractive Waste Management Plans with relevance to the Circular Economy Action Plan' was held on 12 September 2018 in Brussels. The participants were experts from Member States (Finland, Ireland, Netherlands, Spain, France and Sweden), stakeholders from associations and extractive industries (Euromines, Euracoal, IMA-Europe, Federation of Norwegian Industries, and The Global Oil and Gas Industry Trade Association), from the Commission (DG Environment and DG Grow), as well as the project consortium. The experts and other stakeholders provided insights on the perspectives that should be considered during the drafting of EWMPs, as well as comments on specific topics of particular concern for the industry.

[3] Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.- OJ of the European Union of 17.01.2014: L13/1-L13/73

2. Synthèse

Ce rapport est le rapport final d'une étude commandée par la DG Environnement afin en vue de soutenir l'élaboration d'orientations sur les meilleures pratiques dans le cadre des plans de gestion des déchets extractives (PGDE), en conformité avec la Directive 2006/21/EC (ci-après 'la Directive') concernant la gestion des déchets de l'industrie extractive. Le contrat de mise en œuvre porte la référence 070201/2017/768854/ETU/ENV.B.3. L'étude a été réalisée par Eco-Efficiency Consulting and Engineering Ltd. en collaboration avec WEFalck, Pöyry Finland Oy, Botond Kertész et CRS Ingenería. Ce rapport comprend deux documents d'orientation : (1) Les meilleures pratiques dans le cadre des plans de gestion des déchets concernant les dispositions d'un plan d'action en faveur de l'économie circulaire et (2) les meilleures pratiques pour l'élimination sûre des déchets d'extraction.

Ce rapport comprend: (a) cette synthèse, (b) la version consolidée du document d'orientation sur les meilleures pratiques dans le cadre des plans de gestion des déchets extractives en faveur de l'économie circulaire, en tenant compte des commentaires reçus lors d'une réunion de travail qui s'est tenue à Bruxelles le 12 septembre 2018 (ch. 3), et (c) un document consolidé sur la mise en œuvre des meilleures pratiques concernant les dispositions énoncées à l'article 5, paragraphe 2, points c) et 5, paragraphe 3, de la Directive), qui comprend les commentaires reçus de la DG ENV (ch. 4).

Les travaux entrepris incluent :

- la collecte de données et l'évaluation des données fournies par la Commission Européenne, résultant d'un appel à contribution, invitant les États membres à fournir un ou plusieurs des éléments suivants (a) leurs lignes directrices sur la manière de développer des plans de gestion des déchets de l'industrie extractive, b) plans de gestion des déchets de l'industrie extractive soumis aux autorités nationales compétentes, c) des plans présélectionnés concernant la gestion des déchets d'extraction incluant les potentielle meilleures pratiques d) les potentielle meilleures pratiques liées au paradigme de l'économie circulaire.
- Evaluation des informations fournies et des autres données rassemblées par les contractants, enrichies par des visites en France, en Grèce, en Hongrie, en Espagne et en Suède, ainsi que par une recherche bibliographique afin de proposer une méthodologie de développement de PGDE, selon les principes de l'analyse du risque, évaluation des risques et traitement des risques.
- Identification des meilleures pratiques dans les plans de gestion des déchets d'extraction en vue de :
    - L'article 5(2)(a) de la Directive : prévenir ou réduire la production de déchets et les effets nocifs qui en résultent
    - L'article 5(2)(b) de la Directive : la récupération des déchets de l'industrie extractive par des moyens de recyclage, de réutilisation ou de valorisation de ces déchets.

  - Les articles5(2)(c) et 5(3) de la Directive : assurer l'élimination sûre à court et à long terme des déchets d'extraction, particulièrement en tenant compte, durant la phase de conception, de la gestion pendant l'exploitation et après la fermeture de l'installation de gestion de déchets.
- Une réunion de travail des parties prenantes sur les résultats de la première phase du projet concernant les meilleures pratiques contribuant aux aspects d'économie circulaire dans les PGE.
- Ces deux documents servent de guide et ne sont pas juridiquement contraignants. Ils ciblent les autorités compétentes et les exploitants des industries extractives, afin d'intégrer dans les plans de contrôle des déchets d'extractions les principes de l'économie circulaire et des éléments-clés de la gestion sûre des déchets à court et à long terme. Le projet couvre toutes les industries extractives (les minéraux industriels, les combustibles minéraux solides, les minéraux de construction, les minerais métalliques). Ce projet a eu lieu indépendamment et en complément du document de référence sur les meilleures techniques disponibles (BREF) relatif à la gestion des déchets de l'industrie extractive (MWEI BREF, 2018[4]).

2.1 Un plan d'action en faveur de l'économie circulaire

La Communication "Boucler la boucle - Un plan d'action de l'Union Européenne en faveur de l'économie circulaire"[5] décrit l'économie circulaire dans laquelle la valeur des produits, des matières et des ressources est maintenue aussi longtemps que possible et la production des déchets est réduite au minimum. Les aspects de l'économie circulaire, tel que prévenir ou réduire la production des déchets et les effets nocifs qui en résultent et encourager la valorisation des déchets d'extraction en les recyclant, en les réutilisant ou en les valorisant sont stipulés à l'article 5 "Plan de gestion des déchets" de la Directive sur les déchets extractifs. Le premier livrable de cette étude s'est concentré sur les dispositions de l'article 5 (2) (a) et 5 (2) (b) de la Directive.

Les plans de gestion des déchets de l'industrie extractive sont évalués conformément aux principes de l'économie circulaire. Il faut souligner que, la Directive sur les déchets extratifs, en particulier son article 5, reflétait déjà en 2006 ce qui était l'essence d'une transition vers une économie circulaire.

La planification de la gestion des déchets d'extraction est un processus complexe et est influencée par les conditions géologiques, géochimiques, climatologiques et sociales du dépôt naturel. Pour cette raison, une approche systémique du cycle de vie a été choisie. Plus précisément, les meilleures pratiques proposées concernent principalement les cinq premières phases du cycle de vie minier (prospection, conception/aménagement, construction, extraction et traitement des minéraux) puisque ces étapes sont directement liées à la génération et à la gestion des déchets d'extraction.

[4] Garbarino, E., Orveillon, G., Saveyn, H.G.M., Barthe, P., Eder, P. (2018): Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries in accordance with Directive 2006/21/EC.- JRC Science for Policy Report, EUR 28963 EN: 722 p., http://publications.jrc.ec.europa.eu/repository/handle/JRC109657

[5] Commission Européen (2015): Communication de la Commission au Parlement Européen, au Conseil, au Comité Économique et Social Européen et au Comité des Régions. Boucler la boucle - Un plan d'action de l'Union européenne en faveur de l'économie circulaire.- COM(2015) 614 final. Brussels. https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0003.02/DOC_1&format=PDF.

L'étude souligne qu'une gestion efficace des matières extractives commence dès la phase de conception de la mine, car la production de déchets d'extraction peut être réduite en optimisant l'extraction et le traitement des minéraux. En fonction de la formation extraite, il est possible d'optimiser l'extraction et le traitement du minerai en renforçant le rôle des deux premières étapes du cycle de vie de l'exploitation minière (exploration et conception). La mise au point de nouvelles stratégies et technologies visant à accroître le recyclage des déchets permettra de réduire davantage la quantité de ces déchets à éliminer.

Au total, 75 fiches d'information ont été préparées, sur la base des plans de gestion des déchets extractifs collectés et lors des visites dans les pays. La majorité des informations disponibles concernait les minerais métalliques et les minéraux de construction ou industriels. Les résultats du processus de collecte de données ont montré que l'industrie extractive recherchait activement des stratégies pour maximiser l'utilisation des ressources et minimiser les déchets. En général, s'il existe un marché, les «déchets» de fouilles sont commercialisés. Les pratiques concernent principalement :

- Les considérations sur la production de déchets des industries extractives et de la gestion de ces déchets dès la phase de conception
- Replacer les déchets d'extraction dans les trous d'excavation après l'extraction des minéraux (Remarque : certains États membres considèrent ces matériaux comme des déchets et d'autres comme des matières premières secondaires. Ce document présente des techniques en faveur de l'économie circulaire ; son but n'est pas de discuter de ce qui est déchet et de ce qui ne l'est pas.)
- Encourager la valorisation des stériles pendant les opérations minières actives pour la réalisation des terrassements et à des fins de remise en état comme matériau d'aménagement ;
- Commercialiser des stériles en tant qu'agrégats, pour des applications générales de génie civil ou pour l'industrie chimique ;
- Encourager la valorisation des déchets d'extraction en les recyclant les déchets historiques ;
- La réutilisation ou recyclage des eaux usées ;
- La ségrégation et la réutilisation la couche arable pour la réhabilitation après la fermeture de l'installation ou en tant que produit commercialisable ;

Les informations évaluées ont été intégrées dans un document de travail qui a été envoyé à un large éventail de parties prenantes pour révision ; y étaient impliquées : des autorités compétentes, l'industrie, le groupe d'experts sur les déchets, le groupe l'approvisionnement en matières premières, les membres du Groupe de Travail Technique du document de référence sur les meilleures techniques disponibles (BREF) relatif à la gestion des déchets de l'industrie extractive, le milieu universitaire et les organisations non-gouvernementales (ONG). Ces experts ont été invités à la réunion de travail "Les meilleures pratiques dans les plans de gestion des déchets en faveur d'un plan d'action pour l'économie circulaire" qui s'est tenue à Bruxelles le 12 septembre 2018.

La version consolidée du document d'orientation sur les meilleures pratiques dans les plans de gestion des déchets en faveur de l'économie circulaire est joint au chapitre 3 de ce rapport.

Ce document n'interprète pas la législation de l'UE concernant la gestion des déchets de l'industrie extractive et l'Article 5 de la Directive, mais l'accent est mis sur le rattachement des dispositions de l'Article 5 aux objectifs du plan d'action pour l'économie circulaire dans toutes les industries extractives. Les " pratiques" illustrées sont plus génériques et se concentrent sur les aspects de la gestion des ressources dans le secteur extractif qui peuvent jouer un rôle central dans l'économie circulaire.

Le document d'orientation combine des considérations de l'analyse des risques et du traitement des risques pour la sélection d'options de gestion des déchets appropriée en faveur de l'économie circulaire. Les considérations fondées sur les risques contribuent à établir des priorités pour la protection de l'environnement et de la société de manière objective et scientifique. La gestion des risques aidera à développer des solutions spécifiques et viables en conformité avec le contexte spécifique d'un pays, au cours de l'extraction de minéraux ou des opérations de traitement. Par conséquent, une méthodologie fondée sur les risques pour élaborer des plans de gestion des déchets d'extraction est proposée, en fournissant une sélection d'exemples et de détails des plans de gestion des déchets d'extraction déjà soumis par différentes industries extractives opérant en Europe.

2.2 Court et long terme élimination sûre des déchets d'extraction

Les plans de gestion des déchets devraient être structurés de manière à permettre une planification adéquate des options en matière de gestion des déchets d'extraction, en conformité avec les dispositions de l'article 5 de la Directive. La clé visant à garantir une gestion environnementale sûre et responsable des résidus miniers s'avère être un cadre de gestion efficace tout au long cycle de vie des installations de gestion de déchets. Les objectifs tels que (a) la protection de la santé publique et de la sécurité publique, (b) l'atténuation les effets nocifs pour l'environnement et (c) procédures sécuritaires après la fermeture de l'installation sont les concepts clés à intégrer dans les plans de gestion des déchets. Ce document d'orientation décrit les approches conceptuelles pour développer les plans de gestion des déchets en respectant les critères de l'Article 5(2)c et l'Article 5(3) de la Directive et fournit des exemples de meilleures pratiques qui ont été identifiées dans les plans de gestion des déchets examinés.

Le document d'orientation est joint au chapitre 4 de ce rapport.

Les exploitants des industries extractives doivent garantir la sécurité opérationnelle à court terme non seulement en incluant les mesures techniques et les conceptions mais aussi en mettant en oeuvre les mesures prises pour la gestion des déchets. Les plans de gestion de déchets d'extraction qui sont évalués couvrent principalement les aspects opérationnels et s'attachent à respecter la réglementation en vigueur. Cependant, la dimension du temps dans le sens de garantie de la stabilité (physique et chimique) à long terme des solutions choisies pour le management des déchets extractifs et pour le management des installations d'extraction de déchets, la plupart du temps n'est pas mentionnée explicitement.

Par conséquence, le document d'orientation est particulièrement concerné par la dimension du temps dans les plans de gestion de déchets extractifs, en particulier par la garantie de la stabilité à long terme des solutions de management des déchets extractifs.

La nature et la quantité des déchets d'extraction, qui dépendent du contexte géologique du gisement, ainsi que de l'extraction des minéraux et les opérations de traitement sont des paramètres qui influencent la capacité de gestion à long terme des résidus.

Cet exercice a eu lieu indépendamment et en complément du document de référence sur les meilleures techniques disponibles (BREF) relatif à la gestion des déchets de l'industrie extractive, qui se concentre à assurer la stabilité géotechnique à court terme et prévenir les effets néfastes, sur l'environnement ou sur la santé des personnes. Par conséquent, ce document se concentre explicitement sur les différences entre les dispositions de la directive, mesures de sécurité opérationnelle et les paramétrés de sécurités pour déposer des déchets à long terme. Pendant la transition de la phase opérationnelle à la phase après la fermeture les exploitants des industries extractives prennent toutes les mesures nécessaires pour assurer une continuité de sécurité géotechnique et environnementale. La perspective du cycle de vie lors de la planification assure l'utilisation efficace des ressources en considérant les exigences dans la phase après la fermeture, pendant la phase opérationnelle. Une telle approche présente également l'avantage que la fermeture des installations de gestion de déchets des industries extractives, n'a pas lieu jusqu'à ce que les opérations minières aient cessé. Cette approche réduit le phénomène d'installations de gestion de déchets abandonnées.

La Directive exige d'assurer la stabilité des déchets et de garantir un monitoring approprié après la cessation des opérations. Le monitoring des installations de gestion de déchets fournit l'assurance que l'installation fonctionne comme prévu. Cette procédure complète également la documentation des produits au cours des phases exploratoires et opérationnelles. Cette documentation est censée faciliter la maintenance et les réparations et vise à garantir la stabilité à long terme de la structure de l'installation.

La rupture d'un barrage minier au Brésil a souligné l'importance d'une gestion globale des risques y compris l'identification, l'analyse, l'évaluation et l'atténuation des risques. Le risque et sa gestion sont les principaux moteurs derrière les concepts et les solutions de gestion des déchets d'extraction. La prise de décision basée sur le risque aide à focaliser les plans de gestion des déchets sur les aspects essentiels et permet ainsi d'utiliser efficacement les ressources, tout en maximisant le niveau de protection de l'environnement et de la santé humaine.

Un problème apparu pendant l'évaluation des plans de gestion des déchets concernait les conflits (potentiels) entre les objectifs d'élimination sûre des déchets d'extraction et les politiques de l'économie circulaire. La décision de déclarer un matériel extrais comme déchet et de procéder à son élimination est prise quand aucune utilité bénéfique ne peut être trouvée pour ce matériel, ce qui, en soi, dépends du contexte économique à ce moment-là. Par conséquence, ce déchet peut contenir des éléments qui peuvent gagner en valeur plus tard. La possibilité de collecter ces éléments dépend de la méthode de d'élimination de ces déchets. Les dépôts situés près de la surface, tels que les décharges de stériles ou les bassins de résidus, peuvent être relativement facilement accessibles et relativement simples à retravailler. La situation est différente pour des minéraux replacés dans les trous d'excavation après l'extraction des minéraux, parce que non seulement il est difficile d'y avoir accès après la fermeture, mais c'est aussi dangereux. Ce dilemme entre les solutions sûres de gestion des déchets d'extraction à long terme et le maintien de l'accès à des ressources potentiellement précieuses doit être soigneusement pesé pendant le développement d'un plan de gestion des déchets.

Les dangers résultant de l'exposition aux rayonnements ionisants sont exclus du champ d'application de la Directive. Cependant, ce document d'orientation traite du sujet des matières radioactives naturelles conformément à la Directive 2013/59/EURATOM[6].

Il a été noté que la stabilité à long terme telle que postulée dans la Directive n'était pas reflétée dans les plans de gestion des déchets évalués pendant ce projet. Pour cette raison, les meilleures pratiques proposées concernent principalement la remise en état d'installations fermées. Pour combler ces lacunes, le document d'orientation a été enrichi en utilisant des informations fournies par l'industrie extractive, ses Associations et des organismes internationaux.

2.3 La réunion de travail avec les États membres et les parties prenantes

L'échange d'information sur les meilleures pratiques a eu lieu pendant la réunion de travail "Les meilleures pratiques dans les plans de gestion des déchets en faveur d'un plan d'action pour l'économie circulaire" ayant eu lieu à Bruxelles le 12 septembre 2018. Les participants étaient des experts des États membres (Finlande, Irlande, Pays-Bas, Espagne, France et Suède), parties prenantes des associations et des industries extractives (Euromines, Euracoal, IMA-Europe, Federation of Norwegian Industries, and The Global Oil and Gas Industry Trade Association), la Commission (DG Environnement et la DG GROW), ainsi que le consortium du projet. Parties prenantes et spécialistes ont offert leur vision sur les perspectives dont il devait être tenu compte pour la rédaction d'un plan de gestion des déchets, mais ils ont également commenté sur des sujets spécifiques de préoccupation et d'intérêt particulier pour l'industrie.

[6] Directive 2013/59/EURATOM du 5 décembre 2013 fixant les normes de base relatives à la protection sanitaire contre les dangers résultant de l'exposition aux rayonnements ionisants et abrogeant les directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom et 2003/122/Euratom

3. Development of a guidance document on best practices in the Extractive Waste Management Plans - Circular Economy Action

3.1 General information

3.1.1 Introduction

The Communication "Closing the loop - An EU action plan for the Circular Economy" describes the 'Circular Economy' as an economy wherein the value of products, materials and resources is maintained for as long as possible, and the generation of waste minimised. The Communication announced that the Commission will develop guidance and promote best practices in the extractive waste management plans (EWMPs) by 2018. The Commission requested information from public authorities, industry, environmental NGOs, knowledgeable experts and civil society. This report presents the results of the assessed received information and additional gathered data that identifies best practice in extractive waste management plans, placing a focus on those aspects related to Circular Economy.

3.1.2 Background

The present guidance is part of a study[7] pertaining in particular to (a) the integration of Circular Economy aspects into an Extractive Waste Management Plans and (b) the identification of Best Practices in Extractive Waste Management Plans (EWMPs) for aspects related to the Circular Economy. The scope of the present guidance is to explore approaches beyond minimum requirements of the Directive 2006/21/EC (Extractive – EWD) in order to promote Circular Economy concepts in the mining sector. According to Article 5 ("Waste management plans") of the Extractive Waste Directive 2006/21/EC (EWD), the Member States have to ensure that operators draw up an extractive waste management plan (EWMP). Specifically, Articles 5(2)(a) and 5(2)(b) of the EWD specify objectives of the EWMP related to the prevention or reduction of waste production and its harmfulness as well as the recovery of extractive waste by means of recycling, reusing or reclaiming such waste where this is environmentally sound. Thus, the EWD and in particular its Article 5 reflected already in 2006 what is in essence a Circular Economy perspective.

> "Optimisation of the ore extraction can be achieved by strengthening the role of the exploration and design phase, aiming the prevention of waste generation within the possible extent"

The mining sector is especially complex due to geological, geochemical, climatological, and social conditions of the location of each deposit, but also because of the breadth and range of the mining life-cycle, which is presented in Figure 3-1. According to the Swedish Guidance for the handling of the extractive waste, extractive waste generation can be

[7] Service contract № 070201/2017/768854/ETU/ENV.B.3

prevented by optimising mineral extraction and processing taking into account the ore that is mined (developing new knowledge and technologies that address how to increase recycling of waste) (Swedish Environmental Protection Agency, 2016). An optimisation of the mineral extraction and processing can be achieved by strengthening the role of the two first steps of the mining life-cycle (exploration and design). The present guidance describes practices in the field of recycling and recovery of extractive waste (potential use) that may be applied to the first five basic phases in a mining life-cycle (exploration, design, construction, extraction, and processing), and which have direct consequences on the generation and management of the extractive wastes.

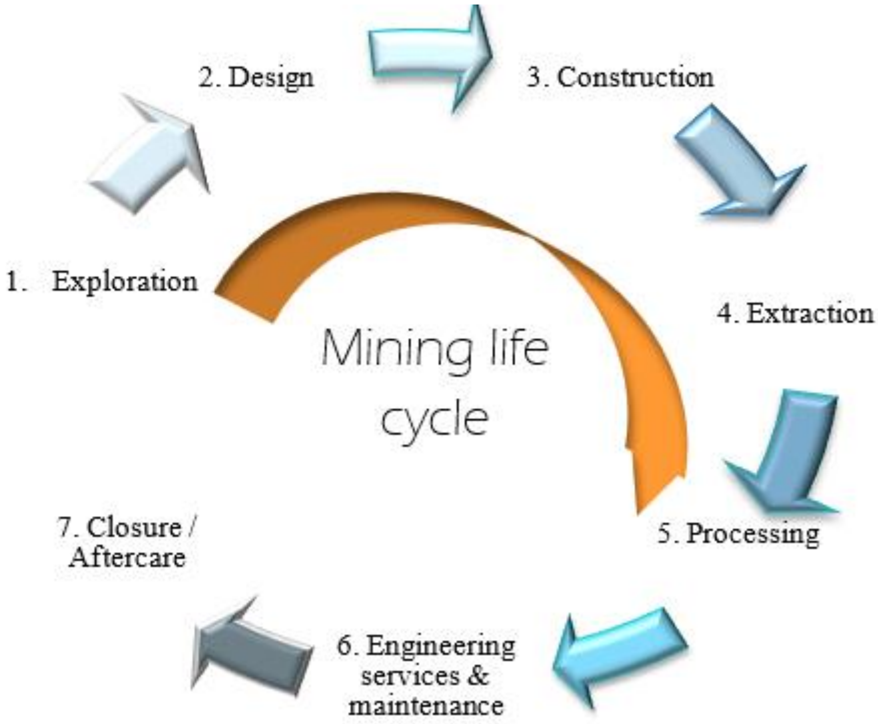

Figure 3-1: The mine life cycle

From the beginning of the implementation of the EWD, some experience with EWMPs has been accumulated. Mine operators have to plan their operations in such a way as to ensure efficient use of resources by minimising extractive waste generation and are encouraged to promote the use of secondary raw materials and their accessibility as future resources. The extractive industry actively searches for circularity aspects that can be included in the mining operations, which may be summarised in EWMPs or EIAs. Therefore, for the development of the present guidance, an investigation on best practices from submitted EWMPs and EIA studies of the extractive industries was conducted, focusing mainly on those that reflect the essence of the Circular Economy perspective. In any case, it should be emphasised that the decision on the selection of best practices should take into consideration always the local geotechnical, geological and economic conditions.

3.1.3 Methodology

In July 2017, the Commission called on relevant stakeholders in the Member States' (MS) extractive industry, public authorities, industry, environmental NGOs and the civil society, to contribute their expertise and experience by providing one or more of the following:

- Guidelines on how to develop EWMPs
- Sample Extractive waste management plans (EWMPs)
- Pre-selected EWMPs containing candidate best practices
- Candidate best practices
- Hosting a visit to investigate the Circular Economy aspects within the EWMPs

In total 64 data items were gathered by the European Commission initiative in various forms, such as common industrial practices, national projects for extractive waste management, MS guidance documents, etc.

Following the European Commission's initiative, a further data collection process was conducted by a team of consultants in order to obtain more details on the practices in EWMPs that cannot be obtained through desk research alone. This project has also included country visits in order to collect relevant technical information. This further research via country visits was conducted in France, Germany, Hungary, Greece, Spain and Sweden.

The information collected supported the first milestone of the project, namely, to identify candidate best practices with respect to their provisions towards the Circular Economy Action Plan. This project has a strong reliance on the information provided to the Commission and the further data collection process by the consultant relying on publicly accessible information. Therefore, the best practices presented in this guidance are not necessarily comprehensive.

The EWMPs have been assessed, taking into account the following aspects:

- processes to prevent or reduce extractive waste generation and its harmfulness
- extractive waste management in the design phase and in the choice of the method used for mineral extraction and treatment
- the changes that the extractive waste may undergo in relation to an increase in surface area and exposure to conditions above ground
- placing extractive waste back into the excavation void
- putting topsoil back in place after the closure of the waste facility or re-using topsoil elsewhere
- using less dangerous substances for the treatment of extracted minerals
- recovery of extractive waste by means of recycling, re-use or reclaiming of such waste
- approaches for monitoring the implementation of EWMPs and their review

Furthermore, best practice identified should be considered in EIA and EWMPs, but local circumstances might not allow applying it in a given geological context. Similarly, the examples of best practice from a subsector might not be applicable for all installation of this subsector due to a given geological context.

In addition to highlighting best practices for extractive waste management, it is equally important to develop a methodology that describes how EWMPs can be produced. The role risk-based considerations play in choosing appropriate solutions is a useful guide to understanding the development of EWMPs. Most of the Risk based considerations would have been already undertaken as part of the Environmental Impact Assessment. The EWMP acts as a vehicle to describe the chosen extractive waste management activities and to communicate these to regulators and the interested public alike.

3.1.4 Initial assessment of the information gathered

Overall, a total of 75 Fact-Sheets were prepared, based on the EWMPs collected and through the country visits. As is shown in Figure 3-2, the majority of the collected practices are related to the metal ores and construction minerals. The collection process revealed a number of relevant practices, which prove that the extractive industry actively searches for strategies to maximise resource use that can be included in the mining and processing operations. The practices are mostly related to:

- Considerations of extractive waste production and its management in the design phase
- following strategies and techniques to fill excavation voids with extractive material (Note: in some MS these excavated materials are considered as waste and in some others as secondary raw material; the scope of the present guidance is only to present techniques that strengthen the role of the Circular Economy and not to discuss what is waste and what not)
- utilising waste rock in different kinds of earthworks on site during active mining operations, as landscaping material, or it may be sold outside for use as aggregate
- utilising extracted material that would otherwise be waste in various ways outside the mine environment, in earthworks, and even in the chemical industry
- Recycling or re-using of historical extractive waste
- Recycling of waste water
- Segregation and re-use of topsoil

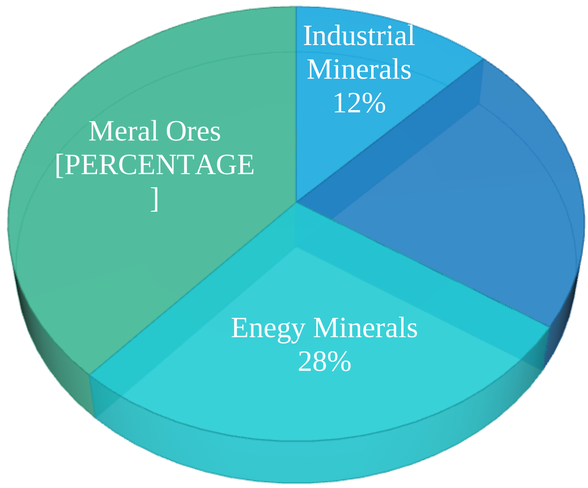

Figure 3-2: Percentage distribution of the sectors from which data could be collected.

3.1.5 Stakeholder consultation and workshop

The assessed information was cast into a Background Document (BD) that was sent to a wide range of stakeholders, such as competent authorities, the extractive industry, Expert Group on Waste, the Raw Materials Supply Group, the Technical Working Group on the Best Available Techniques Reference document on the management of waste from extractive industries, academia and NGOs, in order to be commented on and to solicit additional practices. These experts were also invited to a Workshop on 'Best Practices of Extractive Waste Management Plans', which was held on 12 September 2018 in Brussels.

Although the investigation of the practices was mainly focused on the EWMPs, the pre-licensing design phase for extraction is in most cases based on the Environmental Impact Assessments (EIAs), which covers the whole life-cycle of operations. In most cases the final EIA is the outcome of an iterative procedure that begins with the original proposal for extraction, processing of the extracted material, and the eventual (re-)use and disposal of materials for which no economically beneficial use can be found. Different extraction methods, processing techniques, and disposal options will result in different impacts on different environmental compartments. This iterative procedure ideally yields a process design and disposal solution for EW that provide the maximum economic benefits, while entailing environmental impacts deemed acceptable. In contrast to the EIA, the EWD requires a review of the EWMP every five years in order to take into account any substantial changes to the operation of the waste facility or to the waste deposited. The objective of the EWMP is to summarise these findings with respect to the actual extractive waste management options to be implemented. Article 5 of the EWD already contains provisions with respect to what later became known as the Circular Economy Action Plan. It has to be understood, however, that the (environmental, geotechnical, health) safety of the disposal option is a very important parameter and must always be considered in relation to environmental and Circular

Economy aspects. To this end the EWMP will demonstrate that the necessary steps had been taken to prevent waste generation where it is possible and to encourage the recovery of extractive waste by means of recycling, re-using or reclaiming such waste, where this is environmentally sound and economically feasible.

This Guidance does not aim to interpret EU waste legislation including Article 5 of the EWD but aims to link the relevant provisions of Article 5 with the objectives of the Circular Economy Action Plan, covering all the extractive sectors' minerals. It is thus independent of and complementary to the work on the Best Available Techniques reference document on the management of waste from extractive industries (MWEI BREF). It is intended as legally non-binding guidance, targeted at competent authorities and extractive industry operators for the purpose of promoting the Circular Economy principles.

3.2 Risk based considerations

3.2.1 Scope and purpose of risk-based considerations

Risk Assessment is a technical-scientific methodology to estimate quantitatively and qualitatively environmental and social risks arising from the technical options of extractive waste management. As noted before, in most cases such assessment would have been carried out as part of the EIA that is usually the basis of an operating license. However, scope and detail of the EIAs may vary from MS to MS and the following serves as a tool to cross-check, whether the Risk Assessment undertaken under the EIA is sufficient to support the development of the EWMP.

One of the aims of the risk-based considerations and choices in extractive waste management is to predict from the very beginning (design phase) potential impacts resulting from the generation and the management of the extractive waste and investigate possible solutions to avoid them. Any significant change that may arise at some point during the mining life-cycle may lead to proportional evaluation of the risk assessment. Risk management indeed is a procedure that iterates with operational planning and needs to be adapted progressively to changing operational conditions.

3.2.2 Risk based considerations used in the development and evaluation of the EWMPs

Risk based considerations contribute to setting priorities for environmental and social protection in an objective and scientific way. EWMPs reflect the risk-based selection of appropriate extractive waste management options, taking into account the waste hierarchy:

1. to prevent or reduce waste generation and its harmfulness;
2. to encourage the recovery of extractive waste; and
3. to ensure short and long-term safe disposal of the extractive waste. Risk management for this activity is elaborated in BAT 5 of the MWEI BREF (European Commission, 2018c)

The combination of information on risks and impacts is helpful to develop workable solutions for the specific context of a country and a company. Each of these possible solutions is reviewed with respect to the risk reduction strategy applied (based on relevant engineering principles) considering risks, impacts, as well as economic and social aspects. Typically, this stepwise process of risk management planning includes: establishing the design context, impact identification and failure risk identification, designs for risk elimination or reduction, and monitoring for efficacy (see Figure 3-3). Impact is a predicted (potentially prolonged) effect of the operation. On the other hand, risk is the probability that an unplanned event might occur multiplied by its impact.

Extractive waste risk evaluation is a complex procedure and may be associated with a wide range of failure scenarios. Site specific conditions (including for example geology and surrounding land-use) should always be considered. Sources, pathways and receptors should be adequately identified.

EWMPs are reviewed both internally and externally. Internal review is typically carried out on a regular basis to identify updating requirements. External review is typically carried out by competent authorities – for both, new and updated EWMPs. When reviewing an already submitted EWMP, one may follow the principles of risk assessment in order to identify potential risks to environment and human health. The review should also assess whether sufficient information is provided to enable the competent authority to evaluate the operator's ability to meet the three objectives listed above (prevent/reduce, recover, safely dispose). Moreover, it should ensure that the updated plan explains, in particular, how the extractive waste management considerations from the design phase, and the choice of method used for mineral extraction and treatment, will still fulfil its objectives.

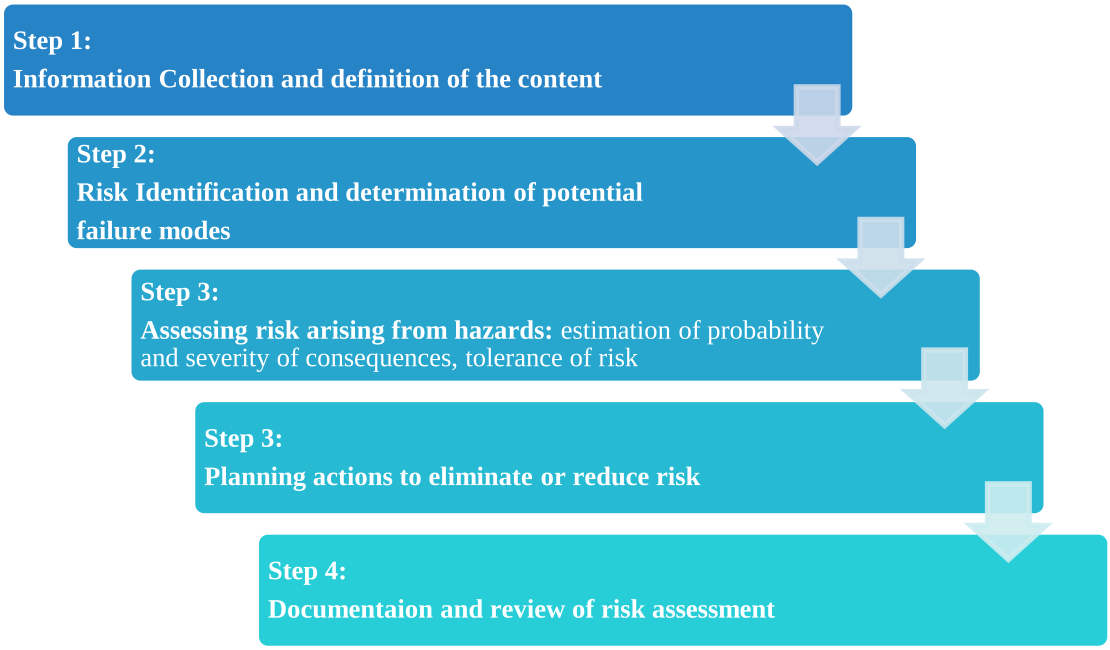

Figure 3-3: General Risk Assessment methodology scheme

3.2.3 Risk identification along the life-cycle of an extractive operation

The characterisation of extracted material that may become waste should be the starting point of the Risk Assessment, which also takes into the consideration the chosen waste management option. It should be noted that the scope of the present guidance is only to present the key considerations of the Risk Assessment and not to discuss whether specific elements of the whole methodology will be covered by the EIA of the operation or by the preparations of the EWMP.

The purpose of this characterisation is to determine the nature of the extractive waste and steer possible management options, based on its geological and mineralogical characteristics, its geotechnical behaviour and geochemical characteristics. Commission Decision 2009/360/EC completing the technical requirements for waste characterisation laid down by Directive 2006/21/EC specifies technical requirements for extractive waste characterisation. Since the first EWMP is submitted at a project phase, where operation has not yet started, information obtained from the characterisation of extractive waste is relevant for the (periodic) reviews of these management plans.

Extractive industries provide mineral raw materials that are essential to downstream industries and economic sectors. Extractive industries provide, first of all, primary raw materials. However, the processing often targets only one or a few constituents. Hence, what would become extractive waste can actually be a potential source of further raw materials. Therefore, extracted material characterisation should include all parameters necessary to inform about potentially valuable constituents or properties that can be utilised in order to avoid the material becoming waste.

The design phase in many extractive industries is complex and may identify a wide variety of potential hazards, as they are given in detail in the MWEI BREF. The overall evaluation of risks may require some kind of aggregation to make different practices and scenarios comparable when selecting the final design.

The design phase of any particular extractive installation necessarily relies on several key input parameters related to the main purpose of the project, namely sustainable development of the mineral deposit. However, opportunities to consider extractive waste management and/or recovery may be found in the following areas:

1. Exploration phase
2. Selection of the most appropriate extraction methods
3. Extraction process planning
4. Design of the site layout
5. Selection of mining equipment
6. Optimisation of the process plant
7. Development of a commercial plan

Figure 3-4 illustrates the complexity of waste management in the extractive sector since parameters such as site-specific conditions, including the technical characteristics of the Extractive Waste Facility (EWF), its geographical location and the local environmental conditions, behaviour and characteristics of the extractive waste and geological background of deposit are only some issues that are described in Commission Decisions, such as:

- Commission Decision 2009/360/EC completing the technical requirements for waste characterisation laid down by Directive 2006/21/EC
- Commission Decision 2009/359/EC completing the definition of inert waste in implementation of Article 22(1)(f) of Directive 2006/21/EC
- Commission Decision 2014/955/EC amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC
- Commission Decision 2009/337/EC on the definition of the criteria for the classification of waste facilities in accordance with Annex III of Directive 2006/21/EC

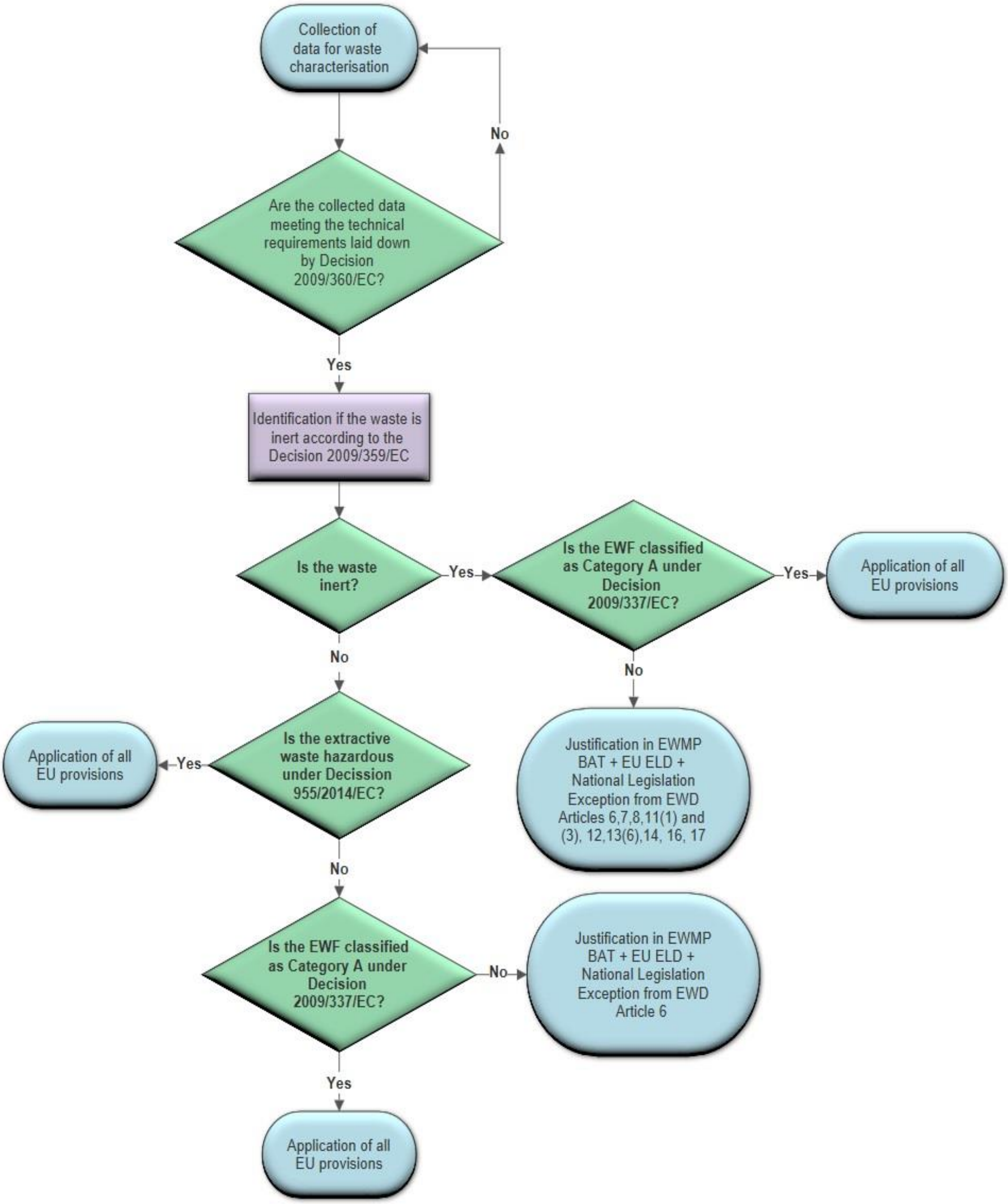

Figure 3-4: Decision tree for waste characterisation under the provisions of COM Decisions

In order to establish the necessary scope of the Risk Assessment, one needs to identify where, when and why these risks arise. Risks can then be quantified and management measures proposed. It is important to appreciate that risks can be managed as and when they arise ('end-of-the-pipe' treatment paradigm) or the root-cause can be identified and eliminated, thus also eliminating the risk. This may require a wider scope than what would normally be covered by the EWMP. Normally, the EWMP may be considered as a reporting platform of work that has already been done for either feasibility studies or licensing purposes.

The following non-exhaustive list shows examples of aspects that would need to be considered in order to establish the content of the Risk Assessment along the life-cycle phases of an extractive operation. It is known that in some cases, changing the processes in mining and subsequent treatment of the excavated material may result in wastes that are easier to manage and in EW management solutions with fewer inherent risks.

1. <u>Exploration phase:</u> the more thoroughly the resource has been explored, the more targeted and efficient the extraction can be, meeting the objectives of Art. 5§2 (a) and (b) of the EWD. A good knowledge of the mineral deposit allows for optimisation of the extraction, resulting in less extractive waste.
2. <u>Selection of the most appropriate mining methods:</u> the selection of the mining method, e.g. underground vs. open-cast, and mining technology is governed by a multitude of factors. While it is understood that CAPEX and OPEX in a given market environment are critical variables, today aspects of resource efficiency and minimisation of extractive waste generation also need to be taken into account. Modern at-the-face rock characterisation methods, selective extraction, utilisation of waste rock (in pit or for filling excavation voids) reduces the generation of extractive waste. For example, in room-and-pillar methods the utilisation of waste rock my not only reduce the amount of EW to be managed at the surface, but also increases the recovery of the target mineral.
3. <u>Site design and scheduling:</u> Good mining planning and scheduling based on good exploration and data handling is the basis for a targeted and efficient extraction, avoiding unnecessary extraction and thus excessive extractive waste generation. (This phase is continuously being developed.)
4. <u>Choice of mining equipment:</u> the choice of mining equipment may not only be determined by the needs, but also by the availability of and limitation to CAPEX. Operators will need to be aware that inadequate mining equipment may result in unnecessary generation of waste rock that may need to be managed as EW.
5. <u>Process planning and optimisation.</u> While one can assume that operators have a vested interest in effective processing of marketable products for a given market situation, the manageability of the resulting extractive wastes may not always be a design criterion. Within the limits of CAPEX available, operators may consider reducing risks and associated risk management costs (including insurance premiums) by selecting processing methods that result in less waste that needs to be managed in Category A facilities.
6. <u>Periodic review of material streams:</u> The valorisation of each element of the material streams generated in a mine and subsequent processing changes as a function of market conditions. Hence, it is in the interest of the operator to periodically review

these streams and how they arise with a view to maximising this valorisation. This review will to include materials that previously were considered EW in the sense of the EWD. It makes economic sense to explore possible markets for materials that otherwise would have to be deposited as EW and for which EWMPs would have to be developed.

7. Planning for the long-term safety of EWFs. All EWFs not only have to fulfil criteria for operational safety and minimisation of impacts, but their closure and long-term management need to be provided for as well.

It should be kept in mind that these are multi-dimensional optimisation problems and one always needs to be aware of risk and impact displacement effects. A risk and impact analysis will help to underline the economic, social, and environmental effects of the extracted material. In this sense, the risk assessment and resulting management solutions as presented in an EWMP can serve to demonstrate to regulators and other (public) stakeholders that risks have been minimised and benefits, including those in the sense of a Circular Economy, have been maximised.

3.3 Methodology to develop EWMPs

3.3.1 Introduction

Extractive waste management planning can be a complex process, requiring environmental, social, engineering and economic inputs. It is an integrated part of good operational management and EWMPs can be seen not only as a permitting tool, but also as a communication tool. Developing EWMPs is a systematic way to assess availability and adequacy of all essential components of extractive waste management.

EWMPs present measures for prevention or reduction of extractive waste generation and its harmfulness, as well as the recovery of extractive waste by means of recycling, re-using such waste where this is environmentally sound and economically feasible, and without disregarding the needs for short and long-term safety and stability of extractive waste management solutions. Such actions imply that EWMPs are based on the understanding that waste management imply proactive measures to avoid or reduce waste generation per se.

Some key elements that need to be determined before the drafting of an EWMP are questions such as: which material should be evaluated? who should draft the EWMP and when? This information is discussed in the following boxes.

Question 1: What is extractive waste?

'Extractive waste' means "the waste resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries" but excluding:

- waste that is generated by the prospecting, extraction and treatment of mineral resources and the working of quarries, but that does not directly result from those operations;
- waste resulting from the off-shore prospecting, extraction and treatment of mineral resources;
- injection of water and re-injection 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.

Question 2: What materials are evaluated in an EWMP?

Taking into consideration the EWMPs that were selected through the gathering of relevant data, the following approaches related to the term "management of extractive waste" have been identified:

- Some EWMPs address the management of excavated material after it has been classified as extractive waste
- Other EWMPs develop a wider perspective and address all streams of excavated material explaining the material streams considered as (by)product and those classified as (extractive) waste.

It has to be understood that material that is defined as "extractive waste" is subject to the EWD, while other types of waste that are beyond the term "extractive waste" are subject to the Waste Framework Directive, or Directive 2008/98/EC of the European Parliament, and consequently these wastes are out of the scope of the present guidance.

Question 3: Who is responsible for drafting an EWMP?

The "operator" is the natural or legal person responsible for the management of extractive waste, in accordance with the national law of the Member State (MS). It is known that some jurisdictions require an EWMP from all extractive operations, while other jurisdictions are satisfied if the EIA and the license application demonstrate that no EWs arise, thus obviating the submission of an EWMP.

Question 4: When should an EWMP be drafted and how often shall an operator review it?

According to the national laws of MSs, an EWMP can be submitted as part of an application for planning permission, forming a component of the application documentation or being contained within an environmental impact assessment (EPA Ireland, 2012).

According to the EWD, the waste management plan shall be reviewed every five years and/or amended, if substantial changes have taken place in the EWF or in the extractive waste itself. It should be noted that the EWMP is not necessarily a document that is only submitted once in the first permit application. Competent authorities may need to be notified of amendments.

3.3.2 The role of the mine life-cycle in drafting EWMP

Every mine is unique and, therefore, the type, the amounts and the characteristics of the extractive waste differ, depending on the deposit, the geology and the process technology applied at the site. The extractive waste originates mainly from two production stages: mining (extraction) and mineral processing (Lèbre, 2016).

Although the generation of extractive waste starts mainly at the construction stage, extractive waste management should be taken into consideration along all the stages of the mining project life-cycle, including the exploration and design phase. Figure 3-5 illustrates the phases, where extractive waste can be generated during the life-cycle of a mine. Better advance planning of the operation improves the efficiency of extraction, reducing the amount of unwanted extraction that may become extractive waste, minimising the environmental footprint.

A well-developed EWMP should be based on the best available technical knowledge and the substantial experience established across the mining sector in order to achieve (a) optimisation of extraction, (b) reduction of environmental impacts until deemed acceptable, and (c) strengthening of recycling.

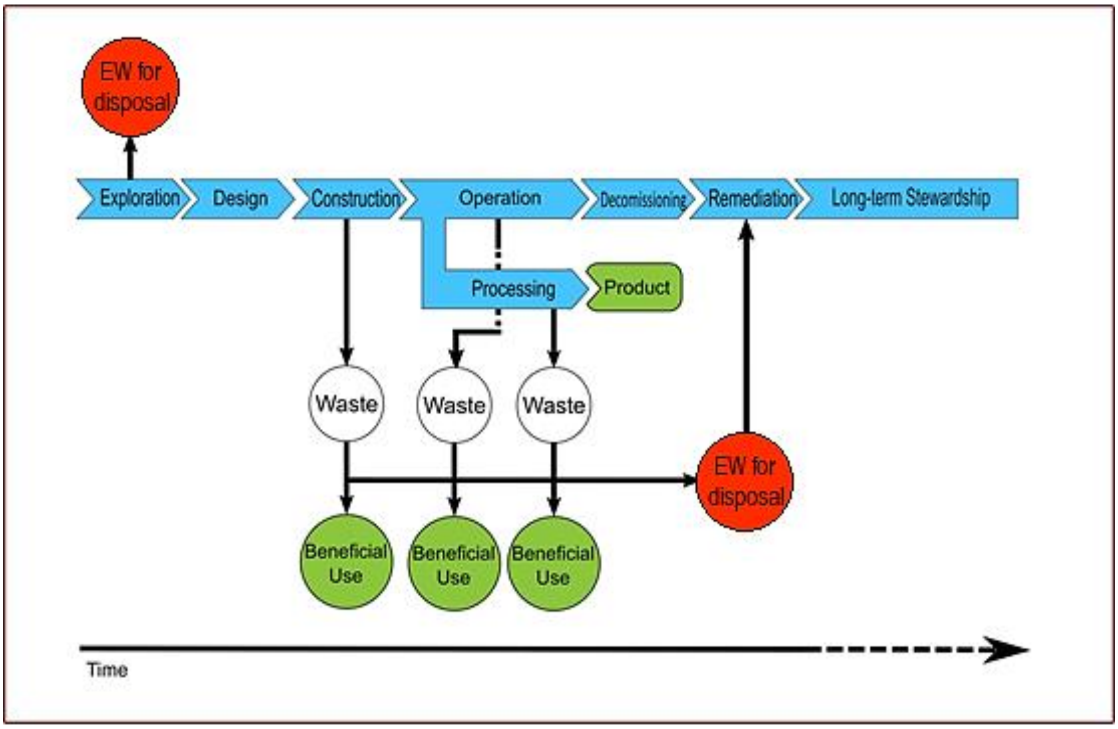

Figure 3-5: Extractive waste as part of the mine life cycle

3.3.3 Guidelines for the development of an EWMP

To assist the reader, Table 3-1 provides a selection of details from already submitted EWMPs from different parts of Europe. This list is neither exhaustive nor tailor-made for every extractive industry or for any location, but it includes a useful selection of issues that should be considered during the drafting of an EWMP.

The actual scope depends on the local circumstances and also on individual MSs requirements, if MSs have formulated such. The EWMP presents (a) a description of the operation generating extractive waste, (b) extractive waste characteristics, (c) quantity of extractive waste generated, and (d) the proposed classification for the extractive waste facility.

A considerable amount of the information is usually generated and/or collated during the different stage feasibility studies and drafting of the initial EIA for the extractive operation. The EWMP provides information on possible adverse effects on the environment and human health, resulting from the disposal of the EW and the mitigation measures, in particular from contaminated run-offs and leachates, water and wind erosion. The time frame to be considered covers construction, operation and post-closure phases, taking into account the geological, hydrological and hydrogeological, seismic and geotechnical characteristics of the site or of the EWF.

Table 3-1 Example contents of an EWMP

Issues covered in the EWMPs	Examples of parameters
Administrative information	Name of the company
	Site location (coordinates)
	Site manager
	Officer responsible for extractive waste area
	Contact details
	Emergency contact details
	Date
Geological description of the mineral deposit	Rock type and mineralogy description of the mineral resource to be used
	Size and geometry of the mineral deposit
Description of materials streams (supported by flow-diagrams)	List of each type of material, including quantities and destination
Waste produced from individual processes	Excavation
	Crushing and grinding
	Flotation, magnetic separation or other separation processes
	Exploration works
	Other processes
Mineralogical and geochemical characterisation per material/waste	Rock type
	Mineral assembly
	Bulk chemical composition including (at least) components of potential concern, such as As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V and Zn
	Acid generation potential and neutralization potential
	Presence of (fibrous) minerals of concern (e.g. asbestos)
	Potential chemical processing residues
	Waste(s) code according to Decision 2014/955 (Waste Catalogue) • Assessment whether the EW is inert is based on the technical requirements that are presented in the Decision 2009/359/EC • Assessment whether the EW is inert, based on method EN 15875: Sulfide sulfur content % (<0,1% or <1% and NTP (normal, temperature, pressure) > 3
	Hazardous Properties according to Regulation 1357/2014/EC - properties of waste that render it hazardous
	Solubility of metals, oxyanions and salts
Geotechnical characterisation and	Grain size distribution

Issues covered in the EWMPs	**Examples of parameters**
material geotechnical behaviour per material/EW	Density
	Porosity
	Permeability
	Fraction composition (dominant mineralogical composition)
	Water content
	Plasticity indices
	Degree of compaction
	Shear strength
	Friction angle
	Compactability
	Compressive strength
Waste class according to COM Decisions 2009/359/EC, 2009/360/EC and 2014/955/EU	Hazardous waste / Non-hazardous non-inert waste / Inert waste
Category of EWF	Category A / Non-Category A (Decision 2009/337/EC)
Facility structures (all EWFs on the site)	Design and constructional details of the EWF
Management of excavated material *Note: though not explicitly covered by the EWD, depending on the operational and market conditions, some of these wastes can become EW at any given moment*	Excavated materials *(quantities as function of time)*
	Quantities and types of excavated materials used for construction purposes in the mine/quarry *(as function of time)*
	Quantities and types of excavated materials used for filling mine voids for engineering or resource recovery reasons (*as function of time)*
	Top-soils removed and stored *(as function of time)*
	Quantities of non-EW and their management routes *(as function of time)*
Management of EW (per waste, supported by detailed maps of the deposition areas)	Quantity of EW deposited *(as function of time)*
	Planned quantity to be deposited EW *(as function of time)*
	Total quantity of extractive waste to be deposited during the life-cycle
	Quantities of EW recovered and re-utilised *(as function of time)*
Risk assessment	Summary of risk assessment carried out under the initial EIA, any updates, or specifically for the EWMP
	Specific conditions contributing to risks: • Climatic conditions (e.g. rainfall intensities and frequencies) as drivers for the migration of contaminants • Description of possible natural events (e.g. earthquakes, vulcanism, etc.) that may compromise

Issues covered in the EWMPs	Examples of parameters
	the EWF
	Risk elimination or risk reduction measure
Emergency plans *(detailing actions and responsible persons)*	Emergency plans for Category A EWFs
	Emergency plans for other EWFs
Operational monitoring	Geotechnical stability (dams, slopes)
	Groundwater: levels, quality
	Surface waters: quantity, quality
	Air quality
	Erosion control (turbidity in surface waters)
	Radiological monitoring (where required)
Closure plans	Provisional plans *(to be updated periodically together with the EWMP)*
	Financial provisions to ensure orderly closure
Long-term management plans	Preliminary plans for the after use of the extraction site and the EWFs *(to be updated periodically together with the EWMP)*
Supporting documentation 1. Geology: nature shape, size and typology of the resource 2. Mineral deposit area: type, final shape, structure of filling and transport type 3. Study of the state of soil and water at deposit area (baseline study) 4. Information of environmental impacts caused by extracted waste and deposit area 5. Information of preventive actions taken to minimize environmental impacts 6. Report of current and post-action control and follow-up 7. Acid rock drainage and metal leaching assessment report 8. Closure plan **Note:** *the majority of the above documentation would have been already produced as part of the baseline survey and the EIA licensing procedure.*	

The scope of the EWMP is steered by the nature of the mining operation and extractive waste generated on the site. EWMP describes how both impacts and risks arising from the EW or the EWFs are managed.

Certain extractive operations are likely to produce only inert wastes owing to the types of geological materials excavated. Such operations may include aggregates, ornamental stones or certain industrial minerals, and operations extracting peat. These operations may be required to produce only simplified EWMPs, not covering the whole suite of variables as outlined in Table 3-1.

3.4 Best Practices from EWMPs related to Circular Economy

The following practices focus on resource management applied in the extractive sector that can play a central role in the Circular Economy.

3.4.1 Best Practice 1: Effective exploration and site lay out

Extractive materials management (including waste) practices start at the design phase for the mine operation. Optimisation of ore extraction and minimisation of waste generation can be accomplished by strengthening the first steps of the extractive industries life-cycle, such as exploration, characterisation and operation design, taking also into consideration the commercial environment.

Figure 3-6: Parameters related to the Circular Economy as applied in the extractive sector

The exploration efforts are the basis for a mining project. Non-invasive exploration methods, namely various types of geoelectrics and seismics, can be used to enable more targeted extraction. Geophysical techniques, such as Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR) or different forms of seismics are used with a view to:

- optimising subsequent use of invasive investigation (drilling)
- improving the quality and marketability of the product, learning in advance its characteristics
- optimising the mineral extraction through localisation of areas to be avoided or targeted

Modelling of the deposit and careful characterisation of the resource can result in minimising the extraction of unwanted and non-marketable materials - thus minimising the generation of extractive waste.

Furthermore, advance planning of the operation improves the efficiency of extraction, avoiding sterilisation of resources and reducing the amount of unnecessary extraction (efficient use of resources). The EWMPs collated for this guidance provide a considerable amount of information with regard to practices involving a detailed modelling of the deposit and choice of mining strategy by selecting underground or open-pit mining techniques. However, any choice of mining strategy depends on a wide range of factors, including the depth of the target mineral below ground, the extent of its occurrence, the characteristics and tectonics of the host rocks, the groundwater hydrology, permissible footprint, available mining technology, and human resources available. In general, near-surface occurrences may be extracted in open-pit mines, while deeper deposits are extracted in underground mines.

Another parameter that it is evaluated during the design phase (pre-licensing process) of an extractive operation are the likely characteristics of the extractive waste. At EU level, the most relevant standards applicable to investigating the expected behaviour and characteristics of future extractive wastes are:

- CEN/TR 16365:2012 Characterisation of waste. Sampling of waste from extractive industries
- CEN/TR 16376:2012 Characterisation of waste. Overall guidance document for characterisation of waste from the 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

Relevance for Circular Economy:

Integrated planning based on the following waste management objectives: prevention, re-use and recycling, highlighting the design phase as a basic step to achieve the Circular Economy principles contribute to the social acceptance of an extractive operation.

Effective characterisation of the resource and extractive waste and advance planning of the operation improves the efficiency of extraction, avoids sterilisation of resources (i.e. helps future generations to have access to virgin raw materials), ensuring a continued, steady and adequate supply of the raw materials needed by society and minimises the amount of unnecessary extraction and thus reduces waste.

The decision between underground mining and open-pit is a key decision during the planning phase and is taken with consideration of the implications for the

Circular Economy in relation to environmental, economic and social benefits. Careful planning to reduce the need for materials handling and to allow progressive rehabilitation can help to prevent or reduce waste production and its harmfulness, in particular by considering the technical, economic and environmental possibilities for placing materials back into the excavation void after extraction.

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Case studies:

According to EWMPs from bauxite mines in Greece (ELMIN (now Imerys) and Delphi-Distomon SA (now MYTILINEOS), bauxite extraction is based on detailed modelling of the deposit, which in turn is based on integrated geotechnical research from the planning phase onwards. The deposit is selectively extracted with the aim of minimising as efficiently as possible the generation of extractive waste.

Data for the integrated planning were also mentioned in the EWMP from Colas Északkő Kft. (Construction Sector) in Hungary. Specifically, Colas Északkő Kft has been planning a complex life-cycle assessment, considering the available raw material reserve and the generation and management of extractive waste. An extensive exploration programme (around 1,250 meters of drilling and large surface geophysical study) helped to estimate the total quantities of product and extractive waste.

The "Lujar" underground mine (Minera de Órgiva, Spain) is located in an impressive valley between the Sierra Nevada and the Sierra Lujar, whose beauty entices tourists to come to the Alpujarra region. To make it easier for mining and tourism to coexist, the Minera de Orgiva´s objective was to be completely unnoticeable in the surrounding villages, reducing to almost zero the environmental impacts. Firstly, Minera de Orgiva installed the mineral processing plant underground, so the ore does not have to be brought to the surface before it has become the final product. Doing so affects a total reduction of noise, dust, land occupation, etc. The company also decided to eliminate the visual impact of the extractive activities by using the extractive waste as material for filling the excavation voids inside its own mine, but also for reclamation purposes outside the boundaries of the mine site (details in chapter 4.5).

In Greece the bauxite mining near Mount Parnassos ten years ago was undertaken partially from an open pit mine and partially underground. According to the EWMP by Delphi-Distomon SA (now MYTILINEOS), the company decided to turn exclusively to underground mining in order to minimise the extractive waste that would have to be deposited on the surface by filling the excavation voids. This decision is also part of the corporate social responsibility policy.

Another example from Greece is the marble quarry of DIONYSSOMARBLE. According to the company, the demand for decorative/ornamental stones has been steadily rising due to their use in modern architecture. Increased demand has led to intensive extraction in existing marble quarries. The immediate consequence of this extraction is the gradual depletion of surface deposits. In addition, strict environmental restrictions already impose the underground extraction of decorative stone deposits.

3.4.2 Best Practice 2: Effective rock breaking

Rock loosening is traditionally effected either by mechanical excavators or by drilling and blasting. An optimal selection of mechanised wall-casings and mining machines depends on the expected geological and geotechnical conditions, leading to more targeted extraction and, as a consequence, to efficient production and waste reduction. The same principle applies to the blasting strategy and technique. The variation of the rock properties and their different mechanical behaviour affects the excavation by drill-and-blasting. The optimisation of the process of drill-and-blast in the design and the operation phase of the mine leads to the reduction of extractive waste and wastage of drill-time and explosives. For both approaches, either with the selection of the appropriate equipment or a blasting design, the key is (a) to investigate the deposit via an in-pit exploration, and (b) to try to minimise the mineral/sterile ratio with computer simulations in order to conduct a more targeted extraction. It should be noted that these strategies may be constrained by technical limitations, such as the minimum tunnel cross-section required for equipment or ventilation. There may also be minimum requirements in a MS's respective mining code.

Relevance for Circular Economy:

The optimisation of the process of drilling and blasting and the selection of the appropriate extraction equipment leads to the reduction of drill time (energy efficiency), consumption of explosives and of waste generation. Furthermore, this practice enables efficient ore excavation and helps to prevent sterilisation of unextracted mineral material on site.

Case studies:

Examples of selective ore extraction by choosing the appropriate extraction equipment were chosen from four operations: Readymix-Lesence Kft. (construction minerals) in Hungary, Delphi-Distomon SA (bauxite) in Greece, JSW S.A. (energy mineral) and Bogdanka Coal Mine, both operating in Poland.

The construction mineral company noted that extraction planning is based on the selection of proper machinery and equipment (for the most part earth-moving machines), primarily with a view to prevent waste generation.

The bauxite mining company mentions that choosing the proper size underground machines necessary for mining and tunnelling works is made according to the shape and the type of the ore leads to the optimum ore recovery.

JSW S.A. Poland limits the extraction of material that would become waste by selecting less contaminated coal (without interlayers) through precise adjustment of the extraction machinery and by considering:

- an optimal selection of mechanised wall casings and mining machines, depending on the expected mining-geological conditions,
- proper longwall projection accounting for the presence of larger geological disorders (faults, horseback etc.).

Lubelski Węgiel "Bogdanka" S.A. ("Bogdanka" Lublin Coal) in Poland noted that rational extractive waste management begins at the design of the extractive operation, while being flexible during the extraction phase. Limiting the amount of mining and processing waste is achieved by use of:

- adequate machinery and equipment for extraction of the ore
- sorting machinery to separate coal from gangue,
- gangue for underground construction works

Baumit Kft (construction minerals) in Hungary noted that the planning of the drilling and blasting phase is one of the most important steps since the optimisation of this phase leads to the prevention of waste generation and efficient use of resources.

Additionally, some operators reported that maximisation of the ore extraction reduces the likelihood of the remaining ore being sterilised, weathered or oxidised, so that no unextracted material can come into contact with mine waters, this contact producing AMD and contributing to the discharges of dissolved metals.

3.4.3 Best Practice 3: Efficient haulage

The mine access and transport network and choosing an adequate hauling equipment and technique is a multi-dimensional optimisation problem that has to be considered at the design phase and may be regulated under national or sub-national mining laws in the Member States. In some cases, extractive materials are transported or pumped many kilometres to an appropriate site for treatment or deposition. Optimising the way (underground or surface transportation, using trucks or conveyor belts, or transported as slurry) usually leads to efficient use of energy, less disturbance of the surroundings and in some cases reduces the amount of rock to be excavated. The costs of using extractive materials that in principle qualify as by-products/products are influenced by the transportation distances and the haulage systems.

A well designed and maintained haulage network is the key to minimising haulage hazards and costs and increasing productivity. However, the design of the network should also take into consideration local conditions and safety. Efficient haulage is an essential part of the whole mineral extractive project since no amount of maintenance will fix a poorly designed network.

A life-cycle emission and energy balance of the hauling equipment may lead to the proper decision being made whether maintaining and repairing existing equipment at the bottom line leads to higher emissions and/or energy requirements than using new, more energy-efficient equipment.

A poorly designed and constructed road infrastructure may need repeated maintenance (consumption of raw materials) and may lead to accidents. Each component of the road infrastructure should therefore be adequately addressed at the design stage (Thompson, 2010).

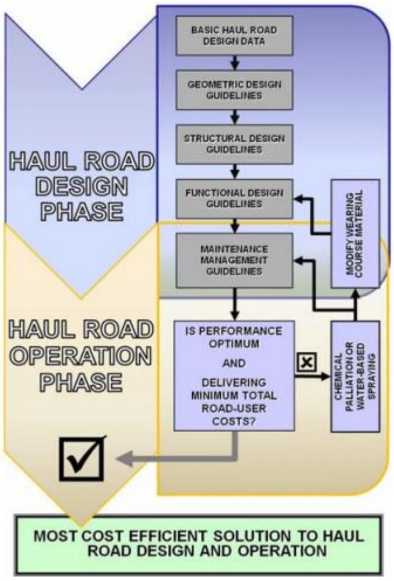

Figure 3-7: Typical integrated approach to road design (Thompson, 2010)

Relevance for Circular Economy:

Optimising the access to the operational site and transport network and choosing an adequate hauling equipment and technique usually leads to efficient use of energy, less disturbance to surroundings and in some cases reduces the amount of rock to be excavated.

Case study:

Two examples highlighting the importance of effective haulage have been chosen, one from Greece, from the metal ore sector, and one from Hungary (construction minerals). Both argue that the benefit of optimising the transportation network and the selection of modern equipment achieve a reduction in CO_2 emissions and improved energy efficiency.

One should be aware, however, that replacing existing mining equipment with more modern equipment may lead to operational energy savings, but a life-cycle energy balance has to show that this replacement leads to overall energy savings and thus reduced environmental impacts. Maintaining and repairing older equipment may consume less virgin materials and energy and thus be more in the spirit of the Circular Economy.

3.4.4 Best Practice 4: Effective ore sorting and selective ore processing

Separation of processing fractions maximises beneficiation efficiency and may, in some cases, reduce the harmfulness of the extractive waste produced.

Better *in situ* separation of ore from extractive waste occasionally means prevention of waste generation and better extractive waste management. For example, better distinction between ore and waste rock may reduce wear and tear of machines by avoiding excavating unnecessary quantities of harder rock.

In certain instances, separation practices may create opportunities to identify and commercialise by-products. Furthermore, this practice prevents leaving unextracted mineralised material on site (resource sterilisation).

Relevance for Circular Economy:

Waste management objectives regarding prevention, re-use, and recycling highlight that the distinction between ore and waste rock may strengthen the application of Circular Economy principles by producing secondary raw material and by reducing the environmental footprint of extractive waste.

Case studies:

Selective ore processing at Aitik mine in Sweden consists of desulphurization and reducing the amount of hazardous waste. Desulphurisation offers an interesting integrated approach to tailings management and control of acid mine drainage (AMD) (e.g. Benzaazoua et al. 2000, Benzaazoua & Kongolo 2003, Bois et al. 2004, Hesketh et al. 2010). In desulphurisation, acid forming sulphide mineral fraction is either partly or fully separated from the tailings by froth flotation before the final deposition into the mine waste area (Kongolo et al. 2004, Kauppila et al. 2011). The application of selective ore processing in the mine closure phase at Aitik mine offers an integrated approach to both tailings management and control of seepage water quality.

This practice is applied during the pre-processing of Greek diasporic bauxite, which contains approximately 2-3 % of $CaCO_3$. In order to reduce the consumption of caustic soda and to reduce the amount of bauxite residues (=dewatered red mud) the Company removes the $CaCO_3$ using heavy media separation. The separated $CaCO_3$ is sold as a secondary material for construction purposes and as a raw material in the cement industry.

3.4.5 Practice 5: Effective usage of excavated materials

Filling excavation voids with excavated material

Certain mining, remediation and construction methods require the placing back of extracted materials into excavation voids. Application of these strategies - as far as they are technically and economically feasible and environmentally sound - requires due consideration of the requirements of equipment access, costs, productivity, stability and/or ventilation, which are investigated in the design phase and regulated under national or sub-national mining laws in the Member States.

In many EWMPs submitted to the European Commission, the application of placing back extracted materials into excavation voids is presented as best practice since it contributes to the prevention and/or reduction of extractive waste generation, simultaneously contributes to site remediation, and avoids occupying new land for the collection, storage and disposal of extractive waste. At the same time, instead of using virgin construction materials for rehabilitation purposes, the extractive industry utilises its own waste. Furthermore, in some cases, this practice allows for the exploiting of secondary stopes once the backfill of the primary stopes has structurally consolidated, resulting in resource efficiency.

In EWMPs related to tailings, reference is made to Cemented Tailing Backfill (CTB) technology. Its components (cement, tailings and water) are combined and mixed in a plant usually located on the ground of the mine. CTB, according to the mining sector, helps to alleviate the environmental impact of potentially hazardous mill tailings and extends the life-time of the tailings management facility since less volume is required. Instead of cement, material with hydraulic properties, such as fly-ash, are commonly used as binder. Potential and actual environmental impacts from CTB need to be balanced against safety gains by less surface disposal of tailings.

Whilst this often means that the material placed back into excavation voids becomes inaccessible itself for future use or re-processing, it usually also avoids leaving more valuable mineralised material on site (sterilisation of resources).

Relevance for Circular Economy:

Placing of excavated materials back into excavation voids contributes to the prevention/reduction of space needed for the disposal of extractive wastes and their harmfulness. The extractive material is not deposited or stored at the surface and at the same time contributes to the remediation purposes.

Cases studies:

The practice of filling excavation voids with extractive material was mentioned by all the mineral sectors and almost one third of the practice examples received were related to strategies and techniques for (back-)filling EWs into mined-out voids. Some examples are:

a) ***Lafarge, 35771 Vern-sur-Seiche from France***: Backfilling of EW in order to raise the pit floor above the groundwater level in order to reduce the volume of water to be pumped out of the pit.

b) ***JSW S.A. (energy mineral sector) from Poland*** argues that the usage of EW as material for filling excavation voids achieves the goal "zero waste generation and using waste as resources" (usage of EW instead of virgin aggregates).

c) ***Mina Lujar (Minera de Órgiva), Spain (industrial minerals)*** uses extractive waste not only to fill excavation voids in the underground mine "Lujar", but also uses the extractive materials for reclamation purposes outside the boundaries of the mine site.

d) ***Minas de Aguas Teñidas S.A.U. from Spain (metallic mineral sector)***: Use of thickened and cemented tailings for the filling of underground stopes. Backfilling the primary stopes with paste tailings could be considered as a best practice, taking into account the practical reasons below:

- Filling excavated stopes with CTB that achieve sufficient structural strength allows mining of the space in between them, thus increasing resource efficiency by more extraction from the same mine.
- The tailings are cemented in paste processing plants such that the resulting material has the required quality to backfill the excavation stopes.
- Approximately 50% of the total amount of tailings are finally disposed into the mine. This practice prevents ARD generation through buffering. The cement used in the paste preparation results in an ARD inert backfill. From a geochemical point of view, the paste is stable, which minimises the generation of ARD.

e) ***Agnico Eagle, Finland, Kittilä Mine***: Their EWMP also refers to the paste backfill with tailings in underground mining.

f) ***Chaux et Dolomie Francaises, Neau (53) Chaux de Provence SACAM, Châteauneuf -Les-Martigues (13) in France***: The dolomite quarry produces various Ca-Mg-oxides, lime and dolomites for a wide range of applications. The dolomite is subject to thermal treatment to obtain the oxide and residues are returned to the quarry. The various residues are mixed and backfilled into the mined-out part of the quarry. The mixing of the various types of extractive and processing wastes leads to an inertisation of the quicklime and the mixtures can be used for backfilling and remediation purposes. The benefit is an inertisation of reactive processing residues by mixing them with EWs (saving virgin raw materials).

g) ***Boliden Mineral AB***, mine Garpenberg, Sweden: The mining strategy is to backfill waste rock and, according to the conditions in the permit, the tailings as well. The tailings that are not used for backfilling are transported wet in a pipe-line (a backup line is installed to make the maintenance easier) to the tailing pond that is water-saturated.

h) The Swedish EWMPs from ***LKAB***, ***Malmberget Mine*** (EWMP 2012) and ***Zinkgruvan,Nya Enemossen*** (EWMP 2015) also apply the practice of filling excavation voids with excavated material.

Construction minerals as marketable materials from extractive wastes

Overburden and waste rock may be recovered for the production of aggregates and lead to a reduction of volumes of extractive wastes that need to be managed in EWFs. The viability of producing construction minerals depends strongly on the local market demand for material of defined properties (e.g. meeting respective norms and acceptable transport costs). Aggregates are used in building, road construction, civil engineering, coastal protection, and for construction purposes in the mines themselves. While inert residues by definition do not pose a problem with respect to environmental acceptance, under national or sub-national laws in the Member States, non-inert non-hazardous excavated material may be acceptable for certain applications, e.g. road foundations. This depends on their specific properties, and the technical, economic and environmental requirements. Some EWMPs, mainly from the construction minerals sector, declare that (certain) waste materials can become materials marketable to the chemical industry, where it can be justified in environmental terms in accordance with binding environmental standards at Community level.

Relevance for Circular Economy:

Using extracted by-product or waste as construction minerals – as far as it is technically feasible and environmentally sound – leads to less extractive waste being generated and offsets primary production of construction minerals elsewhere.

Cases studies:

The extractive sector places importance on the use of construction minerals as marketable materials from extractive wastes since one third of the collected practices (27%) are methods related to recycling or re-use strategies.

Most of the companies that belong to the construction sector make a reference to the practice "use (recovery) extractive waste for the production of mineral aggregates" in their EWMPs. Specifically, the majority of EWMP collected in France (EWMPs from 43 quarries) show a common practice of:

- setting aside top-soils for building (temporary) vegetated dams around the extraction operation; the top-soil will be later used in remediation;
- separating storage of overburden to back-filled at closure and for landscaping the excavated area;
- using suitable and non-marketable materials for construction purposes in the extractive operation;
- quarries and pits tending to market as much as possible of the extracted material but depending on (local) demand and market conditions.

Swedish EWMPs mention the utilisation of extractive waste for construction purposes inside and outside the site or facility (e.g. LKAB Kirunavaara Mine, LKAB, Malmberget Mine, LKAB Mertainen Mine). Specifically, LKAB's Mertainen mine re-uses waste rock for the construction of roads and impoundments outside the mine site (a notification to the authorities is needed and the material needs to be characterised so it is safe to use for the construction purpose). Waste rocks that are suitable for construction work are utilised by many quarries in Finland (e.g. Nordkalk Oy Ab's Mustio limestone quarry, Mondo minerals B.V. Uutela's talc mine, SMA Mineral, Kalkkimaa factory, and the Rantamaa and Ristimaa limestone quarries).

For the industrial mineral sector, companies such as Interbeton Construction Materials S.A (kaolin quarry in Greece) propose that part of the extractive waste (sterile material) is used inside the site for earthworks and maintenance of the road network. This practice helps to reduce the amount of waste that needs management as well as replaces virgin construction raw materials.

Many companies in Poland (JSW S.A., Bogdanka S.A. (Lublin Coal Mine), Polska Grupa Górnicza S.A., TAURON Wydobycie S.A. (ZG Sobieski and ZG Janina) show that aggregates production technology is simple and possible for use in construction works, among others, as filling, land levelling as well as aggregate in concrete. Specifically, JSW S.A. follows recovery approaches for waste management, such as the following:

1. "The use (recovery) of extractive waste for the production of mineral aggregates"***:*** Use of extractive waste from mechanical coal sorting (waste code 01 04 12) for the production of aggregates, according to technical approval and systematic quality control by
   - the *Roads and Bridges Research Institute* in Warsaw for a construction material named "Mineral and mine aggregate of JSW" and
   - the *Technological-Natural Institute* in Falenty for a product named "Hydrotechnical aggregate of coal mine slate of JSW"
2. "Sales and use of extractive waste in not-processed form": Waste under the waste codes 01 01 02 and 01 04 12 produced by the mining industry of hard coal mining may be used as construction material (earthworks, hydrotechnical embankments) or some generated waste from the flotation procedure may be used as raw material for the ceramic industry

In Hungary, Colas Északkő Kft. (construction minerals) managed a large-scale landscaping project at the Tállya Andesite Quarry, which is inside a Natura2000 area and UNESCO Tokaj Wine Region Historic Cultural Landscape World Heritage protection zone, until 2014. A total of 170,000 m^3 mining waste was used for the landscaping project.

From the ore mining sector, the EWMPs by Rosia Montana Gold Corporation S.A. and Hellas Gold S.A. (mixed sulfides) note that overburden and waste rock, due to the suitability of their geotechnical and geochemical characteristics, will be used particularly for the construction of the waste facility, but also for other uses (e.g. road construction). The Swedish EWMP from Zinkgruvan, Nya Enemossen mentions utilisation of tailings in dam constructions.

3.4.6 Best Practice 6: Effective management of topsoil

Topsoils are mineral-organic materials that provide the growing substrate for the plant cover. Topsoils are ecosystems of their own, depending on a set of environmental conditions, such as rainfall distribution and temperature ranges. This means that the functionality of topsoils can be easily impaired or destroyed. Rebuilding this functionality takes years, if not decades.

Putting topsoil back in place after the closure of the waste facility or, if this is not practically feasible, reusing topsoil elsewhere (for example, landscaping and re-vegetation purposes) may strengthen the application of Circular Economy principles. Therefore, all topsoil removed during construction and preparation for mining should be stored at separate locations and under conditions that impair their functionality as little as possible. For the same reason, their reuse is encouraged as expeditiously as possible. During the operational phase, the soil heaps will vegetate by free succession, which provides a protection against their erosion and dust generation and also helps to maintain their fertility.

Relevance for Circular Economy:

The use of local topsoil works best for fast re-vegetation with local plant species and avoids extraction and transport of topsoil from elsewhere.

Case Studies:

Rosia Montana Gold Corporation S.A. in Romania: The topsoil stockpiles and the overburden stockpiles are expected to cover some 40 ha of land altogether. The total area of these stockpiles is relatively small, as about 30% of the soil stripped during the operational phase can be re-used during the same phase and only 70% need to be stored for later re-use during the closure phase. Temporary land-use at the stockpile sites is primarily agricultural with cattle and sheep grazing, fields for forage and some woodland. Sterilisation of the soil resource under the topsoil piles will be temporary for the life of the Project. Following removal of the topsoil stockpiles the soils are expected to return to their original use, supporting pastures for grazing and forage.

Readymix-Lesence Kft. in Hungary: The management of stripped topsoil is based on a careful analysis and planning of the material flows of the extractable mineral raw materials. Topsoils are stored for later use in re-cultivation and reconstitution of arable lands. It is important to return and spread the topsoil over the original area as soon as possible, possibly within three years, in order to retain fertility. If this is impossible within the three-year time frame, the topsoils are treated as inert waste, and are taken into account in the waste management plan.

The use of local topsoil for landscaping and covering purposes is also mentioned in Finish EWMPs (***Agnico Eagle Finland Oy,*** Kittilä Mine (gold), ***Mondo Minerals B.V,*** Uutela Mine (talc), ***Yara Suomi Oy,*** the Sokli project (phosphate)). An important aspect is to keep organic and inorganic material separate when stripping the ground, in order to keep the material characteristics for the landscaping purposes.

3.4.7 Best Practice 7: Disposal planning and management for later recovery

Re-processing of historical extractive waste is a long-standing practice that is adopted for all kinds of minerals: energy, metal ores, industrial and construction. Residues of low value originally, which are readily available in tailings or heaps, undergo processes of recovery in order to obtain fully qualified products, such as metals, aggregates, coal (energy products) etc. Technological advances make it economically feasible to use historical extractive waste as a resource – especially in combination with newly discovered ore-bodies and/or site clean-up and river restoration projects.

The EWMPs may consider such reworking of extractive waste from the outset, at the planning stage, by segregated emplacement where this is operationally and spatially feasible.

Relevance for Circular Economy: Re-processing of historical extractive waste: The utilisation of historical waste as raw material increases the long-term value obtained from the original extraction, offsets primary production elsewhere and simultaneously contributes to site rehabilitation. Whilst this usually improves environmental conditions locally by removing non-inert components, it seldom reduces the total amount of extractive waste to be subsequently managed.

Case studies:

EWMP from Penouta mine in Spain: The Penouta Mine was closed in 1985 without any rehabilitation of the site. Strategic Minerals Spain has carried out several studies to find ways to exploit the tailings ponds containing tantalum and niobium. The processing of tailings from the old Penouta mine produces around 1% of tin, tantalum and niobium metals, and 99% remain tailings. The latter are mainly composed of silicate minerals that can be reprocessed, obtaining around 70% of industrial minerals, namely quartz, mica, feldspar and kaolin. The overall process aims to achieve a reduction of mining wastes by around 80%. The final residue will be used as material for environmental rehabilitation.

Hellas Gold S.A. in Greece: Re-processing of historical waste (tailings from the enrichment of pyrites) to produce concentrates of galena, sphalerite and arsenopyrite. The historical waste is the residue of the ore treatment (since 2000) after recovery of these minerals. The re-working uses more efficient extraction and thus reduces the amount of ARD generating minerals in the tailings.

Canteras de Santullan S.A. in Spain (aggregates and production of calcium carbonate): Under the pressure of a very difficult situation due to the economic crisis at the end of the 2000s, the company decided to reconsider fundamentally and from a mining-technical point of view all existing processes and, with relevant investments, to increase drastically the recovery of reserves and recycle large stocks of old wastes.
The decision reduced mining costs, improved the quality of and added value to the final mineral products, transforming the company from a small local supplier of low-value construction aggregates to one of the biggest European exporters of high-quality industrial and chemical limestone products by sea transport from Bilbao port.

Interbeton S.A. (Titan Group) in Greece: Company owns a heap of low-grade kaolin (as old historical residue), which is mixed with high-grade kaolin (according to the trade specifications), targeting use of the total of the historical extracted material. This historical residue was not mixed with other waste (like overburden) during the production phase, thus it can be used now as raw material due to new lower grade marketing needs. This illustrates the benefit of segregated disposal in view of later re-working.

3.4.8 Best Practice 8: Effective monitoring of the implementation of the EWMPs and their review

Each Extractive Waste Management Plan is reviewed by the operator every five years and/or amended, as appropriate, in the event of substantial changes to the operation of the waste facility or to the waste deposited. Monitoring is an important tool to verify that an EWMP meets its objectives. The monitoring of an EWMP should be dynamic and provide records that can be utilised as a basis for the continuous optimisation of resources use and minimisation of the residual material that will end up in an extractive waste facility.

Typically, the operator develops a monitoring plan that also includes parameters relevant to the EWMP. The details of the proposed monitoring actions may include water and soil sampling and on-site or in situ measurements, geotechnical tests, topographical surveys, and surveys using remote sensing techniques.

An EWMP's monitoring records not only demonstrate compliance with the initial permit, but also may provide useful information for:

- decisions related to waste minimisation
- research for minimisation of hazardous properties of extractive wastes
- prevention or at least minimisation of any long-term negative effects, for example attributable to migration of airborne or aquatic contaminants from the waste facility

- Assurance long-term geotechnical stability of any EWF exists in the ground surface

EWMP is reviewed by the operator every five years and/or amended, as appropriate, in the event of substantial changes to the operation of the waste facility or to the waste deposited, supported by monitoring techniques, in order to prevent or reduce as far as possible any negative effects - actual or potential - on the environment or on human health, and lead to fast corrective actions, if needed.

Relevance for Circular Economy:

Starting from the design phase of a mining site, the EWD emphasises the concept that effective design will reduce the generation of extractive waste, encourage its recovery and minimise short- and long-term liabilities. Indeed, the ultimate goal would be to ensure that, where possible, a closed site can be left without the need for on-going monitoring. Therefore, keeping regular records of the all the quantities and composition of extractive waste generated at a site will aid decision-making on its fate and ensure its optimal management.

Case study:

According to the ***EWMP from Rosia Montana Gold Corporation S.A.*** (Romania) the EWMP is subject to periodic review and update over the life of the mining operation, in response to internal and external reviewer comments, regulatory changes, changes in mining operations, stakeholder communications, internal audit and management review results, and other factors. The implementation of the Extractive Waste Management Plan is also supported by a number of detailed, lower-tier Standard Operating Procedures. The Structural Relationship of lower-tier Management Plans in the Environmental and Social Management System is presented in the following figure.

Figure 3-8: Environmental and social management system (Source: EWMP from S.C. Rosia Montana Gold Corporation S.A.

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4. Development of a guidance document on best practices in the Extractive Waste Management Plans Best Practices for the implementation of the provisions set out in Article 5(2)(c) and 5(3) of the Extractive Waste Directive

4.1 Introduction

4.1.1 Context

The management of extractive wastes is regulated by Directive 2006/21/EC, the Extractive Waste Directive (EWD, 2006).

The Communication "Closing the loop - An EU action plan for the Circular Economy" (COM/2015/0614 final) by the European Commission describes the 'Circular Economy' as an economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised (European Commission, 2015). This Communication announced that the Commission will develop guidance and promote best practices in the extractive waste management plans (EWMPs) by 2018 in order to foster the implementation of the stipulations of the EWD. To this end the Commission requested information from national authorities, industry, environmental NGOs, knowledgeable experts and civil society on pertinent EWMPs. This report presents the results of an assessment of the information received and additional data gathered with a view to identify practices that can be considered as examples for best practice. In chapter 3 the related companion report, "Development of a guidance document on best practices in the Extractive Waste Management Plans - Circular Economy Action" (Eco Efficiency et al., 2019) considered the circular economy aspects whereas this report focuses on the aspects related to ensuring the short- and long-term safety of disposal of extractive waste. This encompasses the whole life-cycle, from the design phase, the management during the operation, to the after–closure phase of an extractive waste facility (EWF).

The mining sector is particularly complex due to the specific geological, geochemical, geotechnical, geomorphological, climatological, ecological, and socio-economic conditions of each site. Also, the mining life-cycle (cf. Figure 4-1) encompasses many phases that may span years or even decades. As a matter of fact, the ultimate phase after closure extends in time due to the fact that all remaining extractive waste (EW) will remain at the site for ever.

While the chosen technical waste management solution must ensure the short-term and long-term protection of human health and the environment, it also needs to ensure the short and long-term after-closure stability with as little maintenance as possible. The EWMP has to detail the respective strategies and rationales for selecting the technical solutions.

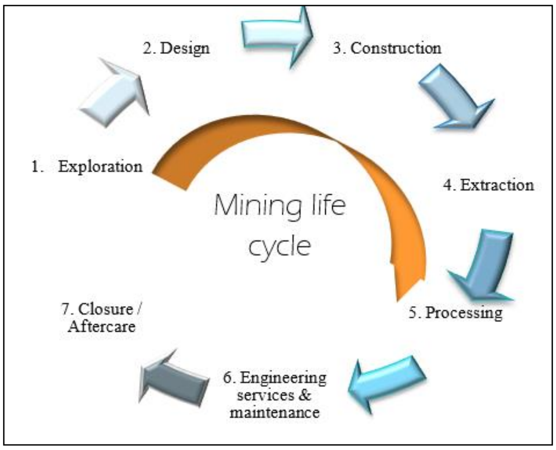

Figure 4-1: The phases in a mine life-cycle that will determine the EWM solution

As has been pointed out in the related report on the Circular Economy aspects in EWM (Eco Efficiency et al, 2019), waste minimisation through optimised extraction and re-use is the key. It will also be shown that the choice of processes and the resulting waste-type can significantly influence the manageability of the waste and, hence, short- and long-term safety of the EWF. Therefore, a systemic life-cycle approach is likely to result in more long-term stable EWM solutions, i.e. solutions that have minimal impact on the surrounding environment and remain physically intact.

4.1.2 Objectives of this report

The present report is part of a study to support the European Commission in the elaboration of guidance on best practices in developing EWMPs with a view to improve the implementation of the EWD. It addresses in particular to (a) the integration of Circular Economy aspects into Extractive Waste Management Plans (Eco Efficiency et al, 2019)), and (b) the identification of Best Practices in Extractive Waste Management Plans (EWMPs) to ensure the short- and long-term safety of EWFs. This report only covers activities that are under the scope of the EWD.

According to Article 5 ("Waste management plans") of the EWD, the Member States have to ensure that operators draw up an EWMP. Specifically, Articles 5 (2) c and 5 (3) of the EWD outline objectives of the EWMP related to the prevention of short and long-term environmental impacts.

This report will outline a methodology to develop EWMP with respect to the criteria listed below. It will discuss the desirable scope and contents of EWMPs with a view to ensuring the short- and long-term safe disposal of extractive waste, in particular by considering, during the design phase, the management during operation and after the closure of an EWF and by choosing a design that

- requires minimal and, if possible, ultimately no monitoring, control and management of the closed waste facility (minimise long-term stewardship needs);
- prevents or at least minimises any long-term 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.
- for Category A facilities: major accident prevention policies and related safety management system, internal emergency plans;
- for facilities not categorised as Category A, information on justification including identification of possible accident hazards;
- extractive waste characterisation in accordance with Annex II of the EWD and approaches to estimate total quantities of extractive waste to be produced during the operational phase;
- description of operations generating extractive waste;
- assessments of how environment and human health may be adversely affected by the deposition of extractive waste;
- preventive measures taken to minimise environmental impact during operation and after closure;
- control and monitoring procedures pursuant to Articles 10, when applicable, and 11(2)(c);
- plans for closure, including rehabilitation, after closure procedures and monitoring as provided for in Article 12 of the EWD;
- measures for the prevention of water status deterioration in accordance with Directive 2000/60/EC and the prevention or minimisation of air and soil pollution pursuant to Article 13 of the EWD;
- surveys of the conditions of the land to be affected by the waste facility.

There will be, in many cases, a gradual transition from the operational phase to the closure, post-closure and long-term management phase. The foundations for safe long-term management will be laid during the operational phase, so that there will be a close relationship between the recommendations given in this document and the recommendation of the Best Available Techniques reference document on the management of waste from extractive industries (MWEI-BREF, 2018). This report will point out the particular long-term aspects in extractive waste management.

The scope and contents of the EWMPs collected as part of this study were reviewed with respect to the above criteria. From these a number of cases were selected that can be considered as examples for 'best practice'.

4.1.3 Provisions of the EWD

For easy reference, the provisions of the relevant Article 5 of the Extractive Waste Directive (EWD, 2006) are given below. Article 5 of the EWD sets out the requirements for Extractive Waste Management Plans (EWMPs)[8]. The present report focuses on aspects related to Article 5 (2) c and 5 (3) of EWD.

[8] Relevant definitions are provided in Article 3 of the EWD.

Article 5

Waste Management Plan

1. Member States shall ensure that the operator draws up a waste management plan for the minimisation, treatment, recovery and disposal of extractive waste, taking account of the principle of sustainable development.
2. The objectives of the waste management plan shall be:

   (a) to prevent or reduce waste production and its harmfulness, in particular by considering:

   (i) waste management in the design phase and in the choice of the method used for mineral extraction and treatment;

   (ii) the changes that the extractive waste may undergo in relation to an increase in surface area and exposure to conditions above ground;

   (iii) placing extractive waste back into the excavation void after extraction of the mineral, as far as is technically and economically feasible and environmentally sound in accordance with existing environmental standards at Community level and with the requirements of this Directive where relevant;

   (iv) putting topsoil back in place after the closure of the waste facility or, if this is not practically feasible, reusing topsoil elsewhere;

   (v) using less dangerous substances for the treatment of mineral resources;

   (b) to encourage the recovery of extractive waste by means of recycling, reusing or reclaiming such waste, where this is environmentally sound in accordance with existing environmental standards at Community level and with the requirements of this Directive where relevant;

   (c) to ensure short and long-term safe disposal 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:

   (i) requires minimal and, if possible, ultimately no monitoring, control and management of the closed waste facility;

   (ii) 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

   (iii) ensures the long-term geotechnical stability of any dams or heaps rising above the pre-existing ground surface.
3. The waste management plan shall contain at least the following elements:

   (a) where applicable, the proposed classification for the waste facility in accordance with the criteria laid down in Annex III:

   — where a Category A waste facility is required, a document demonstrating that a major-accident prevention policy, a safety management system for implementing it and an internal emergency plan will be put into effect in accordance with Article

6(3);

— when the operator considers that a Category A waste facility is not required, sufficient information justifying this, including an identification of possible accident hazards;

(b) waste characterisation in accordance with Annex II and a statement of the estimated total quantities of extractive waste to be produced during the operational phase;

(c) a description of the operation generating such waste and of any subsequent treatment to which it is subject;

(d) a description of how the environment and human health may be adversely affected by the deposit of such waste and the preventive measures to be taken in order to minimise environmental impact during operation and after closure, including the aspects referred to in Article 11(2) (a), (b), (d) and (e);

(e) the proposed control and monitoring procedures pursuant to Articles 10, when applicable, and 11(2)(c);

(f) the proposed plan for closure, including rehabilitation, after-closure procedures and monitoring as provided for in Article 12;

(g) measures for the prevention of water status deterioration in accordance with Directive 2000/60/EC and for the prevention or minimisation of air and soil pollution pursuant to Article 13;

(h) a survey of the condition of the land to be affected by the waste facility.

The waste management plan shall provide sufficient information to enable the competent authority to evaluate the operator's ability to meet the objectives of the waste management plan as set out in paragraph 2 and his obligations under this Directive. The plan shall explain, in particular, how the option and method chosen as mentioned in paragraph 2(a)(i) will fulfil the objectives of the waste management plan as laid down in paragraph 2(a).

4. The waste management plan shall be reviewed every five years and/or amended, as appropriate, in the event of substantial changes to the operation of the waste facility or to the waste deposited. Any amendments shall be notified to the competent authority.
5. Plans produced pursuant to other national or Community legislation and containing the information specified in paragraph 3 may be used where this obviates the unnecessary duplication of information and the repetition of work by the operator, on condition that all requirements under paragraphs 1 to 4 are met.
6. The competent authority shall approve the waste management plan on the basis of procedures to be decided by the Member States and shall monitor its implementation.

4.2 Methodological considerations for developing EWMPs to ensure short- and long-term safe disposal of extractive waste.

4.2.1 Conceptual framing – the dimension of time

A continuum of geotechnical and environmental safety has to be assured during the transition from the operational to the post-closure phase. Conditions and parameters will differ somewhat for assuring the short-term operational safety and long-term safety.

From a conceptual point, the main difference between the two is that during the operational phase, safety is assured by continuous maintenance of the EWF. To the contrary, after closure only periodic monitoring and maintenance will be undertaken, if at all. The best solution will be, of course, a maintenance-free solution. Both situations may result in differing designs and parameters for the EW facility. However, as will be pointed out subsequently, the operational design is best chosen so as to facilitate transition into the closure and post-closure phase.

In order to better understand the relationship between short- and long-term risk and safety aspects, short-term and operational safety are briefly reviewed in the following.

Ensuring short-term operational safety not only encompasses technical measures, design criteria and designs, but also management measures, or in other words governance issues. Mining operations evolve over time. This may include changing staff as well as changes in ownership and economic boundary conditions. In order to preserve institutional knowledge of the EW facility, adequate records management provisions have to be put into place. EWMPs need to spell out, how the records are to be managed and by whom (e.g. IAEA, 2006). EWMPs would identify the responsible individuals and how responsibility is to be handed over in the case of change (MAC, 2017).

A wide range of EWMPs have been collected for this project from Member States, as well as industry associations (Eco Efficiency et al, 2019). These EWMPs cover predominantly the operational aspects and those concerned with compliance with applicable rules and regulations. Strategic considerations beyond the economic scope of the operation do not normally play a role. Particularly, the dimension of time in the sense of long-term stability of the chosen management solutions for EW and EWFs mostly is not mentioned explicitly. It is tacitly assumed that someone will monitor and maintain EWFs, particularly those containing materials that may cause impacts to the environment and human health. However, it is very likely that a few hundred years after their construction the knowledge of their contents and even their existence will become lost. Designing for long-term stability has to keep this in mind.

Hence, this guidance is particularly concerned with the dimension of time of the EWMPs, namely with the long-term safety and stability of the selected EWM solutions. The long-term manageability of mining residues depends *inter alia* on their nature and quantity, which in turn depend on the host geology, as well as the mining and processing methods. For this reason, the long-term safety and stability of EWs have to be seen in a life-cycle context as it is schematically presented in Figure 4-2.

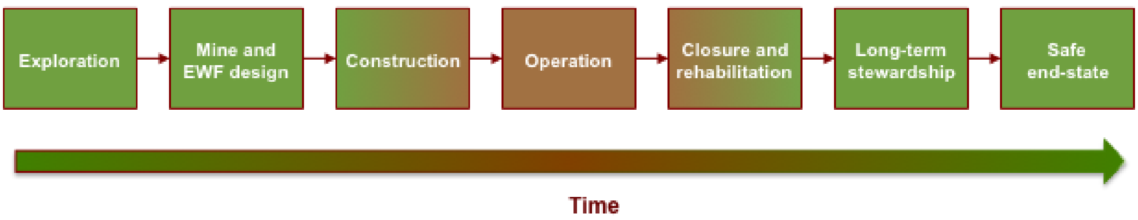

Figure 4-2: The life-cycle of an extractive operation.

Extractive wastes and their retaining structures (e.g. dams, liners) constitute a potentially alien body of geological material in a given landscape or geological setting. For instance, slopes may be steeper than the natural ones, the material is sterile due to the absence of top-soil, the material is less cohesive than the surrounding materials, the wastes may contain constituents (e.g. sulfide minerals) that are unstable from the geochemical point of view when exposed to the atmosphere, wastes from processed minerals contain a certain chemical potential with respect to their surroundings, etc. Therefore, it is likely that natural processes will alter the wastes themselves and/or any man-made retaining structures. Such alterations may compromise the stability or functionality and, hence, the safety of the disposal site. The classification of extractive wastes into "*inert*", "*non-inert non-hazardous*", or "*hazardous*" (see European Commission, 2009) reflects the risk associated with such processes.

It needs to be noted that natural geological systems are highly variable and may be known only to a limited extent until the actual excavation takes place. Therefore, only guidance on desirable objectives can be given and decisions need to be made on a case-by-case and site-by-site basis. The socio-economic and geographical context will also have a decisive influence on the actual design of mines and their associated EWMPs.

Any EWMP is the result of an optimisation between addressing identified risks, the pre-existing natural conditions, MWEI-BREF (2018), technical feasibility of mitigation measures, economic opportunities, and cost. EWMPs will need to be adjusted to changing circumstances.

4.2.2 Integration into the mine planning and licensing process

EWM should not be an end-of-the-pipe process but integrated into the overall planning of the extractive activity. Thus, assessment of what would constitute a best practice in EWMPs has to be undertaken using a systemic and life-cycle approach. This allows to identify where in a system one can interfere to either reduce wastes or to re-use/re-cycle them. Managing wastes alone is not "good" practice. Good practice addresses the waste at their originating process (c.f. also Eco Efficiency et al, 2019). To this end, a material flow analysis for a particular operation will have to be undertaken. Changing mining and milling processes might lead to residues that have a better potential for utilisation. However, a change in procedures/processes will only be accepted by mining companies, if they entail economic benefits or, if other, external incentives are provided. In any case it is desirable that such changes in processes do not lead to wastes that pose greater challenges with respect to their long-term management.

As has been pointed out in European Commission et al. (2019), the development of EWMPs is an iterative process, taking into consideration mining and processing technology aspects as well as resulting potential environmental and human health impacts that would be addressed in the related Environmental Impact Assessment (EIA). When considering the long-term aspects in an EWMP, one may need to revisit certain aspects of the EIA from a long-term perspective.

A life-cycle approach helps to ensure both, the short and long-term safe disposal of extractive waste, in particular by considering already during the design phase the management during the operation and after closure of a waste facility. This approach ensures that EWM does not merely operate following the “end-of-the-pipe” paradigm, but tries to create synergies between the design of the operation of a mine and mill and the disposal of its wastes. A life-cycle approach also has the advantage that the closure of extractive waste facilities is not left until the mining operation ceases, but can be undertaken, while the mine and its infrastructure and staff still exist (c.f. Falck et al., 2009; Falck & Fernandes, 2009 – though addressing nuclear operations, the same concepts apply to mines and mills; Falck, 2016b). This reduces the likelihood of abandoned and not orderly closed mine waste sites in case the mine ceases operation prematurely. A life-cycle approach to EWMPs may consider the following aspects:

- EWMPs would be drawn up at the start on the basis of the initial extraction plan and the EIA for the overall operation
- EWMPs need to be continuously updated as processes and markets evolve
- Designs for mining and processing, the EIA, and the EWMP development need to be iterative processes
- Good process design aims to minimise materials moved and materials used
- Processes and EWM need to be optimised for the economic circumstances
- Energy requirements and CO_2-footprints need to be considered and balanced against other potential impacts
- All material moved would be processed for valuable constituents, if the economic circumstances permit it
- Processing may need to be delayed depending on market conditions -> stockpiling
- Mine and process wastes are best returned to the mined out voids, whenever possible and if it can be done safely and without impacts to the underground environment
- However, such ‘back-filling’ should not preclude eventual access to any remaining resources
- Contingency plans for premature closure need to be developed

4.2.3 EWMPs and change management

Continuous improvement is one aspect of change management, which also ensures continuity in the case of changing personnel, ownership, designs, operations, as well as policy and regulatory requirements. Adequate records management facilitates change management. For instance, good records of what kind of waste has been deposited where, will facilitate later retrieval, if a beneficial use has been found. The periodic updating of the EWMPs according to Article 5(4) of the EWD (EWD, 2006) allows to follow the principle of continuous improvement (Fig. 4-3).

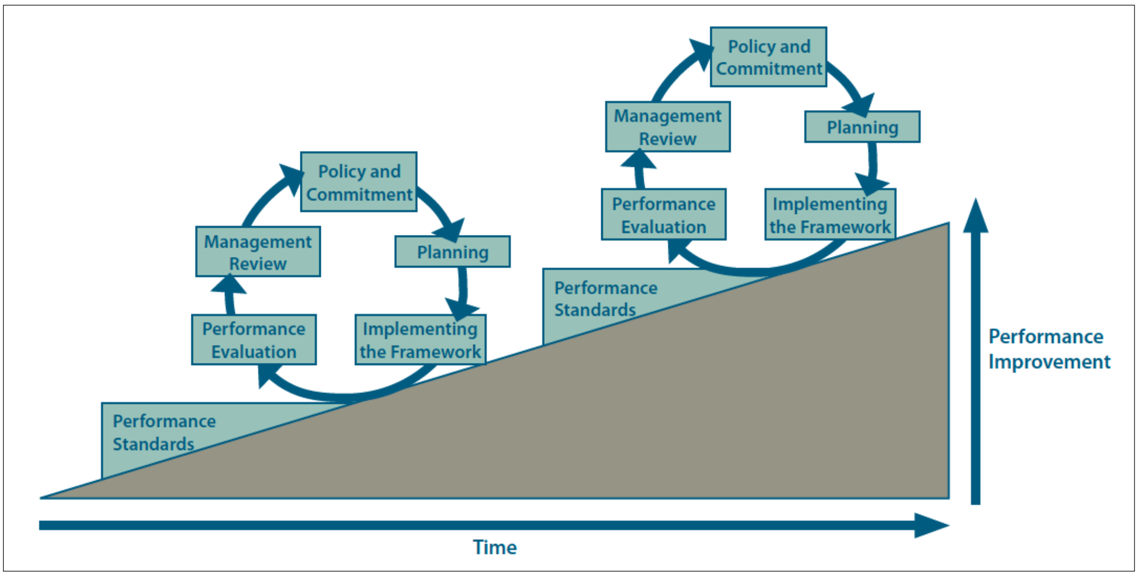

Figure 4-3 The principle of continuous improvement (MAC, 2017)

4.2.4 Managing the implementation of an EWMP

Appropriate governance structures (see e.g. MAC, 2017) will provide clear management routes and accountabilities. Their description in the EWMPs is a good practice and can serve as a valuable communication instrument with a wide range of stakeholders.

Periodic independent reviews of EWMPs is an instrument to ensure that the plans are adequate, up-to-date, emulate current BAT/BAP (MAC, 2017; MWEI-BREF, 2018) and policy frameworks, such as the Circular Economy Plan. These reviews are part of the governance structures, as they provide the basis for executive decisions by the management. The reviews also provide assurance to the regulatory bodies.

A quality management plan (QMP) that follows the relevant ISO 9001 guidelines would encompass not only quality control (QC), but also forward-looking quality assurance (QA) measures, that would be put into place as an overarching management instrument. The aspect discussed in the following all contribute to this QMP.

It is recommendable to subject the QMP and its (technical and governance) components to an independent, periodic review by competent individuals or organisations.

4.2.5 Risk Management in EWMPs

Conceptual considerations

As noted before, the management of extractive wastes is not a purely technical matter, but has to be undertaken in a context of global risk reduction, which includes secondary risks and impacts, such as the release of CO_2 from the various types of operations. Risk displacement resulting from specific risk management actions has to be also taken into consideration.

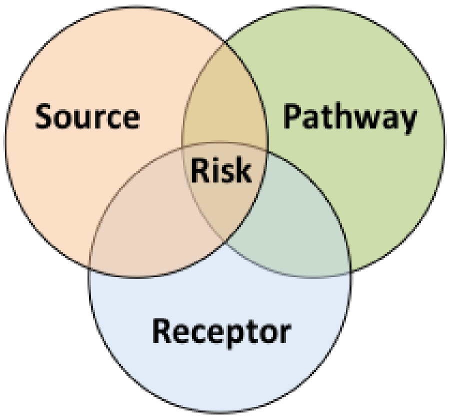

Figure 4-4: Risk Source-Pathway-Receptor model

Risk and its management are major drivers behind EWM concepts und solutions. Risk-based decision-finding helps to focus the EWMP on the essential aspects and hence to use resources efficiently while maximising the level of protection of the environment and human health. Risk and safety are complementary concepts, saying that by managing and reducing risks, the safety of an operation or installation is increased. In general, risk assessment is concerned with features, properties, and events that can lead to undesirable out-comes in the shorter or longer term. Risk is a human-defined concept and based on

values that individuals or societies would like to see protected, namely lives, health, and property. It is helpful to visualise risk in a source-pathway/vector-receptor model (Figure 4-4). A risk is only present, when all three factors are present or inversely the risk can be removed by removing either of the three factors.

The objective of risk management is to reduce or eliminate impacts on the receptors, i.e. effects on the values to be protected. Figure 4-4 indicates that there can be three fundamental strategies in risk management, namely the elimination of the source, the elimination of the pathway, or the removal of the receptor. The removal of the receptor, e.g. of people by evacuation, in many cases is neither desirable nor feasible. As a matter of fact, the main motivation for risk assessment and ensuing risk management measures is to avoid the removal of receptors, as this may entail considerable inconveniences and social or economic impacts. A classical example for removing a source of risk would be the removal of a soil contamination. If the contaminant cannot be destroyed, e.g. by incineration as for organic contaminants, it has to be placed into a safe, engineered repository. Engineered waste disposal facilities are also an example for removing pathways, as the containment of the facility is designed to inhibit pathways by which a contaminant could effect its surrounding environment. All management measures for extractive wastes can be viewed conceptually as following one of the above risk management strategies.

One has to be aware of risk displacement effects. For instance, the removal of a contaminant at one place, perhaps on the instigation of potential receptors (e.g. the ‚public'), will have the effect that around the chosen disposal location other potential receptors might be exposed to an albeit hopefully much lower risk. For this reason a chosen EWM option always has to be carefully vetted for risk displacement effects.

Risk management from the operators perspective

From the perspective of the operator the various environmental and geotechnical risks in the first instance constitute a business risk that may entail costs. Risk management activities entail costs, so-called opportunity costs, as the money spent either reduce the profit or are not available for further investment. Therefore, there is an economic incentive to keep risk management and thus EWM costs to the minimum required in order to comply with the various applicable regulations. There is often a limited awareness among operators of the various business risks associated with minimal risk management. The breach of a tailings management facility will have impacts beyond the health and safety of the workforce and the downstream communities and environments. To the cost of rehabilitation and rebuilding the facility, the opportunity costs of loss of business, loss of reputation and trust among investors, business partners and last not least the local population will have to be added. Loss of social acceptance to operate can constitute a fatal business risk (Falck, 2016a).

4.2.6 The transition from operational to long-term safety

Most of the features and provisions that ensure geotechnical, environmental and human health safety of EWFs have been covered in the MWEI-BREF (2018). The following discussion focuses on the differences between operational and long-term safety features and provisions. Again, a life-cycle perspective during planning ensures a smooth transition from the operational to the post-closure phase and an efficient use of resources by considering the requirements of the post-closure phase already during the operational phase.

Solid waste dumps

Operational geotechnical safety of solid waste dumps. Good engineering practice and the requirements by the competent authority determine the controlling parameters for the emplacement of residues, such as grade of slope, required levels of compaction, maximum height of emplacement, and maximum height of each berm. The construction permission would normally also ensure that the underlying strata have been adequately characterised in order to ensure their stability when loaded. Grades of slope are often chosen as steep as possible in order to save space, or according to the natural angle of deposition. However, in order to avoid re-grading of slopes during closure and rehabilitation, it will be of advantage to mimic the surrounding natural geomorphology (see Best Practice Example A).

Compacted waste is more geotechnically stable and has higher erosion resistance. It will be of advantage to foresee in the EWMP a strategy to consolidate the materials as early as possible. Thus, when vehicles are used to dump the waste, it will be of advantage to choose a strategy of emplacement whereby the vehicles run repeatedly over the waste, which will compact it without additional effort and energy expenditure.

Non-cohesive material has its highest degree of geotechnical safety around the so-called optimal water content. Higher water contents reduce the stability of slopes. Therefore, it is good practice to reduce the meteoric water input at the earliest stage possible and to foresee in EWMPs re-vegetating the dumps and/or covering them with material of low permeability. This also eliminates or reduces a key vector in the risk of generating acid drainage (see below).

When residue dumps are created in natural depressions (e.g. valleys), any pre-existing water courses must be permanently diverted to avoid saturating the waste and thus destabilise it. The diversion channels must be designed to cope with at least 100 year-rainfall events, or whatever national legislation may prescribe.

For a variety of (practical) reasons in civil engineering ‚as built' is not necessarily the same ‚as designed'. Regular project reviews and on-site monitoring are required to detect possible deviations from construction permissions and the EWMP. These deviations have to be assessed with respect to their significance and, if needed, remedial action has to be taken. This requires a strong and competent regulatory oversight.

Operational environmental safety of solid waste dumps. Ensuring the geotechnical stability also reduces the risk from eroded or spilled materials that may impact e.g. water courses or cover valuable land with slumps and land-slides. Measures to reduce water ingress and gas exchange reduce the generation of acid drainage and leaching of contaminants by eliminating the vector water. Covering with cohesive material and re-vegetation further reduces infiltration and the risk of dust generation, that may impact the surrounding environment. EWMPs, therefore, may want to foresee an early (partial) coverage of waste dumps. In the case of materials particularly prone to erosion when dry spraying with a binding agent, for instance acrylic emulsions or water glass, will supress dust generation in dry climates until the proper one can be constructed.

While geological materials are normally stable on a secular scale in their natural environment, excavation changes the boundary conditions, e.g. with respect to redox conditions, driving the materials towards new equilibria. Such re-equilibrations manifest themselves, for instance, in the generation of acid drainage, but also in form of processes that would be described as ‚early diagenesis' in natural geological environments. It is, therefore, wise to try to re-establish conditions in emplaced materials that are close to those originally found. For this reason it is good practice to emplace, as far as possible, excavated materials in the same sequence as they occurred naturally and in contact with the source material where they came from. Segregation of extracted materials, particularly overburden, for this purpose, therefore, is considered good practice. Depending on the size of the dump, material properties, and economic circumstances, it may also be possible to introduce solidifying agents that aid the diagenetic processes mentioned earlier.

Tailings management facilities

Operational geotechnical safety of tailings management facilities. A tailings management facility (TMF) comprises two main critical components, the retaining structures, such as dams, and the impounded tailings themselves.

A large amount of good practice for design and construction criteria for dams has been accumulated over the past decades. Those drafting EWMPs are well advised to take into consideration the guidance given e.g. in UNECE (2014) and the International Commission on Large Dams (http://www.icold-cigb.net/) *inter alia*. Critical factors include the internal structure of the dams (materials used, grain-size distribution, mode and level of compaction, etc.), the way how they are ‘keyed’ into the surrounding geology (e.g. slope of the terrain on which the dam is built, drainage properties), avoidance of ‚high-energy’ points (e.g. sharp corners, precise levelling of the crown to avoid singular points, where overtopping may occur, etc.), lining of dams to prevent excessive soaking, porewater pressure built-up and thus piping and suffusion, and protection of the crown against the effects of overtopping and erosion to avoid catastrophic failure due to regressive erosion.

Where infiltrating porewaters can lead to the contamination of underlying strata a liner may be required. In such cases a bottom drainage will need to be foreseen in order to avoid undue accumulation of waters. Such drainage at the inside toe of the dam or at the lowest point in the impoundment also prevents excessive porewater pressure built-up that can lead to the failure of the dam.

Practical experience shows that dams often are not built as designed. The actual construction has to be closely monitored to ensure that the design and its materials parameters are followed. This, in principle, is a construction licensing issue to be monitored by the competent authorities, rather than the subject of the EWMP as such. In consequence, the regulatory control of the competent authorities over civil engineering project in a mine and the regulatory control over the EWMPs have to be integrated to ensure adequate safety.

While applicable national civil engineering and mining regulations provide the licensing framework for dam projects, the EWMPs needs to look at the development of the retaining dams over the life-cycle of the mine. For cost reasons, a tailings dam is not normally constructed right away to take up all the tailings that expected to arise over the life-time of the mine, but it is enlarged or more typically raised as time progresses. The EWMP would outline the likely development and the envisaged method of raising as a function of the kind of tailings to be deposited (Figure 4-5). Upstream raises require little material for dam construction, but rely on the successful consolidation of the tailings. Other methods are likely to be safer options. Since a tailings management facility almost invariable becomes a permanent installation, the EWMP should also make outline provisions for the closure and post-closure developments. This includes strategies for the final capping as well as drainage and surface water diversion systems. Dewatering of liquid tailings can take decades, so that temporary capping to reduce the addition of meteoric waters needs to be considered. This applies also to TMFs, where thickened tailings are deposited (see below).

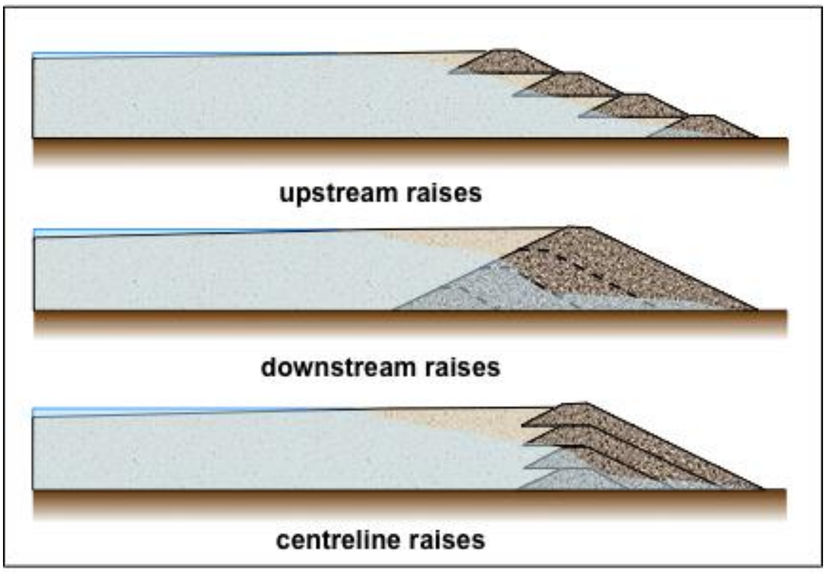

Figure 4-5: Different methods of raising tailings dams (WEF)

The second critical component, the tailings themselves, are a key aspect in the EWMP. The form in which the tailings arise depends on the geological material, the comminution technique, the process technique and any subsequent conditioning. Normally, tailings arise in form of slurries with a significant water content. The comminution tries to achieve a small and uniform grain-size with a view to enhance leaching. This makes the material unstable and difficult to handle from a geotechnical point of view. The major process, when tailings are consolidating upon emplacement, is the expulsion of the water. The fine, even colloidal nature of many tailings make this a slow process under natural conditions. Tailings are usually also thixotropic, meaning their viscosity changes dramatically, if shear forces are applied. This is one reason for the dramatic effects of dam failures: as soon as they begin to creep through the breach, they become liquefied with a cascading effect into the tailings mass. EWMPs therefore may foresee measures to accelerate dewatering or better the emplacement of largely dewatered (‚paste') tailings. Paste tailings have a number of benefits, including better geotechnical stability, smaller volumes, shorter times to final closure, and the possibility to recycle process waters. The MWEI-BREF (2018) recommend thickened tailings as best practice. These advantages are bought at the expense of possible less convenient handling, i.e. transport on conveyer belts rather than pumping, and higher energy expenditure and thus larger CO_2-footprint. However, ensuing risk reduction will also result in lower costs for third-party insurance, emergency preparedness, and rehabilitation costs in the case of an incident. The EWMPs for TMF would take these benefits from risk-reduction measures into consideration.

A tailings pond in operation will also interact with the surrounding environment. For instance, it can change the stability of slopes on which it is built and the water balance in the adjacent geological strata. This can lead to instabilities, such as hydraulic heave, and collapse of slopes into the ponds, which due to the displaced tailings masses can lead to overtopping and the failure of the dam. Although such scenarios should have been investigated as part of the licensing procedure, the EWMPs may need to foresee regular monitoring in order to detect early any detrimental changes in the surrounding geology.

Operational environmental safety of tailings management facilities. The operational environmental safety of tailings management facilities is largely linked to their geotechnical safety, but not exclusively. While the geotechnical safety concerns mainly catastrophic failures, there may be also chronic effects from tailings ponds.

In the past tailings ponds where typically constructed without liners. This aids in the dewatering of the tailings, but also provides a pathway/vector for contaminant dispersion. Modern tailings ponds are often constructed with liners and drainage water collection systems. Any drainage water is then treated before being released into the environment. Similarly, there must be a system to collect surface decant waters. These are waters expelled from the compacting tailings and need to be treated before release into the environment. Due to the slow dewatering of liquid tailings, drainage water collection and treatment may need to continue for decades after the closure of a mine and mill. In consequence, the final closure of a tailings pond typically can only performed long after mining has ceased. This requires that adequate financial provisions are provided to ensure that these activities can be performed long after mining has ceased.

The surface area of a tailings pond collects the atmospheric precipitation that mixes with the decant waters. Further, if the pond is constructed in a natural depression, it forms part of the natural watershed, collecting the run-off from the surrounding area. Ideally a diversion system collecting such run-off has to be constructed in order to minimise the input of clean precipitation that would mix with potentially contaminated decant waters. All water collection and treatment systems have to dimensioned to be able to cope with at least 100-year-rain-events, as noted above for the waste dumps.

Uncovered tailings that dry out are prone to wind erosion and dispersal of contaminated dust, particularly in arid and semi-arid areas. Covering the tailings will also reduce the input of atmospheric precipitation, if the respective run-off is collected.

Depositing the tailings as a paste will reduce the amount of seepage and decant waters that have to be handled thus reducing the associated risks. It will also reduce the amount of time until the tailings can be covered, thus reducing the risk associated with an open tailings pond.

Monitoring of tailings management facilities. Due to the geotechnical and water-borne risks discussed above, an adequate monitoring and surveillance programme has to be put into place until final closure. A number of direct and indirect methods have become available, particularly in recent years. The main hazard associated with tailings management facilities is that of catastrophic containment failure. Nevertheless, there may be also chronic failures, such as the leakage of contaminants into aquifers beneath the tailings.

The monitoring of the containment mainly concerns the stability of dams and the functioning of constructed drainage systems to divert excess waters. Excess waters can lead to catastrophic failure of dams due to overtopping and ensuring retrograde erosion, which in a self-enhancing mode can lead to a complete failure of a dam. The EWMP needs to provide for periodic inspection of these drainage systems, e.g. with respect to silting up.

Dams can fail by a variety of mechanisms including suffusion, excess porewater pressure and toe failure. Modern geophysics and remote-sensing offers various tools to continuously monitor the conditions of a dam. Air-borne LIDAR geo-referenced with high-resolution satellite-supported positioning (e.g. GPS) allows to monitor the shape of an earth-dam and to detect early movements or distortions. 3D-resistance tomography allows to map porewater contents in real-time within a dam and to send respective warnings. The more traditional method would be a network of piezometers.

Chronic failure of dams can be also monitored by assessing the sediment load downstream. Due to low loads and likely significant fluctuations as a function of flow-rates, integrative methods would be better suited than sporadic sampling.

The tailings themselves would also be observed in order to assess, whether dewatering progresses as predicted, e.g. by geotechnical modelling. Again airborne LIDAR would be a modern choice to map the settling periodically.

The monitoring programme would also need to include the waters collected in the various drainage systems. In most cases these drainage and supernatand water will need to be treated before they can be released into the environment. Regular monitoring would be part of the operation of such treatment plants.

For large-scale tailings ponds that for operational reasons remain uncovered and that are located in (semi-)arid areas several air-monitoring stations down-wind of major wind directions may be needed in order to detect dust problems.

These monitoring programmes would be integrated into a formal management system for the site. This requires also a data management system that ensures the safe handling of the data and through which monitoring data can be made available to regulators and the public, the latter with a view to gain confidence and thus support the social acceptance to operate.

Emergency Preparedness and Response Plans (EPRP)

According to Article 5 of the EWD in cases of Category A waste facility it is required, that the EWMP has to include an internal emergency plan. The emergency plans have to fulfil the following objectives according to Article 6(3) of the EWD:

- to contain and control major accidents and other incidents so as to minimise their effects and in particular to limit damage to human health and the environment,
- to implement the measures necessary to protect human health and the environment from the effects of major accidents and other incidents
- to communicate the necessary information to the public and to the relevant services or authorities in the area
- to provide for the rehabilitation, restoration and clean-up of the environment following a major accident

Article 6 of the EWD applies to Category A waste facilities, save for those waste facilities falling within the scope of Directive 96/82/EC ('Seveso Directive', European Council, 1996).

Examples of possible emergencies that need to be addressed in EPRPs include: structural failures of the facility; rising water levels within a facility; cracking of a dam; a sudden loss of environmental containment of the facility; or other events typically linked to the loss of one or more critical controls (MAC, 2017).

The EPRPs rely on the monitoring programmes to supply the data for the necessary (real-time) assessments. EPRPs can be drawn up, for instance, on the basis of FEP (*Features*, *Events*, *Processes*) catalogues (e.g. Mazurek et al., 2003) and related scenario analyses. *Features* here means e.g. engineering designs, natural landscapes etc. while *Events* may include e.g. earthquakes, storms, etc., and *Processes* include categories such as erosion, dispersion, contaminant migration, etc. FEP catalogues are a kind of score-board against which a facility can be assessed with respect to potential failure modes and scenarios, taking into account also common-mode and common-cause failures. Pre-developed scenarios are helpful to identify possible event chains that can threaten the safety of waste management facilities, particularly tailings dams.

The EIAs that have been developed during the licensing phase of an operation will also inform the EPRPs. Additional assessments may be required. For instance, these could include numerical simulations of the flood waves that would develop in the case of a tailings-dam failure. Such simulations allow to predict the areas potentially affected, which in consequence may need to be evacuated. In turn, this allows to assess which essential services (roads, bridges, telecommunication, water supply, etc.) might be under threat, so that alternative routes for emergency services can be worked out. The simulations will also indicate the time-frame within which a flood is likely to proceed and, hence, how much time for initiating emergency response measures will remain.

Informing the potentially affected parties, including the general public, is part of emergency preparedness. In this way the people will know what to do (or not to do) in case of an emergency. This may be, indeed, a difficult subject, because adequate emergency management is likely to be a key subject for discourses over the social acceptance to operate. Modes of informing potentially affected people of an imminent emergency have to be pre-established and these people informed about these modes. Likewise communication channels with the relevant authorities need to be established. In collaboration with the relevant authorities emergency plans for rescue services, hospitals, etc. have to be drawn up. Utilities, such as waterworks and electricity companies, in the potentially affected areas have to brought into the discussions, so that plans for shutting down their operations (temporarily) in order to avoid secondary impacts (contamination of water supplies, power surges, etc.) and hazards (e.g. cut, but life electric cables) can be minimised.

EPRPs have to remain in force after mining and milling have ceased and while tailings impoundments are not yet in a safe closure state. They are part of the long-term management plans.

4.2.7 Recommended scope of EWMPs to ensure the short- and long-term safety of EWFs

In the following Table a number of elements and topics are listed that are deemed necessary or useful to be covered by EWMPs, particularly also with respect to Articles 5 (2) c and 5 (3) of the EWD. Potential environmental and human health impacts addressed in the Environmental Impact Assessment (EIA) need also to be taken into account in EWMPs as part of an iterative process. It is understood, that MSs would define the scope and contents of the EWMPs and EIAs under their respective jurisdiction. For this reason the following are non-binding recommendations.

A question to be resolved is, whether the EWMPs are to be submitted per EWF or per operation/mine. There is not necessarily a one-to-one relationship between mines/ quarries and EWFs, some mine may have several EWFs or one EWF could be used by several mines/quarries. In the following it is assumed, for convenience sake, that an EWMP is prepared for a single EWF. Table 4-1 gives a comprehensive overview over the elements that would need to be presented in an EWMP. However, depending on the risk originating in the EWF or the EW therein, certain details may be omitted in line with the requirements of the EWD.

Table 4-1 Scope of an Extractive Waste Management Plan

Issues covered in the EWMPs	Examples of parameters[9][10]
Administrative information	Name of the company
	Site location (coordinates)
	Site manager
	Officer responsible for extractive waste area
	Contact details
	Emergency contact details
	Date
Geological description of the mineral deposit	Rock type and mineralogy description of the mineral resource to be used
	Size and geometry of the mineral deposit
Description of materials streams (supported by flow-diagrams)	List of each type of material, including quantities and destination
Waste produced from individual processes	Excavation
	Crushing and grinding
	Flotation, magnetic separation or other separation processes
	Exploration works
	Other processes
Mineralogical and geochemical characterisation per material/waste	Rock type
	Mineral assembly
	Bulk chemical composition including (at least) components of potential concern, such as As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V and Zn
	Acid generation potential and neutralization potential
	Presence of (fibrous) minerals of concern (e.g. asbestos)
	Potential chemical processing residues
	Waste(s) code according to Decision 2014/955 (Waste Catalogue) • Assessment whether the EW is inert is based on the technical requirements that are presented in the Decision 2009/359/EC • Assessment whether the EW is inert, based on method EN 15875: Sulfide sulfur content % (<0,1% or <1% and NTP (normal, temperature, pressure) > 3

[9] Relevant information may also be addressed in the related Environmental Impact Assessment (EIA) as well as under specific legislation at EU or MS level (see e.g. Annex IV of EIA Directive, Annex V of the WFD or EQSD).

[10] INSPIRE Directive Data Specification for the spatial data theme "Geology", "Mineral resources" can be used as reference (see https://inspire.ec.europa.eu/Themes/Data-Specifications/2892)

Issues covered in the EWMPs	Examples of parameters[910]
	Hazardous Properties according to Regulation 1357/2014/EC - properties of waste that render it hazardous
	Solubility of metals, oxyanions and salts
Geotechnical characterisation and material geotechnical behaviour per material/EW	Grain size distribution
	Density
	Porosity
	Permeability
	Fraction composition (dominant mineralogical composition)
	Water content
	Plasticity indices
	Degree of compaction
	Shear strength
	Friction angle
	Compactability
	Compressive strength
Waste class according to COM Decisions 2009/359/EC, 2009/360/EC and 2014/955/EU	Hazardous waste / Non-hazardous non-inert waste / Inert waste
Category of EWF	Category A / Non-Category A (Decision 2009/337/EC)
Facility structures (all EWFs on the site)	Design and constructional details of the EWF
Management of excavated material *Note: though not explicitly covered by the EWD, depending on the operational and market conditions, some of these wastes can become EW at any given moment*	Excavated materials *(quantities as function of time)*
	Quantities and types of excavated materials used for construction purposes in the mine/quarry *(as function of time)*
	Quantities and types of excavated materials used for filling mine voids for engineering or resource recovery reasons (*as function of time*)
	Top-soils removed and stored *(as function of time)*
	Quantities of non-EW and their management routes *(as function of time)*
Management of EW (per waste, supported by detailed maps of the deposition areas)	Quantity of EW deposited *(as function of time)*
	Planned quantity to be deposited EW *(as function of time)*
	Total quantity of extractive waste to be deposited during the life-cycle
	Quantities of EW recovered and re-utilised *(as function of time)*
Risk assessment	Summary of risk assessment carried out under the initial EIA, any updates, or specifically for the EWMP
	Specific conditions contributing to risks: • Climatic conditions (e.g. rainfall intensities and frequencies) as drivers for the migration of

Issues covered in the EWMPs	Examples of parameters[9][10]
	contaminants • Description of possible natural events (e.g. earthquakes, volcanism, etc.) that may compromise the EWF
	Risk elimination or risk reduction measure
Emergency plans *(detailing actions and responsible persons)*	Emergency plans for Category A EWFs
	Emergency plans for other EWFs
Operational monitoring	Geotechnical stability (dams, slopes)
	Groundwater: levels, quality
	Surface waters: quantity, quality
	Air quality
	Erosion control (turbidity in surface waters)
	Radiological monitoring (where required)
Closure plans	Criteria for when closure is achieved
	Provisional plans *(to be updated periodically together with the EWMP)*
	Financial provisions to ensure orderly closure of EWFs
Long-term management plans	Preliminary plans for the after use of the extraction site and the EWFs *(to be updated periodically together with the EWMP)*
Supporting documentation 1. Geology: nature, shape, size and typology of the resource 2. Mineral deposit area: type, final shape, structure of filling and transport type 3. Study of the state of soil and water at deposit area (baseline study) 4. Information of environmental impacts caused by extracted waste and deposit area 5. Information of preventive actions taken to minimize environmental impacts 6. Report of current and post-action control and follow-up 7. Acid rock drainage and metal leaching assessment report 8. Closure plan **Note:** *the majority of the above documentation would have been already produced as part of the baseline survey and the EIA licensing procedure.*	

The above list looks at the life-cycle of an EWF from a more technical side. As will be discussed in the following chapter, the closure of a mine and its associated EWF(s) will have wider ramifications that may need to be taken into consideration. This is particularly important also with a view to ensuring the long-term integrity through building a lasting relationship between the communities hosting mining and the EWFs that will remain a feature of the landscape for ever. Therefore, the closure and rehabilitation aspect in the EWMP should also consider the following aspects:

- Regional state of the environment at closure
- Mine site baseline environment
- Closure objectives with respect to the environmental conditions
- Socio-economic context

- Post closure vision for the site
- Final-land use and processes for agreement with stakeholders and competent authorities
- Summary of residual environmental risks/impacts
- Information gaps and required studies to achieve an accepted closure plan

4.3 Proposed practices for closure, site rehabilitation, and long-term safety

4.3.1 Mine closure

Mine closure encompasses all activities that ensures a safe transition from an operational mine with operational EWFs towards an end-state that renders all deposited extractive wastes safe. It also covers the decommissioning and rehabilitation of the actual mining (and milling) facilities. While the latter are not subject of the EWD as such, facility decommissioning and site rehabilitation ideally are co-ordinated activities, so that rehabilitation can utilise the existing mine and mill infrastructure (e.g. Falck & Fernandes, 2009; Falck et al., 2009). Final closure of a mine and mill involves the decommissioning of surface and subsurface facilities. Both activities will give rise to wastes, including EWs that will need to be managed in an EWF. This aspect needs to be considered in the EWMP and provisions being made for the disposal of these wastes.

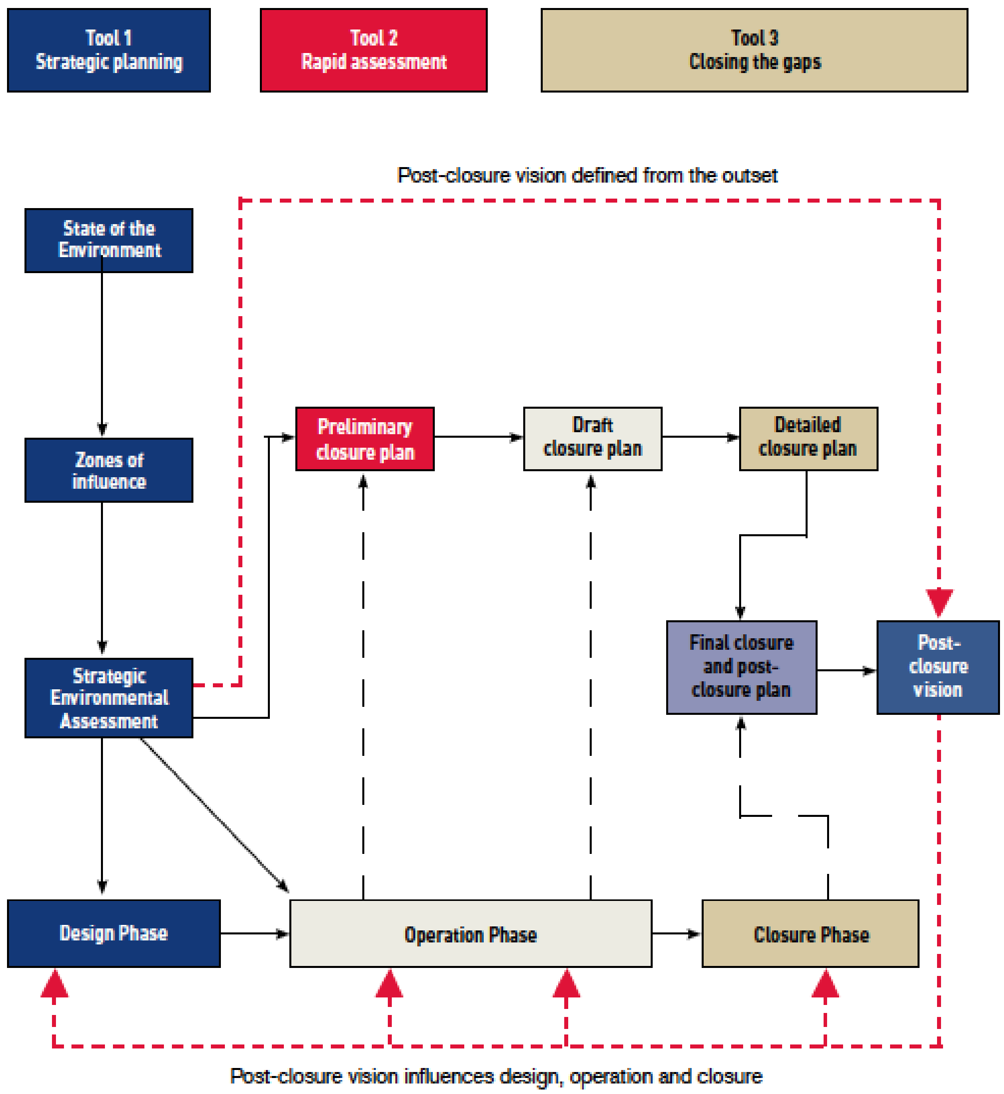

Figure 4-6: Anglo-American Tool-Box for mine closure (2016)

While decommissioning and rehabilitation wastes are not covered by the EWD, they may actually be used in the construction or rehabilitation of EWFs. It would of advantage during mine closure to re-use on site as much of those materials that cannot be marketed, but do not require management as other (e.g. hazardous) waste. When deciding on the use of materials, one has to take into consideration the monetary and the environmental cost of bringing in new materials from the outside. Although it might be possible to market certain materials, it may be at the bottom line more environmentally and economically efficient to use these materials during closure and rehabilitation.

Mine closure and rehabilitation have been the focus of considerable attention and a number of guidance documents have been developed across the world. For instance, the Anglo-American Tool-Box for mine closure (Anglo-American, 2016) provides a comprehensive spread-sheet that guides mine operators through the closure planning that ideally begins at the design phase (Figure 4-6) and covers the whole life-cycle of a mine. The spread-sheet guides the operators through the process and allows them to objectively assess their readiness levels and indicates the way for improvement.

Although closure may be years or even decades away, Article 5 3(f) of the EWD requires closure plans to be part of the EWMPs. However, the EWD does not give any requirements on the scope and level of detail of such closure plans within the EWMP. The closure of mines and EWFs are separate and distinct steps in their life-cycle and the associated licensing procedures. Therefore, usually comprehensive closure plans are produced as separate documents. These would not only cover the technical and environmental impact prevention aspects, but also the future site use that is compatible with the chosen technical solution, e.g. the grading and capping of EWFs. Future site use is best developed in a deliberative procedure with the stakeholders concerned. As a matter of fact, this after-use can become an important element of the overall acceptance of mineral extraction and, therefore, should be an important element of the life-cycle management of extractive operations (see Figure 4-2).

The EWD (2006) stipulates that financial arrangements are being made to have funds for closure and rehabilitation of an EWF available. This financial management plan must also contain provisions for early and unexpected closure or temporary ‚care and maintenance' status, which may arise due to market conditions. Actual arrangements will depend on the Member States' legislation for mine licensing. A companion report to this report under development is expected to address this issue in more detail.

Following the design criteria discussed in the previous section will facilitate the closure of the mine and the associated EWFs. The step from operation to closure and post-operation will be less steep, requiring less work, compared to a situation when everything is only designed with operational aspects in mind.

4.3.2 Site rehabilitation

Timing. As indicated before, closure, decommissioning and rehabilitation are actions that are best developed concurrently and that may not be clearly distinguishable from each other in practice. Rehabilitation is concerned with the removal of contamination that may pose a hazard to the environment or human health, with rendering structures geotechnically safe, and in a wider sense also concerns the rebuilding of the (environmental, societal, economic) functions of areas that are not needed anymore by the operations. Thus, rehabilitation is concerned with rendering EWFs stable over the long-term.

It needs to be understood that return to original conditions at a site affected by mining and milling activities is not always possible. It only will be possible to partially rebuild pre-mining features and functions. In most cases the EWFs will form a permanent legacy and new features in the landscape.

The **objectives** of site rehabilitation are largely determined by the envisaged after-use of the former mining and milling site, including their EWFs. This after-use needs to be determined in collaboration with the host-community. Concepts for re-use need to satisfy a variety of technical and other requirements: the need to ensure the integrity of an EWF, regulatory requirements (environmental protection, Natura 2000 compatibility, land-use planning, etc.), as well as the economic, environmental, social and aesthetic needs of the host-communities. Typically, the site re-use has to be integrated into regional land-use and development plans. This requires a multi-stakeholder dialogue that commences at the planning stage of a mine. This dialogue must be maintained throughout the life-time of a mine in order to reflect the development of the mine, which may operate for several decades, and the changing public stakeholders and their changing needs. A deliberative approach to defining site re-use ensures that use restrictions that have to be imposed for technical reasons are accepted and adhered to. A deliberative approach helps stakeholders to better understand the technical and safety motivations for such restrictions.

Rehabilitation is *inter alia* concerned with rendering safe any environmental **contamination** that has arisen from the extractive activities. Contaminants can be constituents of the mined geological materials, such as heavy metals or arsenic, but also derive from materials used during the operation, particularly also processing chemicals. While it would have been advisable to deal with spills etc. as soon as they have occurred, this may have not been done at the time.

There are various strategies for dealing with contamination, as is outlined in Figure 4-7.

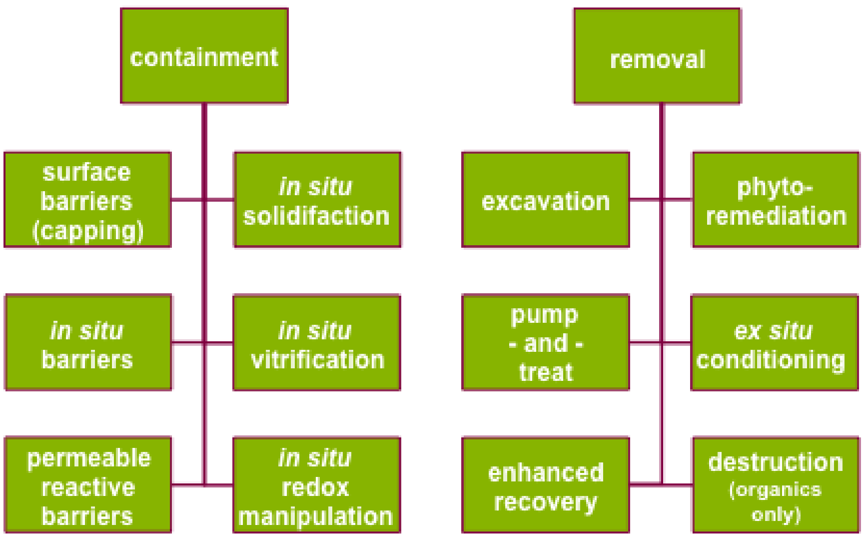

Figure 4-7 The principal strategies for dealing with contamination (WEF).

Depending on the strategy and technology chosen, **rehabilitation wastes** will arise that usually are deposited in the EWFs. These wastes will have to be assessed in order to decide on the subsequent management route and for any valuable constituents that may be recovered and marketed. In some instances the sale of such constituents can cover some of the rehabilitation costs. Rehabilitation may involve the reworking of materials in EWFs in order to recover marketable materials and to render the EWF safer. This may give the opportunity to segregate materials (see below) for more efficient management.

In any case, the materials will need to be carefully segregated into the different categories of EWs in order to minimise the arisings of Category A waste, if at all possible. The EWMP should forecast the likely arisings of the different categories of rehabilitation wastes and indicate adequate management routes. Where only small amounts of organic or hazardous wastes arise, such as some soil contaminated by a spill of machinery oils, it will be of advantage to find an off-site management route, rather than to build a Category A facility on-site.

Acid mines or rock drainage are common problems and rehabilitation may also be concerned with the groundwaters adjacent to the mines. While such activities are not covered by the EWD, groundwater treatment may result in sludges that usually are managed together with EWs from the operation or rehabilitation. The time-profile of the various mine-closure operations, such as sealing of tunnels, flooding, etc., will determine the time-profile of the groundwater treatment waste arisings. Volumes and time-profiles with which they arise need to be integrated into the EWMPs.

4.3.3 Enhancing the long-term stability of EWFs

The EWD implicitly refers to the long-term stability of the wastes to be deposited by distinguishing between ‚inert' and ‚non-inert' wastes. Waste classified as ‚inert' by definition means that it does not undergo (significant) changes after deposition, in other words that little potential energy is stored in them. In consequence, inert wastes do not require significant measures to isolate them from the surrounding environment. To the contrary, non-inert wastes need to be isolated from their surroundings by engineering measures. The level to which this needs to be done depends on the degree of hazardousness and the projected time evolution of the associated risk. MSs may waive certain requirements, when the absence of risk can be demonstrated.

These EWFs themselves, i.e. any retaining structures, cappings or liners, will be subject to change, alterations or degradation, such as erosion. In the following paragraphs the processes and forces that will alter EWFs over time and may compromise their function are discussed together with strategies to counteract and delay these alterations.

Physical and chemical potentials - Based on thermodynamic considerations (2nd Law of Thermodynamics), one notes that engineering structures are inherently instable and require the input of energy in order to remain in their desired state. Translated into more practical terms this means that engineered structures and other features of a mine and the associated EWF require constant maintenance in order to retain their shape and function. While engineered structures may be stable over a human time-scale, this is not likely to remain so over the extended time-scales we expect EWFs to function. Due to natural weathering and related processes man-made slopes, dams, and similar features or retaining structures will slowly erode and collapse. This is generally due to high relief energy or chemical potentials stored in them and that have the tendency to dissipate according to the 2nd Law of Thermodynamics. Closure, site rehabilitation and preparations for long-term safety have to, therefore, aim to minimise these potentials with respect to the surrounding environment. In this sense, the classification of a waste as ‚inert' means that it contains little physical or chemical potential with respect to the surrounding environment, or that the activation energy would be too high for any reactions leading to change.

Resistance vs. resilience - Many engineering features are designed for ‚resistance', i.e. resisting change due to external forces. As was noted above, this only works, when such facilities are actively maintained. However, such maintenance cannot be expected over time-scales that exceed hundreds of years. Thus, facilities have to be designed as maintenance-free as possible. The key criterion here is to reduce unnecessary potential energy stored in them. The guiding principle ideally is ‚engineering with nature, not against it'. A ‚good practice' approach would review a given situation in this respect and try to minimise these effects.

Design for closure – The EWD stipulates that the eventual closure of EWF has to be kept in mind and that adequate provisions for this have to be made. In order to minimise such closure efforts, it is advisable, within operational constraints, to design mine operations and EWFs with the closure measures in mind. This applies in particular to tailings management facilities that are unlikely to be relocated or otherwise redesigned. While some EWFs eventually may be re-mined to recover additional commodities of value, they are best conceived, designed, constructed, operated, and closed on the assumption that they will become permanent facilities to ensure an optimum long-term safety and to not leave unresolved problems to future generations in case of premature closure of the operations. Tailings facilities, designed for closure, are true future engineered landforms, intended to remain physically and chemically stable for the long-term. The same concept applies to other types of residue management, such as dumps.

Landscaping - Features and shapes of mines and EWFs are typically designed with operational convenience in mind. This means that, for instance, quarry faces are designed as steep as the material properties and the geology permits, or that the slopes of residue dumps are made as steep as possible to reduce the footprint of the dump. While such designs might find favour with regulators and other stakeholders alike due to the apparently small impacted area, they will not be stable without maintenance. At the moment of closure, such slopes will need to be re-graded to a near natural angle in order to ensure long-term stability (see Best Practice Example B). It is, therefore, adamant that the EWMP foresees such adjustments. In order to minimise the relief energy with respect to the surroundings the engineered landforms of EWFs should mimic the surrounding topography.

Figure 4-8 below gives examples for how the potential energy in waste dumps can be minimised. It is obvious that placing waste underground or into geomorphological depressions would increase the long-term stability of such facilities. However, one was to consider the overall relief energy in the surrounding environment. Steep slopes and high surface run-off may compromise the long-term safety of a dump even though it has been put below the average surface elevation of the surrounding landscape.It is important to understand the function and evolution of the surrounding landscape and to integrate the man-made features into them. Modern surveying (e.g. air-borne photogrammetry, LIDAR) and modelling techniques allow to develop a detailed geomorphological analysis of the surrounding landscape. This in turn allows to analyse the surface drainage patterns. These analyses then form the basis for developing a model of a most stable contour of the waste heaps, including the small-scale drainage patterns that mimic the adjacent landscape. Together with the re-vegetation this would lead to a stable, erosion-resistant geomorphology of the constructed EWF.

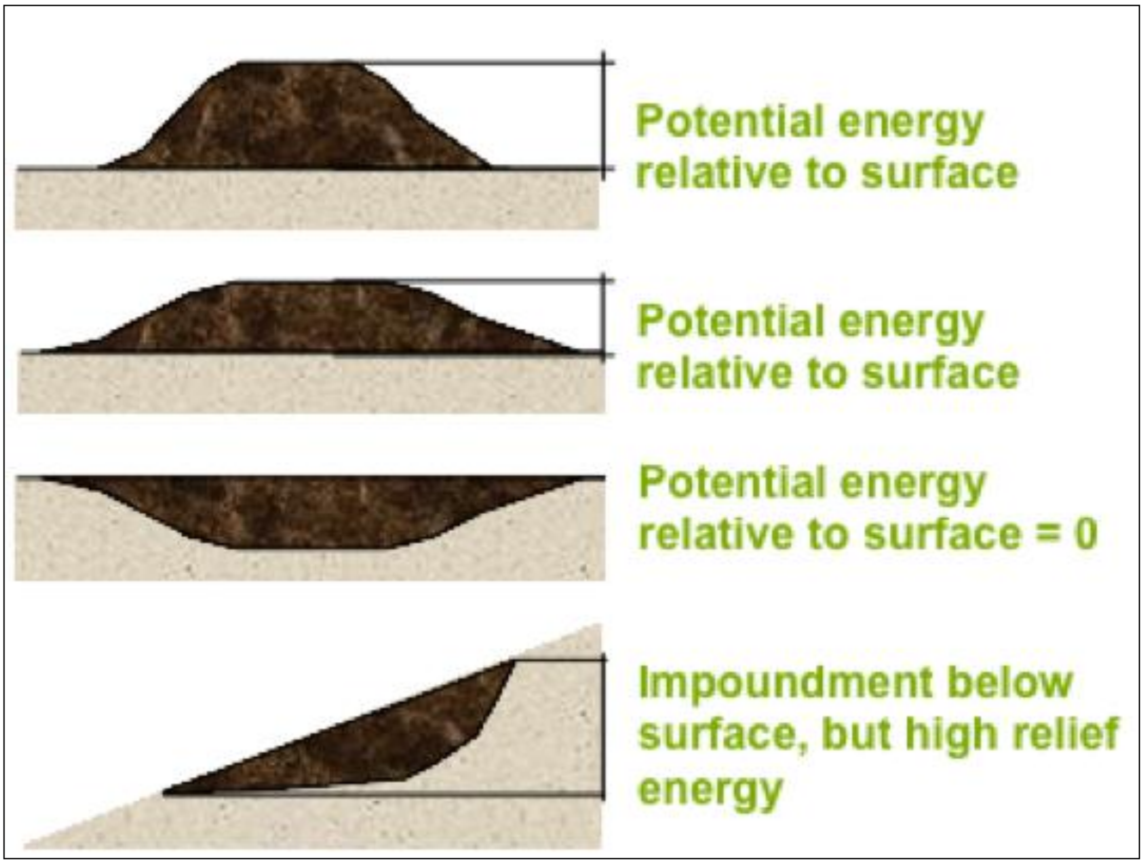

Figure 4-8 Strategies to reduce the potential (or relief) energy stored in waste dumps (WEF).

Capping and vector reduction - The concept of ‚engineering with nature’ must be extended also to the cover design for waste management facilities. The profile must mimic the local soil profile in order to have comparable infiltration and run-off properties, which will counteract the erosive forces of surface precipitation. Figure 4-9 shows examples for arid and semi-arid areas in the USA, but analogue profiles can be drawn for local soils in Europe. One should note that in all cases there will be a drainage layer above the waste in order to divert infiltrating water away from the waste. Under natural conditions this water would eventually reach the groundwater table.

As even inert wastes can impact the environment, for instance as wind-blown dust or as turbidity in surface waters after being eroded from their impoundments, they will require some form of capping to reduce the vectors wind and water.

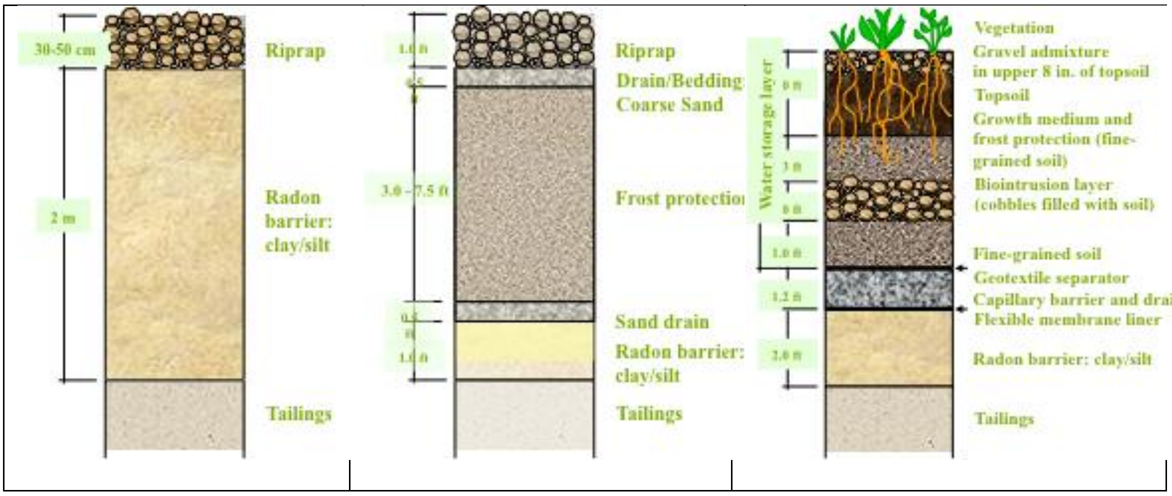

Figure 4-9 Three examples for cover construction over tailings from the USA (Source: WEF).

Re-vegetation – These efforts will be more successful, if modelled after the natural vegetation of the surrounding landscape. It is understood, however, that in Europe most landscapes have been significantly altered by human activities, in particular turning forests into agricultural land. Nevertheless, one can strive to establish a biodiversity appropriate for the prevailing soil and climatic conditions. While reforestation with local tree species is a viable strategy for EWFs containing inert wastes, this is problematic for other wastes due to deep roots that can penetrate cappings and liners and in this way compromise the isolation of these wastes.

Cost profiles - It is important to ensure that short-term financial or operational priorities do not prevail over better design and operational practices that would have lower long-term impacts, complexity or risks. It has to be repeated that designing and operating for closure has to be a systemic approach, and takes all aspects of the extractive operation into account, not just, say, a tailings facility itself. For example, design and operational decisions related to mining and ore processing can impact both the quantity, and physical and chemical characteristics of tailings and associated drainage water, and can have long-term implications for the management of tailings: management of tailings begins upstream in the operation – in the mine planning and in the ore processing plant (MAC, 2017).

4.3.4 Securing the long-term stability of extractive wastes

Excavating geological materials and emplacing them into an EWF will disturb the natural secular geochemical equilibria with respect to their surrounding environment. The EWD (2006) distinguishes EWs that react (very) slowly upon such disturbances, i.e. they are inert, from those that react faster, i.e. those that are not inert. Certain wastes would be inherently inert, for instance because certain minerals contained in them are not stable under atmospheric conditions, others have become inert as a result of the milling processes. Hence, the upstream processes in mining and (ore) processing can have a significant effect on the manageability of the resulting wastes. As part of an overall life-cycle materials management, it may be, therefore, beneficial to investigate whether and how processes can be changed so that the resulting wastes become (more) inert. The exact strategies will have to be defined on a case by case basis, but some principal strategies can be considered. Likewise, it will be important to understand the natural processes that control the evolution of EWs once deposited.

Diagenetic evolution - An understanding of the natural processes of weathering and diagenesis for the given landscape help to predict the geochemical and mineralogical evolution of the disposed wastes over long time-scales. This in turn will help to understand e.g. the potential for the generation of acid rock drainage and to design measures to combat it within the EWF, rather than to collect and treat it. A possible strategy is to mix or interlayer EWs with acid generation potential with EWs that have an acidity or redox buffering capacity (source reduction). Secondary mineral formation will clog existing pore-spaces (forming an 'engineered' hard-pan) and in this way reduce the action of the vector porewater (pathway reduction). As the necessary assessments and predictive modelling are complex undertakings, they would only be warranted (and affordable) for larger scale EWFs.

Segregation – It is often only one component in the waste that give rise to it being classified as 'non-inert'. Removing this component can lead to a considerable reduction of the volumes of waste that need to be managed as 'inert waste' and frees the remainder for potential beneficial use or for simplified disposal options. All steps in mineral processing may need to be reviewed in order to decide on where segregation would be applied best. It may be that an early segregation step, e.g. froth floatation, not only is beneficial for later waste management, but reduces the quantities of raw materials that need to be processed for the target mineral. Hence, beneficiation and pre-concentration steps are ideally designed keeping later disposal requirements in mind. A good EWMP would reflect such integrated process design.

Segregation of different types of overburden so that it can be placed back into the mined-out voids ensures the compatibility and reduces the creation of geochemical anomalies (potentials). In this way it can also be ensured that sulfide-bearing materials, where it is possible, are below the water table, in order to reduce their acid-generation potential after the closure of the mine. This is now common practice in e.g. lignite mining (see Best Practice Example D). While this reduces the access of oxygen from the ambient air, the main driver for the generation of ARD, it cannot completely preclude the possibility of sulfides being oxidised. A hydraulic flow-model or a combined flow-reaction model may have to demonstrate that oxydation rates are slow, leading to negligible generation of ARD.

Removal of process chemicals – Wastes otherwise 'inert' become 'non-inert' when they contain residues of process chemicals that are hazardous and/or reactive above certain threshold concentration. A good example is the cyanide used in gold extraction that can be recovered for further use or destroyed by oxygenation and exposure to UV-light before tailings are impounded. Neutralising acidic or alkaline wastes is another example but will typically increase the volume of the residual waste due to the precipitates forming. The long-term stability of the neutralisation products in the view of changing conditions in the impoundment or the possible influx of acid rock drainage also needs to be considered. With a view to resources and energy conservation, recovery normally would be given preference over destruction or neutralisation.

Acceleration of alteration processes – A number of minerals, notably sulfidic ones, are unstable under atmospheric conditions. The presence of such minerals can lead to the prolonged emission of reaction products, for instance acid rock drainage. If such wastes have to be deposited in near-surface impoundments, it may be worthwhile to investigate the artificial acceleration of these processes before disposal. Sulfidic material can be ‚roasted’, i.e. the sulfides are thermally oxidised, or the sulfides can be leached on heap-leach pads. Roasting, on the other hand, will lead to gaseous reaction products (SOx) that need to be captured and managed (see below). As such processes are likely to be endothermic, one needs to carefully assess their additional life-cycle energy requirements and associated CO_2-footprints and balance these against the risks from other management options.

Acid rock drainage formation and leaching processes can also be enhanced *in situ*, after deposition, if the area of disposal is sealed against infiltration of leachates into deeper strata, either naturally or by an engineered barrier (see Best Practice Example F). Contaminated leachates have to be collected and treated. The process is similar to heap-leaching used in the recovery of metals from low-grade ores.

Extraction of ‚problematic' components as by-products – Some waste components that can result in extractive waste to be destined for a Class A facility can actually be extracted as by-product, e.g. sulfur from sulfidic minerals. This means that the sulfidic sulfur is converted into a marketable form, rather being deposited as sulfate. The energetics and market conditions have to be investigated carefully in order to assess, whether such approach would be economically viable for the given circumstances.

Accelerated dewatering of tailings - Traditionally, tailings are pumped into topographical depressions or constructed ponds. Some of the water will exfiltrate into the underlying geological strata, if these ponds are not lined. During the settling process excess water accumulates on the pond surface and either evaporates (in arid conditions) or must be drained away. The collected drainage water is pumped back into the plant for residual metal and process chemicals recovery. Drainage ditches can be dug into the surface of the ponds to accelerate drainage, but amphibious machines are needed due to the thixotropic behaviour of the muds. Wick drainages may also be inserted and connected to surface drainage mats that allow earlier capping of tailings. In the process of ‘wet stacking’ partially dewatered (ca. 30% solids) muds are discharged into the ponds. This denser mud will not re-suspend by atmospheric precipitation and rainfall run-off can be collected from the surface. ‘Dry stacking’ can be achieved by mechanical dewatering up to 77% solids (IAI, 2015; recommended by the MWMI BREF, 2006), but requires transportation to the disposal site by conveyor belt, rather than pumping. Dry stacked tailings constitute a lesser risk in case of dam failures, as they will not flow out. Dewatering allows earlier closure and capping of tailings ponds. However, accelerated dewatering and solidification entail materials (e.g. flocculants, neutralising agents) and energy expenditures that will reduce the overall energy efficiency of the metal production.

4.3.5 Long-term management and stewardship

Extractive waste management facilities, such as waste heaps and tailings ponds, will remain features in the landscape for ever. As noted earlier, their design should be such that maintenance needs are minimised as far as possible, mimicking the geomorphology and vegetation of the surrounding landscape.

There may be an interest in using waste heaps for other purposes than just bush- or woodland. These uses have to be compatible with the integrity of the covers, which means that certain restrictions have to put into place, for instance, via zoning regulations. For instance, excavations for building foundations may not permitted or restricted to a certain depth. These restrictions have to be considered in the land-use planning and a regulatory instruments to be put into place to enforce the restrictions. Finding a beneficial and compatible after-use of such EWFs is likely to foster the long-term maintenance of retaining structures and covers (e.g. IAEA, 2006). Ideally, such use is found already during the closure phase or even before, so that closure and rehabilitation options can be tailored to this use and *vice versa*. Such plans can be foreseen in the EWMP as strategic outlook, though a specific after-use may not be foreseeable, particularly for mining operations that continue for decades. Nevertheless an after-use would be an element in a life-cycle planning that keeps also the sustainable development of a region in mind. The provisions in the EWMP may need to be flexible with respect to landscaping and cover design in order to be able to accommodate different types of after-uses.

Long-term management and stewardship will also have to make provisions for the monitoring of EWFs with respect to their integrity and functionality. The problem here is to identify an organisation that can be charged with this task. If there is a beneficial after-use, the new owners of the site may be charged with this, as it is likely to be also in their interest.

Integration of the rehabilitation planning into the long-term regional planning is likely to reduce impacts as well as fostering the a compatible after-use of the sites of EWFs (see Example Best Practice E).

4.3.6 Record keeping and maintenance.

Closure, decommissioning and rehabilitation will produce records in addition to those generated during the exploratory and operational phases. Having such records available will facilitate each subsequent step in the life-cycle of a mining and milling facility, as it avoids or reduces costly and time-consuming site assessment procedures. Records will also facilitate maintenance and repair during long-term management.

There are no clear guidelines on how and where such records should be kept beyond the active life of an extractive facility. The situation is exacerbated by the fact that in some Member States the regulatory oversight over closed sites passes to another regulatory body from the one that regulates active mines. If a site is released freely, with no use restrictions and maintenance requirements, there may be no legal mechanism to retain any records, as no further legal requirements are attached to the land. In some Member States such records would be collected by the competent authorities or the (national) geological surveys. For instance, the British Geological Survey has extensive records on past deep mining activities due to a statutory requirement to submit such records. In the case of EWFs it is not clear, what kind of records would be available and what kind of records would be needed. Another place for such records would be land registers or cadastres, where information on each piece of land is stored. However, the cadastres are not normally prepared to store such information. The issues around preserving knowledge about sites and record keeping have been extensively researched and discussed in the context of the long-term management of radioactive waste disposal and uranium mining and milling sites. A summary of these discussions can be found for instance in IAEA (2006, p. 77ff.)

Record keeping is also important with respect to any land-use restrictions that may have to be imposed (see discussion above of stewardship issues). Such restrictions may need to be reflected in the cadastre.

Records, particularly those on how and where specific extractive wastes have been deposited, may be also of value, if at later stage these wastes may be considered for reworking. Thus record keeping about the deposition of extractive wastes will contribute to the implementation of Circular Economy policies. Thus good record-keeping as part of the EWMP would contribute to the spirit of the Circular Economy.

4.4 Proposed practices for special issues to be considered in EWMPs

4.4.1 Resolving conflicts between policy objectives

Particularly designs to ensure the long-term safety of extractive wastes and circular economy policies may give rise to conflicts of objectives. Decisions to declare some extracted materials as waste and to proceed to disposal are made, when no beneficial use for the waste can be found, which in turn often depends on the economic context at the time. In consequence, such wastes may still contain components that could become valuable at some later point in time. Whether these materials can be recovered at this later point depends on the chosen disposal method. Near-surface repositories, such as waste-rock dumps or tailings ponds may be relatively easily accessed and reworked. The situation is different for materials placed into deep mines. Emplacing waste into a deep mine in general will make these material difficult to retrieve, as re-entering a mine after closure is dangerous due to difficult to predict rock-stress situations. Any cements added may also result in a matrix that is difficult to break up for further processing. This usually means that any remaining resources in the deposited waste become sterilised.

It is recognised that the (long-term) safety of a disposal option may be compromised, when access routes are provided to ensure retrievability for re-use. Providing easy access may compromise the functions of barriers, such as liners and cappings. In the case of wastes deposited underground, access routes would also need to be constantly maintained in order to be safe, being in contradiction to the objective of long-term low-maintenance or maintenance-free solutions. It may be interesting to review in this context the conceptual work undertaken in the context of deep disposal of radioactive waste, where the safety implications of a retrievability of spent fuel for reprocessing have been investigated intensively (OECD-NEA, 2001).

This dilemma between long-term safe extractive waste management solutions and maintaining access to potentially valuable resources needs to be carefully weighed, when drawing up EWMPs. One conclusion could be to destine for disposal back in an underground mine only those materials for which conceivably also in the future no beneficial use can be found. This means to base the decision not only on the current economic situation. Further guidance on cut-off criteria for accepting materials for returning into deep mines may need to be developed.

Conversely, material backfilled into open-cast mines, or material in near-surface EWFs remains more accessible to reworking, as recent interest in re-working old dumps and tailings show. In these instances the material becomes less likely permanently sterilised.

Stabilising materials for disposal, as discussed above, entails additional energy expenditure and additional, often virgin, materials. One has to carefully balance probabilistic and delayed safety gains and geotechnical/environmental risk reduction against actual and deterministic impacts from these measures to increase safety.

4.4.2 NORM-issues in the extractive industries

While radiological issues and radiation protection aspects are not subject of the EWD, the presence of Naturally-Occurring Radioactive Materials (NORM) may need to be considered in the EWMPs so that appropriate management routes and end-points can be defined. The difficulty is that many operators are not be aware of any radiological issues, as their operation is not a ‚practice' in the radiation protection sense.

Radiation protection is covered by Directive 2013/59/EURATOM (European Council, 2014), also known as the *EU Basic Safety Standards for Radiation Protection (BSS)*.

NORMs are present in many geological materials and can become relevant in various raw materials-based activities. With the exception of e.g. uranium, thorium or radium ores, concentrations are usually low and of no concern. However, the processing of NORM-containing geological materials can lead to their concentration in products, intermediates, by-products or wastes. A comprehensive overview over the extractive industries, where NORM-issues may arise is given in IAEA (2003). The International Atomic Energy Agency (IAEA) subsequently also published a range of documents on NORMs in specific extractive industries. In the European context, the BSS (European Council, 2014) lists in its Annex VII those industries that potentially have to face NORM-issues (Table 4-2).

Table 4-2 List of industrial sectors involving naturally-occurring radioactive material (European Council, 2014 – Annex VI).

• Extraction of rare earths from monazite	• Production of Th compounds and of Th-containing products
• Processing of niobium/tantalum ore	• TiO_2 pigment production
• Oil and gas production	• Geothermal energy production
• Thermal phosphorus production	• Production of phosphate fertilisers
• Zircon and zirconium industry	• Phosphoric acid production,
• Cement production, maintenance of clinker ovens	• Coal-fired power plants, maintenance of boilers
• Primary iron production,	• Tin/lead/copper smelting,
• Mining of ores other than uranium ore	• Ground water filtration facilities,

Annex XIII of the BSS (European Council, 2014) gives a list of building materials, some of which are derived from extractive wastes, that may results in radiation exposures (Table 4-3).

Table 4-3 Indicative list of types of building materials considered with regard to their emitted gamma radiation as referred to in Article 75 of European Council (2014).

1. Natural materials
(a) Alum-shale.
(b) Building materials or additives of natural igneous origin, such as: • granitoides (such as granite, syenite and orthogneiss), • porphyries; • tuff; • pozzolana (pozzolanic ash); • lava.
2. Materials incorporating residues from industries processing NORM, such as: • fly ash; • phosphogypsum; • phosphorus slag; • tin slag; • copper slag; • red mud (residue from aluminium production); • residues from steel production

Given that the respective extractive industries may have to face NORM-issues, the competent national radiation protection agency may need to be consulted in addition to the usual environmental protection agencies and competent authorities, when drafting EWMPs. Article 23 of the BSS (European Council, 2014), however, states that "*Member States shall ensure the identification of classes or types of practice involving naturally–occurring radioactive material and leading to exposure of workers or members of the public which cannot be disregarded from a radiation protection point of view. Such identification shall be carried out by appropriate means taking into account industrial sectors listed in Annex VI*". This puts the onus of identifying potential NORM-issues on the MSs' authorities, rather than on individual operations.

Box: Definitions according to the BSS, Article 4 (European Council, 2014)
clearance levels means values established by the competent authority or in national legislation, and expressed in terms of activity concentrations, at or below which materials arising from any practice subject to notification or authorisation may be released from the requirements of this Directive;
exemption level means a value established by a competent authority or in legislation and expressed in terms of activity concentration or total activity at or below which a radiation source is not subject to notification or authorisation.

The BSS (European Council, 2014) provides exemption and clearances levels for all radionuclides (including natural ones) for solid materials (Table A and B of Annex VII). These are given as activity concentrations, i.e. kBq/kg. Raw materials that contain radionuclides below or at these activity concentrations are of no concern, but products intermediates, by-products and residues may have to be checked that any processing does not lead to enhanced concentrations, i.e. to technologically enhanced NORM (TE-NORM), which then may require management according to radiation protection criteria. IAEA (2003) gives an overview over potential concentrating processes per industry.

If a potential problem with NORM has been identified, EWMPs will need to be drafted such that occupational doses are minimised and exposure pathways for critical groups and the general public be removed. Doses would have to assessed with respect to the references levels stipulated by the BSS (European Council, 2014).

When exemption or clearance level are exceeded by products, intermediates, by-products or residues, management options have to be developed together with the competent radiation protection authorities. In some cases, processes can be changed such that no concentration increases above exemption and clearance levels are generated. Article 30 of the BSS (European Council, 2014) stipulates that „*Member States shall not permit the deliberate dilution of radioactive materials for the purpose of them being released from regulatory control. The mixing of materials that takes place in normal operations where radioactivity is not a consideration is not subject to this prohibition. The Competent Authority may authorise, in specific circumstances, the mixing of radioactive and non-radioactive materials for the purposes of re-use or recycling.*“ It appears that this provision would allow the mixing of different by-products or residues derived from raw materials with specific activity levels below exemption and clearances levels in order to revert their overall specific activity below these levels, for instance for the purpose of disposal or re-use within the extractive operation. It would certainly be undesirable to have to manage such by-products or wastes as ‚radioactive waste’.

Based on the known concentration routes in certain industries and approximative concentration factors per process, a simple screening of critical members in the value chain will suffice to decide, whether in a given case there may be any NORM issue previously undetected.

IAEA (2003) and other guidance documents recommend an avoidance strategy in order to pre-empt the arising of NORM-containing waste. While certainly a viable strategy, it may lead to supply issues when ‘critical’ raw materials are concerned. Such avoidance strategy is also applied, for instance, with respect to certain phosphate rocks for fertiliser production that contain high levels of heavy metals. In the future adequate waste management plans may need to be developed or beneficial uses for the constituents in question may need to be found. One such example are REE-ores that can be also rich in thorium, which is currently not used.

Internalisation of the costs and the funding of long-term EWM

It has to be understood that the implementation of best practices depends on a wide variety of factors and boundary conditions. A key criterion for an operator will be the cost profile of implementing the best practice, i.e. when which costs arise and which return on investment can be reaped when. A challenge for adopting many best practice measures is that benefits may be intangible, indirect, or delayed. Many benefits of long-term management measures aim to protect future generations. Many benefits, in fact, will be indirect, as the respective best practice aims at risk reduction, which may/will result in a reduction of mitigation and/or rehabilitation costs, improved stakeholder acceptance, as well as reduced insurance premiums. It is important that the management of extractive operations understands well this indirect nature of benefits and introduces them appropriately into their financial and business management.

Thus, a key aspect in promoting best practices will be that their application results in an internalisation of costs associated with certain business risks. For instance, the application of paste technology for the conditioning and disposal of tailings, will significantly reduce the risks associated with large tailings ponds and thus can reduce the premiums for liability insurances. It also reduces the business risk of loosing social acceptance to operate following a possible incident at the tailings pond.

A difficult issue are the long-term monitoring and maintenance cost, following closure and rehabilitation, that arise due to stewardship needs. It is clear that they would fall into the responsibility of operators as long as they continue to exist and as long as the operator is the owner of the site. Legislation is not clear and uniform across the EU on this point. The problem is also intertwined with that of the safety of closed mines for which the operator has ceased to exist.

The financing of such costs that can continue into eternity will be the subject of a separate study initiated by the European Commission.

4.5 Potential 'Best Practices' in the EMWPs reviewed

A wide range of EWMPs have been collected for this project from Member States, as well as industry associations (see European Commission et al., 2019). These EWMPs have been reviewed with respect to their coverage of the relevant requirements stipulated in Article 5 and how these requirements will be fulfilled.

Depending on the understanding and care of those, who drafted the reviewed EWMPs, their scope and detail may vary considerably. However, not only components may be missing, but some EWMPs actually exceeded the expectations according to Article 5 of the EWD. The review took note of such cases and lists them as potential best practices. Conversely, missing components were noted, particularly, when this was a recurrent problem. The reasons for the respective omissions or inclusions was elucidated, if possible. Only a small number of EWMPs concerning Category A facilities and in particular tailings ponds were collected, though a number of active tailings ponds are known to exist in the European Union.

In the following a summary of the collected EWMPs is given per country.

Czech Republic **-** The Czech competent authorities stated that there is no metal mining and lignite mining is in decline. Therefore, there would be no need to develop EWMPs. They also noted that the EWD duplicated already existing Czech legislation dating from the 1980s that already covered the relevant aspects.

Cyprus **-** The EWMP submitted concerns a copper/gold mine. The production of copper cathode is based on a triptych Heap Leaching – Solvent Extraction – Electro-winning process. There are seven basic steps in the production process at the Skouriotissa plant: (1) crushing, (2) addition of cement to pelletise the material, (3) adjustion of pH by addition of lime water (this leads to the precipitation of metals (copper, iron) as hydroxides which will consume CN forming complexes, (4) heap leaching with 100-300 mg / l NaCN solution at high pH (pH 10-11), (5) adsorption of gold from the pregnant solution to activated carbon, (6) transfer of the gold and silver from the activated carbon into doré containing gold and silver (7) cyanide destruction to below 10 ppm of weak acid dissociable cyanide in the tailings as stipulated by the EWD. According to the EWMP the detoxification methods employed are (a) treatment with sodium meta-bisulfite ($Na_2S_2O_5$) for the destruction of cyanide (INCO Method as presented in the MTWR-BREF, 2018), (b) neutralisation with lime or caustic soda of the resulting sulfuric acid, and (c) further stabilisation by mixing with bentonite.

The EWMP notes that the location was chosen because:

- it is situated in the immediate vicinity of extraction by minimising the distance of transport of waste;
- the area is already disturbed by previous mining activities;

- it is in the vicinity of an existing spoil heap, so that this heap can be used as fall-back option in an emergency;
- it is a mined-out void that can filled in that way;
- it is remote from other activities, except mining.

The area of waste emplacement is sealed with a double liner of bentonite and HDPE and graded so that any drainage can be collected. Downstream of the emplacement area a storm-water overflow retention basin was constructed.

Overall, the use of pelletised ore on heap-leach pads avoids the need to manage fine-grain liquid tailings and the associated risks of ponds for such tailings.

The EWMP also comprises emergency and contingency plans. Rehabilitation plans are mentioned, but not elaborated in detail. The sites will eventually be re-vegetated to provide erosion resistance.

Finland - Eight EWMPs were reviewed, four of these concerning metal mining and four industrial minerals. Two of the EWMPs concern mines that are not yet constructed and the EWMPs were permitting-stage EWMPs. Metal mining covered gold and base metals and industry minerals covered lime, talc and phosphate.

Characteristic for Finnish EWMPs – particularly for metal mines - is the extensive description of the chemical properties of the waste. This includes the descriptions of the continuous extractive waste chemical quality monitoring programmes. While the methodology for the classification of the EW is rather uniform, as it is determined by the legislation, but methods for definition of long term behaviour vary to some extent. Also the actual scope of EWMPs vary considerably, particularly between metal mines and industrial mineral mines.

The long-term stability and safety management is primarily described in EWMPs of Category A tailings disposal facilities. Dam safety risks are mainly covered by dam break hazard analysis documents, site operation manuals and rescue plans. In the EWMPs of all four Finnish metal mines these documents are referred to or even appended to the EWMPs. In some cases their role in safety management is also summarised in the EWMPs.

It should be noted that the absence of safety details in an EWMP does not mean that these issues have not addressed. Considering the purpose of an EWMP, describing the relationship of EWMP and other related documents seems important.

France - France currently does not have any metal or energy mineral mining. The only mineral raw materials exploited are various industrial minerals and aggregate. The basic provisions for EWM are reflected in the 'Arrêté du 22/09/94 relative aux exploitations de carrières et aux installations de premier traitement des matériaux de carrières', which has been amended at various occasions over the years. A key provision is the classification of the wastes according the risk they pose.

Article 16 bis of the ‘Arrêté du 22 septembre 1994’ demands that *“[t]he operator has to set up an EWMP before operations begin. This plan has to include at least*

- *a characterisation of the EWs and an estimation of their total quantities that will arise during the operation;*
- *a description of which operations produce these EWs and what kind of treatment they will be subjected to;*
- *if necessary, a description of potential impacts of these EWs on the environment and human health, including a description of the measures taken to reduce these impacts;*
- *a description of what steps have been taken to avoid or to re-use/re-cycle these EWs;*
- *a proposal for a rehabilitation plan for EW disposal sites;*
- *proposed monitoring and control measures;*
- *description of measures taken to prevent surface and groundwater contamination and contamination of soils and the air;*
- *an environmental impact study for the areas on which EWs will be deposited;*
- *a risk assessment according to the Arrêté of 19 April 2010 concerning licensed ‘Class A’ facilities.”*

EWMPs has to be revised and updated every five years or when there have been any significant changes to the operational plans. The EWMP has to be submitted to the Prefect. Many planning permissions reviewed simply state that EW follows the stipulations of the ‘Arrêté du 22 septembre 1994’. The EWMPs reviewed shows common practices of

- setting aside top-soils for building (temporary) vegetated dams around the extraction operation; the top-soil will be later used in rehabilitation;
- separate storage of overburden to be back-filled at closure and for landscaping the excavated area;
- washing-fines are collected in settling ponds and deposited for later backfilling;
- suitable and non-marketable materials are used for construction purposes in the extractive operation;
- washing plants operate in a closed cycle;
- inert flocculation agents at low concentrations are used;
- crushing plants are enclosed and fitted with dust-extractors;
- quarries and pits tend to market as much as possible of the extracted material, but depend on (local) demand and market conditions.

The French Union Nationale des Industries de Carrières Et Matériaux (UNICEM, https://www.unicem.fr/) has developed in 2011 a guidance document for developing EWMPs according to the ‘Arrêté du 22 septembre 1994’ (= EWD). This guidance document lays out the format and the content of EWMPs to be submitted to the ‚Prefecture’ as the competent authorities. All EWMPs above drafted after 2011 follow this uniform scheme. A key element in the guidance document are flow-diagrams as decision aiding tool for attributing extracted materials to a specific waste class and hence management route.

Germany **-** EWMPs are the subject of Article 22a of the German Mining Code (Allgemeine Bundesbergverordnung – ABBergV; BRD, 1995) and their scope is detailed in its Appendix 5. This appendix largely transposes the stipulations of the EWD into national legislation.

For the purpose of this report it has been attempted to collect information directly from some relevant mining industries, such as the potash, aluminium, gypsum, and some new metal mining industries. Information only from the potash industry was received. No concrete EWMPs for Germany could be collected.

It is common practice in the open-cast lignite mines to put back into the excavated voids virtually all overburden. It is also attempted to emplace the materials in their natural geological sequence. Top-soils are set aside for later re-cultivation. Fly-ashes from burning the lignite in power-stations are returned to the excavated voids as well, while the flue-gas desulfurication gypsum enters the market for gypsum products to a large degree (see also EUROGYPSUM).

Mining for energy minerals (hard coal and lignite) resulted in a variety of legacies that need to be addressed in long-term stewardship programmes. Hard coal mining ended in December 2018. The last main operator, Ruhrkohle AG (RAG) has set up a foundation (RAG Stiftung, https://www.rag-stiftung.de/) that will fund the water management measures that are required for eternity.

Greece **–** The country is one of the major producers of perlite, bentonite, bauxite, magnesite, lignite and nickel. The legislative framework concerning the management of extractive waste is based on the Joint Ministerial Decision 39624/2209/E103/2009 on measures, conditions and limitations for the management of waste from extractive industries, in compliance with the provisions of the EWD. The EWMPs, that have been collected allowed to draw the following main conclusions:

- The majority of the EWMPs are structured according to Article 5 3(c). Specifically, all assessed EWMPs describe the operations that generate extractive waste, contain elements concerning the waste characterisation and respectively the classification of the waste facility. For non-inert waste the evaluated EWMPs also include: (a) identification of extractive waste site options (b) assessment of the stability of the EWF, (c) control and monitoring procedures and (d) plan for closure. Specifically, the EWMP from Hellas Gold S.A. provide an extensive risk assessment not only to identify possible extractive waste site options but also to estimate the potential risks, concerning the construction of the facility as part of the classification of the EWF.
- The information that is provided in the EWMPs is linked to the classification of the EW. If the EW is classified as inert, the level of detail is less than the one presented for non-hazardous-non-inert or hazardous EW.
- The EWMPs for metal ores include a full mineralogical analysis in order to characterise the extractive waste, in contrast with the EWMPs for the industrial and construction minerals, where the classification of waste is based mainly on the content of heavy metals.

An assessment of the stability of the EWF is included in the EWMPs that concern metal ores or industrial minerals. In particular, the EWMPs from Elmin S.A. (now Imerys) and Interbeton S.A. (Titan Group), that produce industrial minerals, include the stability analysis concerning the depositing of extractive waste. On the contrary, the EWMPs for construction minerals, where the extractive waste is characterized as inert, do not provide information on stability issues.

Hungary **-** The reviewed EWMPs mostly concern the aggregate or cut-stone industry. It is common practice to maximise the marketable amounts by segregation and selective extraction on the basis of careful exploration. Non-marketable residues are returned to the mined-out voids and used for landscaping.

Top-soils are also segregated and retained for later landscaping.

Hungary has also some coal mining, where all the mining residues are returned to the mined-out voids, resulting in nearly no waste at the surface. This is also conducive to a rapid change of the land-use class and to minimise the tax burden for industrially used land - agricultural lands do not attract land-use taxes.

Malta **-** Essentially transposed the EWD into Maltese law 1:1. No best practice documents available.

Poland **-** Provided a list of the relevant laws and regulations and one EWMP fact-sheet (concerning the objective of safe disposal) for (best) practice for efficient tailings dam construction. In addition, a statement on the EWM practices at the Maritsa Iztok lignite field was provided.

Wastes (slag, bottom- and fly-ash) from lignite-burning in power-stations are mixed with mine-wastes to solidify these and are deposited in out-of-pit dumps. These dumps also receive flue-gas desulfurication gypsum (FGDG) for this purpose. While gypsum as such is soluble, the binder reduces the permeable pore-space and thus the vector drainage water for the migration of contaminants. The binder increases the geotechnical stability and reduces the risk of dust generation. Due to the high sulfur content of many Polish lignites the quantities of FGDG are too large to be utilised in marketable gypsum products. The mines claim this as good EWM practices, as it results in an ‘inertisation’ of the wastes. No details on the chemical and mineralogical processes given, but fly-ashes are presumably acting as a hydraulic binder.

Spain **-** Developments in Spain illustrate the economic effects on resources utilisation. The economic downturn in the mid-2000s forced quarries to reconsider the way how they exploit their existing resources in order to maximise benefits. This included the minimisation of waste and re-working of materials previously considered waste.

The Royal Decree 975/2009 provides detailed information on EWMPs (Chapter IV, Articles 16 to 40) including characterization (according to the methodologies in Annex I), description of the activity, impacts on human health and environment, etc. It also stablishes detailed information on the minimum content to be included in extractive waste facility project descriptions, including their post closure phase.

A Spanish company developed a software to analyse characteristic patterns (gradients, sizes of small-scale catchment areas, etc.) in the geomorphology surrounding extraction sites. Mimicking these patterns during (re-)grading and landscaping of EWFs blends them into the surrounding environment and prevents to create high-energy abnormalities. In this way, the long-term evolution of EWFs will be similar to the surrounding landscape (see Best Practice Example B).

Sweden **-** Eleven EWMPs were reviewed, which included iron, gold, silver and base metal mines. All of these are currently operating mines. In Swedish EWMPs it is usual to summarise, where in the document the different legislation-based requirements are addressed. This, in principle, functions as a quality control for the scope of EWMPs.

While the risk identification is presented in Swedish EWMPs, the detail level varies. Risk management, monitoring and accident preparation level are presented in more detail for Category A extractive waste facilities.

Dam safety plays a significant role in Swedish EWMPs. Usually a reference is made to the Swedish mining dam safety guideline GruvRIDAS. GruvRIDAS defines the general dam safety principles, consequence classification, organisational and competence requirements, as well as dam operation and risk preparation. The permit condition-based monitoring, failure reporting and maintenance requirements are described in GruvRIDAS. There is even information about dam constructions and dam safety revisions.

The mine sites' own 'DTU-manuals' (dam operation, monitoring and maintenance manuals) are generally referred to, when there are dams in the mine sites (not 'satellite mines'). In some cases, key points from the DTU-manuals are presented in the actual EWMP documents. For example results of stability monitoring and a summary of the consequence classification of each dam raise are summarised in the EWMP.

EUROGYPSUM **-** All EUROGYPSUM members for which a response has been reported, stated that they do not generate waste. Top-soils are either stored for later rehabilitation measures or sold off to farmers and gardeners. Overburden is stored for later use in re-contouring the mined-out areas.

It was also stated that the difficulty to obtain extraction licenses or to extend existing ones provides a strong incentive to utilise all extracted materials. As the situation has become more difficult over the last few years, there is a strong incentive to rework to extract value from materials that previously had been dumped as non-marketable in order. An example of mechanical separation of clay fines from gypsum rock was given, that allows the utilisation of materials that would have been dumped as waste previously.

As was noted in European Commission et al. (2019), natural, mined gypsum has been replaced to a considerable degree by flue-gas desulfurication gypsum from coal-burning power-stations. In the longer term, an increase in gypsum mining might be exspected, as the use of coal is gradually being phased out in Europe.

European Aluminium (Producers Association) - There are seven alumina producing plants in EU27 (Figure 4-10 below). All employ the Bayer-process on imported ore, which results in large quantities of the so-called ‘red mud’, a caustic slurry containing the accessorial minerals and metals. The caustic property (high pH) is mainly due to $NaAlO_2$, Na_2CO_3, and some NaOH that escapes its recovery process. These ‘tailings’ are deposited in pond-like structures. Due to the fine-grained nature of the solids after the milling process, these muds dewater very slowly. Most R&TD and management efforts have been directed at making the ‚red-muds’ less hazardous and easier to manage.

Figure 4-10: Alumina producers across Europe (Source: https://www.european-aluminium.eu/data/industry-overview/european-overview-aluminium-plants-location/)

Alternative processes are used in some parts of the world (China, Russia), but depend on the type of ore. Alternative processes that could use other aluminium ores with less accessories, thus resulting in less tailings, and that are less energy consuming are also being explored (Rhamdhani et al., 2013). Most of the alternatives investigated do not offer energetic advantages and/or have other plant and/or health&safety and/or environmental impact implications. While industry continues to pursue alternatives, the time horizon for any results is beyond 20 years (http://bauxite.world-aluminium.org/uploads/media/fl0000422.pdf).

The industry, hence, focused on improvements to the Bayer process with the objective to "*Develop[e] methods to achieve a 1,000-year ecologically sustainable storage of red mud and other solid wastes in existing storages, and make substantial progress in storage for later reuse as well as achieve substantial progress in the reuse of the red mud*" (AMIRA, 2001). Research on stabilisation (inorganic polymers or other new chemistries; use of sea water) and alternative uses (metal recovery, absorbent for CO_2, road base/levee construction, soil amendment treatment for acid-generating materials/ acid mine drainage, cement kiln additive, effluent treatment, bricks/building products) was to be undertaken according to this road-map. The sheer volume of red-mud that arises each year, however, makes it difficult to find sufficient alternative uses in the effort to increase recycling and re-use rates. There also remains the problem of existing stockpiles. Improving the Bayer process by looking into options to reduce the NaOH consumption and its loss into the red-mud would reduce to some degree the potential environmental impacts of these highly alkaline muds.

Research on improving the manageability of red mud focuses on an accelerated dewatering, which would render tailings-ponds less hazardous and prone to catastrophic failure (IAI, 2015). Bauxite residues initially contain around 15% solids and can be pumped. When solid contents rise above 28%, the muds exhibit thixotropic behaviour, meaning that they begin to flow, when agitated mechanically. When solid contents rise above 75%, the muds can be handled with excavating machinery. Filter presses and centrifugal separators can be employed for dewatering. Reducing the water content will also reduce the initial disposal volume, albeit at a considerable energy expenditure, thus increasing the carbon-footprint. MWEI-BREF (2018) advocates to dewater tailings by filtering and then dry-stacking them.

Various methods to neutralise tailings, e.g. by accelerated CO_2-uptake or mixing with seawater, have been tested. Enhanced exposure to atmospheric CO_2 will (partially) neutralise the residual alkalinity, which otherwise may hamper re-vegetation.

Mindful of the large quantities of ‚red mud' produced, the industry has been for a long time looking into adding value to this waste by utilising it in marketable products. However, the market volume of possible applications is much smaller than the amounts produced. There is also some potential to extract other metals from ‚red mud'. While there are many technical options, their commercial viability is difficult to assure and overall energy footprints also provide a challenge. The overall environmental etc. impacts from utilisation options have to be lower than those from the disposal option.

Recently a European Innovation Partnership (EIP) on the issue of bauxite processing waste has been started: http://bravoeip.eu.

The risks associated with ‚red mud' management and disposal and pertinent mitigation measures, including good governance are the subject of a ‚good practice' guide prepared for European Aluminium (EA, 2015).

EA (2015) gives a range of 'best practice' recommendations for the management of bauxite residues. The respective recommendations are summarised in Best Practice Example A. These good practices recommendations largely tally with those of the MAC (2017) for tailings management.

Summary observations

The reviews in the preceding sections showed that very few of the EWMPs take the broad view envisaged by the EWD and as broadened in scope by the Circular Economy Plans. Long-term and rehabilitation aspects in particular are rarely explicitly addressed in the EWMPs that were available for review.

4.6 Assessment of collected EWMPs as per stated objectives

The EWMPs available for review were assessed with respect to the objectives stated in Section 1.3.

4.6.1 Processes that lead to extraction

The relationship between the choices of extraction method and the EWM strategies and methods have already been discussed in the companion report, in particular with respect to the Circular Economy paradigm (European Commission et al., 2019). As has been discussed above for the bauxite/red-mud example, such operational choices can significantly influence the way EW have to be managed and the long-term stability of EWFs. Article 5(2)(c) of the EWD (2006) stipulates that during the design phase and the operation (process) designs should be selected that lead to a situation, where minimal and, if possible, ultimately no monitoring, control and management of the closed waste facility are required. By appropriate choices of processes also the long-term negative effects due to water- or airborne releases can be minimised, together with the long-term geotechnical stability of any engineered EWF. There may be various constraints on the selection of processes, such as the actual treatability of the extracted material (rock matrix), the availability of a particular technology at a particular time and location, and the commercial viability (with respect to CAPEX and OPEX) of employing a particular technology. However, with a view to facilitate the safe long-term management of EW, the available technical process options should be explored as part of a systemic design of the extractive operation. EWMPs will have to be reviewed in this respect. The EWMPs available for review to this study do not explicitly treat this conceptual aspect. There can be a number of reasons for this. The main reason probably is that most operations already existed, when the EWD came into force. In consequence, the EWMP are considered as add-on to existing obligations under the national implementation of the EWD. The potential of the EWMP as an instrument to guide operations strategically and as an instrument of communication with the public has not been realised in most of the cases reviewed. However, the difficulty of extending existing licenses and obtaining new licenses has lead to the optimisation of extraction processes with a view to maximise resources use and economic benefits. With a few exceptions also, the reviewed EWMPs did not concern Category A facilities, where such operational choices can have more profound impacts on the long-term performance of EWFs.

The EWMP could be used as an instrument to make these considerations more explicit, as has already pointed out in European Commission et al. (2019).

4.6.2 The characterisation and quantification of wastes according to Annex II of the EWD over the whole life-cycle.

The EWMPs available for review reported the amounts of waste to a varying degree. As operations in most cases existed before the EWD came into force, EWMPs typically cover only forthcoming quantities, but do not give retrospectively quantities that have arisen in the past.

Materials arising from the operations were mainly assessed with two purposed in mind: 1) whether any market for the extracted material exists, and 2) whether „ ... the extractive waste may undergo [any changes] in relation to an increase in surface area and exposure to conditions above ground; ...", i.e. mainly with respect to its acid-generation potential. Point 1 reflects the economic interest in marketing as much of the extracted material as possible and to have to dispose of it as waste as little as possible. Point 2 determines, whether any material considered waste is inert, which simplifies its management, or is expected to react in some way, which will require a specifically engineered EWF, or even a Category A facility, with the associated higher costs. Some EWMPs state that a classification according to Point 1 may change as market conditions change. This results in a changing attributions with time of extracted materials to the categories (by)products, materials returned to the excavated voids e.g. for rehabilitation purposes, and waste respectively.

4.6.3 Category A facilities: accident prevention policies, safety management system, and internal emergency plans

The EWMPs for Category A facilities received through the questionnaires or retrieved from the literature are discussed in the following.

Eleven extractive operations that have Category A Facility have sent factsheets with candidate best practices and another two extractive operations have sent the entire EWMP (in total 13 extractive operations with a Category A EWF).

Table 4-4 Extractive operations with a Category A EWF provided factsheets

Country	Extractive operations with a Category A EWF
Cyprus	Skouriotissa EWMP
Finland	Pyhäsalmi Mine Oy Boliden Kevitsa mine Terrafame Oy Dragon Mining-Svartliden Mine Zinkgruvan-Nya Enemossen Agnico Eagle Finland Oy Kittilä mine
Spain	Minas de Aguas Teñidas S.A.U
Sweden	Boliden Mineral AB for the Garpenberg Boliden Mineral AB for the Maurliden Boliden Mineral AB for the Aitik mines LKAB for the Malmberget Mine
Greece	Hellas Gold S.A. EWMP

As was noted above, dam safety plays a significant role in Swedish and Finnish EWMPs for Category A facilities. In Sweden usually a reference is made to the comprehensive mining dam safety guideline GruvRIDAS. GruvRIDAS defines the general dam safety principles, consequence classification, organisational and competence requirements, as well as dam operation and risk preparation. The permit condition-based monitoring, failure reporting and maintenance requirements are described in GruvRIDAS. However, the relevant safety information is often not contained in the EWMPs themselves, but in companion documents to which then reference is made.

In the EWMP of 2017 for the Boliden Garpenberg Mine in Sweden an extract of the 'DTU-manual' (the manual for operation, monitoring and maintenance of dams) is an appendix to the EWMP and some key points of it are summarised in the actual EWMP. The manual uses a structured approach, documenting the current legislative requirements and how they are met in during the operation, monitoring and maintenance of the dams. Also preparatory plans for exceptional situations are included. For instance, the following points are covered by the Garpenberg Mine EWMP:

- What is the purpose of the DTU-manual.
- Key contents of the DTU manual.
- How the DTU-manual is made available to the staff.
- Consequence classification according to Swedish GruvRIDAS (mine dam guideline).
- Updating routines for the DTU manual.
- Archiving system for the relevant documents.

In the Garpenberg EWMP, the dam stability monitoring programmes for the dam raises are described. Generally dam safety monitoring covers these six different aspects:

- Operational monitoring
- Measurements
- Function proving
- Inspection
- Detailed inspection
- Detailed dam safety evaluation

In addition, the safety reporting procedure for a Category A facility is shortly explained in the Garpenberg Mine EWMP.

The EWMP for the Boliden Kevitsa Mine of 2015 includes a detailed description of the tailings storage facility dam safety monitoring instrumentation, including instrument types (e.g. inclinometers and piezometers) and locations.

4.6.4 Non-Category A facilities: information on justification including identification of possible accident hazards

The EWD and the various Commission Decision amending it lay down the criteria for the determination, whether a facility belongs into Category A or not. The determination is based on the contents of hazardous materials, the reactivitiy of the waste itself, and is to be supported by a risk assessment. The two main criteria to be investigated, hence, are 1) whether the waste itself is inert and its possible content of hazardous substances, and 2) whether the envisaged/actual mode of disposal can give rise to any hazards. Criterion 1 was satisfied in all EWMPs reviewed by appropriate mineralogical and (geo)chemical investigations, i.e. a waste characterisation. Criterion 2 depends on a range of factors, including the mode of extraction, the processing technique, and the chosen mode of disposal. In most cases the dominant risk is that of geotechnical instability, but in most cases the risks are more chronic (erosion) than acute (collapse of impoundments), so that no particular accident scenarios beyond what would be needed to obtain the construction permission by the competent authorities were investigated.

It appears that in most cases some sort of ‘differential diagnosis’ approach is used in order to determine, whether a waste facility belongs into Category A or not. In other words, if none of the criteria is fulfilled that justifies categorisation into Category A, the facility must be outside this category. A good practice in this context are the decision-making flow-diagrams as employed in France for instance. This should be based not only on a risk analysis, but also a consequence analysis, e.g. for dam failures. If there are no significant consequences to be expected, even tailings management facilities may not need to be classified into Category A, as some Finnish examples show. Best Practice example E illustrates another approach by which the *in situ* treatment of historical wastes can avoid the need to construct a Category A facility.

4.6.5 Assessments of potential environmental and human health impacts

Per definition this assessment would pertain mainly to Category A facilities, but inert wastes can also cause impacts due to e.g. turbidity in surface waters from eroded material. Typically, an assessment of potential environmental and human health impacts is the subject of the environmental impact assessment (EIA), which would have been carried out as part of the licensing application. The EIA is one of the bases on which the decision will be made into which category a future EWF would belongs.

Typically, an operator chooses excavation and processing methods based on preliminary studies of the deposit and the materials properties. The EIA is then based on this proposed mode of extraction and processing. An optimisation is undertaken, considering the respective CAPEX and OPEX, which would include the costs of disposal and ancillary costs, such as environmental insurances. Whether further optimisations, as stipulated by the EWD, are undertaken depends on the economic context, as well as the expected benefits vs. costs of the optimisation. The decision-finding process during the planning phase is likely to be an iterative one, i.e. if a practice would lead to unacceptable environmental or human health impacts, this practice needs to be adapted until (actual and potential) impacts are removed or below limits of concern.

Non-hazardous non-inert EWs can also cause environmental impacts. Acid Rock Drainage (ARD) from the oxidation of sulfide minerals is the main concern. Even small quantities of such minerals can give rise to significant mobilisation of potential contaminants in the waste. Sulfide minerals and their ARD formation potential would be assessed during the chemical and mineralogical characterisation of the wastes.

EWs undergo transformation processes akin to natural (early) diagenesis, which change the pore-structure and mineralogy of the excavated materials. These changes can be both, beneficial and detrimental from the point of view of mobilisation of various constituents. The main driver of such processes with be infiltrating meteoric or surfaces waters. With a view to assess the long-term impacts, the development of such processes and their driving forces could be investigated, also using predictive tools.

It would be also useful to develop a flow model that predicts the affected areas in the case of the collapse of a tailings dam, so that protection and early warning measures can be taken. However, this also should be done at the licensing, rather than at the closure stage, when little can be done about it.

Neither of the EWMPs made explicit reference to the EIAs of the operations to which they belong or to any impacts that may arise from the failure of the EWFs.

4.6.6 Preventive measures taken to minimise operational and post-closure impacts

The EWMPs reviewed focused on the minimisation of impacts during operation and less so explicitly on the post-closure phase. There may be a number of reasons for this. One reason probably is that most EWMPs received for this study concern operations that are far away from closure or closure of their EWFs. The main concern of operators is to ensure operational safety and compliance with applicable (national and EU) regulations in this respect. There is also a tendency to imply that operational safety ensures long-term post-closure safety. Many national jurisdictions distinguish between the operational and the post-operational phase, requiring different licenses for each. This may lead to the post-closure phase not being reflected in current EWMPs. The Nordic countries, however, take more of a life-cycle perspective and the after-use and any necessary monitoring programmes are discussed in the EWMPs. As closure is a separate licensing step with potential long-term consequences and uncertainties, closure plans are presented usually in separate documents that have not been reviewed in the context of this study. EWMP may make reference to these (draft) documents though. It appears that the closure aspects are neither treated thoroughly enough in the EWMPs nor in the MWEI-BREF (2018).

Airborne impacts during the operational phase are originating in dusts raised, which are routinely supressed by water-spraying, which is not explicitly mentioned in EWMPs. Today, covering EWFs with top-soil and re-vegetation are standard procedures during closure to minimise erosion and dust dispersal. Top-soil covers also reduce the infiltration of meteoric water as the main driving force of water-borne impacts, including ARD formation. Such measures are almost always mentioned in the EWMPs. The capping would be commensurate with the type of EWF and for Category A facilities or those with wastes of high ARD formation potential usually have to be more elaborate (see Ch. 3) to ensure the long-term erosion stability and to more effectively prevent infiltration.

Some EWMPs pertaining to industrial and construction mineral extraction also mention as good practice during operation the infilling of excavated voids with non-marketable inert material from the operation in order to reduce the exposure of aquifers to impacts from atmospheric contamination.

In some cases it was noted that slopes of EWFs were graded at an angle reflecting the natural angles in the surrounding landscapes. Also, re-vegetation is usually oriented towards the natural vegetation in the vicinity.

Impacts during the operational phase are subject of the EIAs that are the basis for licenses to operate. For this reason, the reviewed EWMPs seem to make rarely reference to impacts as such and focus on operational practices.

4.6.7 Control and monitoring procedures (Articles 10 and 11(2)(c) EWD)

Control and monitoring procedures are mainly undertaken in the context of complying with environmental and other permits on the basis of EIAs and periodic geotechnical stability surveys as stipulated by the mining or construction laws. They are not mentioned explicitly in any of the reviewed EWMPs.

Control programmes are commonly detailed separate documents, but are usually referred to e.g. in Swedish and Finnish EWMPs. For instance, in the EWMP for Terrafame Sotkamo Mine, details of the actual (mine site) monitoring programme are not included, but monitoring is described in general and monitoring objectives are listed for the following categories: operation control, emissions monitoring, impact monitoring, waste quality monitoring and waste facility internal circumstances monitoring (including seepage). Therefore, the EWMP is extended to cover also other types of waste than EW. In the EWMP for the Boliden Kevitsa Mine, EW chemical quality monitoring procedures are presented in detail and chemical quality monitoring results for the EW for the previous two years are presented in EWMP, in order to justify the EW classification. Generally, in Finland it is common in EWMPs, to refer to monitoring programmes as separate documents and to identify the exact authority decision that approves these programs. In Swedish EWMPs dam safety monitoring is often a main focus and DTU-manuals (dam operation, monitoring and maintenance manual) are provided.

After-closure monitoring and surveillance measures as part of measure to assure the long-term integrity of EWFs have not been mentioned in any of the EWMPs reviewed. One must assume that the closure of EWFs is a separate regulatory and licensing procedure under most national jurisdictions. Therefore, post-closure control and monitoring provisions were not part of the EWMPs.

4.6.8 Surveys of the conditions of the land to be affected by the waste facility

Article 5(3)(h) of the EWD is not explicit as to the scope and purpose of these surveys and what ‘land’ actually means in this context.

The various EIAs that are usually required at the different stages of a licensing procedure would cover the environmental aspects including possible contamination of underlying groundwater resources. The EWMPs reviewed usually make reference to these EIAs and also explain why and how the chosen management options and techniques address points raised in the EIAs.

It is not clear, whether Article 5(3)(h) would also refer to the geotechnical situation at the site of a planned EWF. Normally, these site conditions would have been investigated as part of the construction permission procedures by the competent authorities. EWMPs usually make reference to the related documents without reproducing any details. In the Nordic countries more details may be included, particularly for Category A facilities, though the main documents are separate.

4.7 Conclusions

The ambitions of long-term stability as formulated in the EWD have not been reflected in the available EWMPs. It appears that there is a tacit assumption that measures that assure operational safety also will assure long-term post-closure safety. Except for references to setting aside top-soils for later landscaping and re-vegetation purposes, closure and post-closure activities and aims are generally not mentioned in the EWMPs available for review.

Therefore, guidance for best practices in assuring long-term stability of EWFs and the EWs contained therein had to be derived from a small range of EWMPs, where such issue have been addressed explicitly, and from a wide range of guidance documents produced by the industry itself, its associations, and international bodies.

A number of key messages can be deducted from this:

- a life-cycle approach ensures a comprehensive view of waste arisings and their management over time:
- integration of operation and preparation for the closure and post-closure phase facilitates the transition and makes it more efficient;
- EWFs should be designed with closure and rehabilitation in mind;
- contouring and re-vegetation should mimic the surrounding landscape in order to reduce the likelihood of erosion and re-vegetation success;
- segregation and (possibly) pre-treatment of wastes helps to reduce the amount of difficult to manage wastes;
- dewatered tailings ensure operational and long-term safety;
- current EWMPs are drafted with operational aspects in mind, but rarely take a long-term and post-closure view, albeit EWFs are going to be permanent features.

The ambitions formulated in the EWD, particularly those with respect to achieving more sustainability and a circular economy, often go beyond what individual operations would want to achieve. Commercial operations work within a given economic context and have to be profitable. Additional 104ptimization measures are only undertaken, if there is an economic benefit or in order to comply with regulatory requirements. A differing economic context also means that each operation has to be treated individually and ‚best practices', whether from an operational or technical point of view, often cannot be applied uniformly. Thus, for instance, one operation may be able to market a certain fraction of the extracted material as by-product, while another operation extracting the same kind of mineral may not find a market this and, therefore, would need to dispose of it as waste. This may also change with time and EWMPs have to be flexible in order to accommodate such changes.

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4.9 Best Practice Examples

4.9.1 Best Practice Example A: Safe management of bauxite wastes

1. Description

European Aluminium has published a guidance book on the safe management of bauxite tailings (EA, 2015). The summary table of this report is included here, as the scope of this guidance is exemplary and very exhaustive.

Long-term Planning and Design
Integrated planning • residue planning designers, facility management and closure group must work together and communicate to achieve key performance indicators (KPIs). • accountability and designated co-ordinator important. Storage design • capacity should be based on performance and align with risk assessment. Water Balance • integrate a life cycle plan. • establish standards for ground and surface water management. Space • space should be adequate to match refinery life/production expectations. Residue storage plan (include drying time, area needed) needs to be linked/aligned to operations plan (e.g. increase in capacity).
Governance
Governance should cover full facility life-cycle including; • operation design, • construction, • operation and, • closure and post-closure Governance should encompass the following high level processes; • know what to do - responsibility assessment matrix (RACI), know full range of activities • know how to do it - standard work methods and procedures, clear performance indicators • audit at all levels against clear goals Change Management System • clearly defined change management process - particular focus on the management of small changes • clear and simple change management process

Emergency Response Plan

- emergency response plan based on risk assessment is in place and rehearsed

Senior Management Accountability

- ensure clear link between hazards and senior management overview
- well defined management structures and accountability for facility management

Integrated Production and Residue Management

- refinery and residue process closely linked
- decisions made at the correct level in the organisation
- scenario analysis and training
- clearly defined action triggers

Records Management

- maintain history of records
- put records management procedure in place
- put records auditing and archive process in place

Performance Tracking

Policy and planning -

- ensure the structure of the organisation and available resources align with and compliment its ability to sustain the long-term plan.

Training and accountability

- clearly defined to ensure all levels of the organisation are adequately qualified to undertake performance tracking responsibilities; information collected and collated in a meaningful way to ensure the intent of performance tracking activities are met to support both short- and long-term goals and consistent with the long-term plan that is in place.

Data management

- data to be collected in a manner that is appropriate (thorough and representative) and managed to ensure effective communication between all levels (transparent and readily accessible).

Budget

- ensure justification of expenditure is undertaken to implement and maintain Performance Tracking tools and equipment

Performance auditing

- undertaken at an appropriate frequency by an independent third party to ensure sustained operational alignment with long-term plan and continued validation of key underlying assumptions.
- on-going internal auditing of all aspects of residue management performance is required with external audits undertaken at least annually by a suitably qualified third party, who is not part of the usual operational support group to avoid possible conflict of interest issues.

Forward planning

- best-practice goals should be developed to drive a culture of continuous improvement. Inter-operational benchmarking should be undertaken using agreed, standardised measures (such as annual deposition intensity within active disposal area) to ensure alignment of similar disposal techniques with state of the art performance capabilities.

Storage and Disposal

Despite the improvements in technology, it must be accepted that it is often extremely difficult for a plant to change the method of bauxite disposal. Factors such as proximity to the sea; availability of sufficient suitable land area; nature and characteristics of the residue; amount of annual rainfall; the sun and wind evaporative characteristics of the climate where the plant is located; availability of economic pH reduction sources such as carbon dioxide, sulfur dioxide, sea water, acid all effect the decision making. Some of these are impossible to change whilst others could lead to the plant becoming uneconomic. It is essential for each plant to undertake a risk assessment taking into account the solid liquid characteristics of the residue, the quantity stored, the hazardous nature of the stored material (especially pH), the height and type of dam/dyke used to impound the material, the risk in that area for the possibility of earth tremors, heavy rain, hurricanes, cyclones, tsunamis, sabotage etc.

The nature of bauxite residue

- there should be an overarching goal to reduce and/or stabilise the residual soda content in residue (and associated stored liquors).
- where possible a site should neutralise residue to prevent classification as a hazardous material/waste.

Residue Transportation

- where possible separate site transport roads and active residue pipelines.
- control, contain or isolate residue pipelines through burst discs, bunding or removal from trafficked areas.
- establish a benchmark for monitoring of distribution/transportation system
- prepare and test pipeline spill plans and all response to failures/incidents.

Discharge Control & Deposition Management

- define optimal deposition controls for each operation.
- document and justify tasks required for sustained BRSA performance.

Remediation

Factors to be considered when planning the closure, decommissioning and rehabilitation of a bauxite residue storage facility are:

- environment and climate in which the residue storage facility is located
- post-closure land use
- long-term landform stability, including geotechnical and erosional stability
- managing surface runoff and ponding, and the need for a closure spillway
- long-term seepage to the environment of potentially contaminated water
- potential for dust generation both before and after rehabilitation
- surface treatment and vegetation of the top of the residue storage facility
- profiling, surface treatment and vegetation of outer batter slopes.
- post closure land use e.g. restored to original flora, maximum biodiversity, productive crops, recreation
- if deemed necessary, collection and treatment of leachate (e.g. neutralisation, constructed wetlands)

- on-going testing and monitoring of surface and ground water regimes to meet regulatory requirements
- on-going management, security and controls of sites when the refinery no longer exists.

Plan

- defined closure plan developed with community input
- closure costs identified and allocated
- clear closure plan owner identified
- defined community engagement process

Cost

- need to consider residue as a potential resource: both for direct uses, eg soil amelioration, land capping, and uses for the closed residue sites.
- transparent accounting of resources for closure required so that the best low cost sustainable regime can be implemented.

Education

- successful examples of closed facilities

Residue Composition

- recovery of as much sodium as possible
- list all constituents; where possible convert them into harmless stable form.

2. Rationale for selecting as Best Practice

This catalogue of issues to be covered for tailings management is exemplary in its comprehensiveness. These recommendations are applicable not only to bauxite tailings, but to any kind of tailings management facilities.

3. Environmental benefits achieved

If the recommendations in the guidelines are followed, this should greatly reduce the risks from tailings ponds.

4. Economical aspects

The guidelines call for the management and closure cost to be explicitly accounted for in the planning. They also consider the re-use aspect of wastes in other economic applications with a view to reduce the volumes to be deposited.

5. Examples of application

n/a

6. Bibliographic reference

EA EUROPEAN ALUMINIUM (2015): Bauxite Residue Management: Best Practice.- 31 p., https://european-aluminium.eu/media/1340/201507_bauxite-residue-management-best-practice.pdf (accessed 16.05.19).

4.9.2 Best Practice Example B: Landscaping for increased erosion resistance

1. Description

Achieving maintenance erosion resistance is a major pre-occupation during the closure and rehabilitation of EWFs. For a given set of climatological conditions the pre-mining landscape is likely a situation of low erosional losses. Hence, it should be the aim of the rehabilitation to reconstitute contours of waste dumps and mine sites that are compatible with the surrounding geomorphology. This Best Practice Example describes a software-based assessment of the surrounding geomorphology that can be used as the paradigm for the waste contouring. The method is called *GeoFluv* and implemented for instance through a proprietary software. The method is described for the example of El Machorro kaolin mine in Spain (Figure 1; Balaguer *et al.*, 2014).

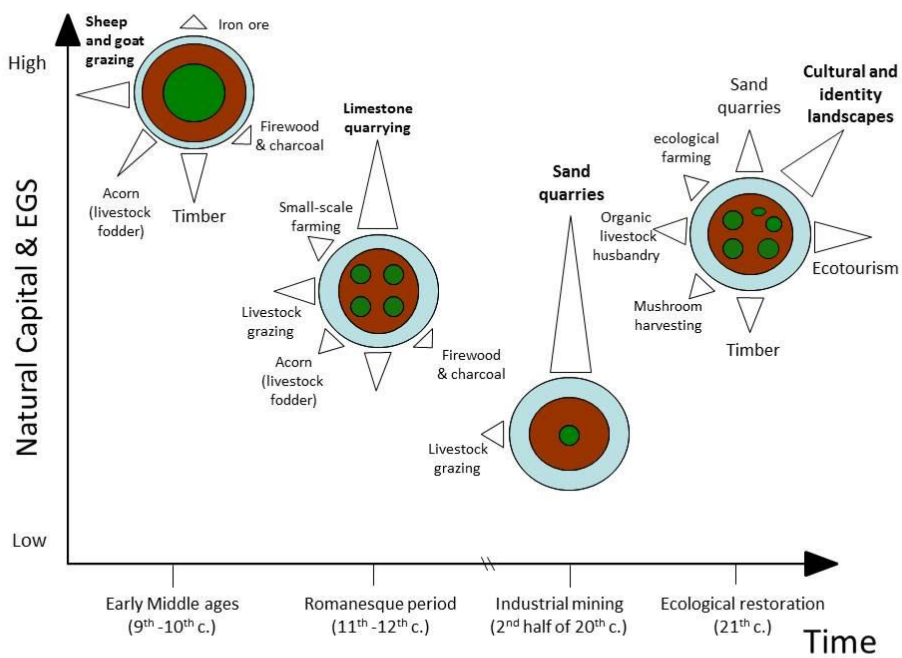


Figure 1: *Assessment of the Natural Capital and Ecosystem Goods and Services (EGS) over the past milennium as the basis for a geomorphology-based rehablitation of the El Machorro kaolin mine site in Spain. The evolution of Natural Capital and EGS are projected into the 21st century. Each 'star' or group of concentric circles represents a historical ecosystem configuration; the inner circle represents the ecosystem itself, while the two outer circles represent the landscape (biophysical matrix) and the socio-economic matrix in which the ecosystem is embedded; the triangular appendages represent the main EGSs. The rehabilitated ecosystems will provide new EGSs (Balaguer et al., 2014).*

A multiannual monitoring has demonstrated its success in terms of erosional stability and ecological recovery. A detailed description of the method and of the evidences of its success have been published by Zapico *et al.* (2018). Geomorphological re-grading is complemented with a geomorphological approach for re-establishing subsoils (surficial deposits, carbonatic colluvium) and top-soils. Its benefits have been also demonstrated in an experimental spoil heap at the Machorro mine (Martín Moreno et al., 2016).

At the example site, the objective was to build stable (steady state) natural landforms through geomorphological re-contouring of the sand and clay wastes with a view to maximize the natural capital and Ecosystem Goods and Services (EGS). This fits perfectly with the Circular Economy paradigm of the European Commission, where the value of products, materials and resources is maintained in the economy for as long as possible, and the quantity of waste facilities is eliminated or minimised.

2. Rationale for selecting as Best Practice

From a legal perspective, the proposed solution is considered a best practise because the El Machorro mine is an approved rehabilitation project according to the Spanish *Real Decreto 975/2009, de 12 de junio,* in accordance with the EWD.

From a technical perspective, the proposed solution is considered as best practise because the monitoring of its performance over a 5-year period (2012-2017) has shown that the sand and clay wastes are in a permanent steady-state way, with minimising sediment yield, runoff and suspended sediment concentration downstream (Zapico *et al.*, 2018). All this was achieved without the use any external capping material. This was achieved by making an expert geomorphological design for recontouring the wastes with *GeoFluv–Natural Regrade* and rebuilding a landscape that replicate the mathematical algorithms of natural landforms. On top of the re-shaped natural landforms, topsoil removed from active areas of the same mine were transferred and spread. Re-vegetation was also carried out, based on an ecological assessment. Therefore, as demonstrated by Zapico et al. (2018), this is an efficient alternative rehabilitation solution compared to the traditional approach of graded terraces and down-drains, which require costly maintenance. The viability of this practise was demonstrated for the highly erodible settings of slopes in Eastern and Central Spain (see Martín Moreno et al., 2018), but would be applicable to other setting across Europe.

3. Environmental benefits achieved

The main environmental benefits demonstrated for the El Machorro site are:

1) The need of constructing waste heaps at the mine is largely obviated. Such heaps have a lower stability and higher visual impact than the re-contouring in the mine of the waste materials.
2) Safe disposal of EW is ensured from short to long term. Not only the geotechnical stability is ensured in this way, but also the stability against erosion by runoff water (the most common cause of instability at mine wastes heaps).
3) Having a permanent reduction in runoff and sediment yield from the rehabilitated areas, to levels equivalent to the baseline, minimises maintenance needs and impacts from turbidity and the dispersal of contaminants into soils and water.
4) High visual integration into hill slopes and stream landforms that mimic the look and the functionality of nature.
5) Maximising biodiversity and natural capital and EGS. Geomorphological restoration provides diverse and complex landforms, that become diverse micro-habitats. At El Machorro many seedlings of *Pinus nigra* subsp. *salzmannii* (priority habitat for the European Union) and *Genista scorpius* have spontaneously colonised the recontoured surfaces. The evolution of this landscape will allow its use for wildlife, timber, mushroom harvesting or ecotourism, among others.
6) Gaining acceptance by the public and regulators. At El Machorro, geomorphology-based rehabilitation is strongly supported by the managers of the Natural Park and by the Environmental and Mining regulators of the Guadalajara province and the Castile-La Mancha region.

4. Economical aspects

Re-grading and reshaping existing conventional flat-toped or terraced waste dumps to geomorphological *GeoFluv*-derived landforms, plus the spreading of top-soils and seeding, cost around 10.000 to 30.000 € per hectare. However, if this strategy is adopted right from the beginning of mine operations by progressive rehabilitation, placing the extractive waste back into the excavated voids, so as to partially covering the highwalls, the reduction is cost can be considerable. In fact, if the the progressive rehabilitation is integrated into traditional waste management operations the costs will be close to the latter, but there is a clear saving in maintenance costs. The economic value of ecosystem goods and services may also be considered, although they may be a value added to the mine operation or off-set other detriments.

Sediment yields at un-rehabilitated areas within the same El Machorro mine are around 292 Mg ha^{-1} yr^{-1} (Martín-Moreno, 2013).

Sediment yields for the traditional approach of graded terraces and down-drains at the same mine are in a range of 10-20 Mg ha^{-1} yr^{-1}. However, it is important to keep in mind that these terraces are recurrently damaged by gullying, showing that they constitute an unstable landform in the long term. The reasons for gullying are either run-off from active hauling roads or slope inversion due to sediment accumulation in the internal part of the berm.

The sediment yield after the geomorphological rehabilitation is around 4 Mg ha^{-1} yr^{-1} (Zapico et al., 2018).

The costs in terms of euros per hectare have not been calculated, but the mining company (CAOBAR) has reported savings in the order of of 55.000 € per year compared to the costs of maintaining the graded terraces and the necessary sediment catchment ponds.

5. Example of application

El Machorro kaolin mine (operator CAOBAR), the María José mine (CAOBAR) and the Nuria mines at Poveda de la Sierra Municipality (Guadalajara Province, Spain) and Somolinos (Guadalajara, Spain). These four mines have the same typology: contour mining in sand and clay materials located at the slopes of the 'mesa and cuesta' landforms of Central Spain.

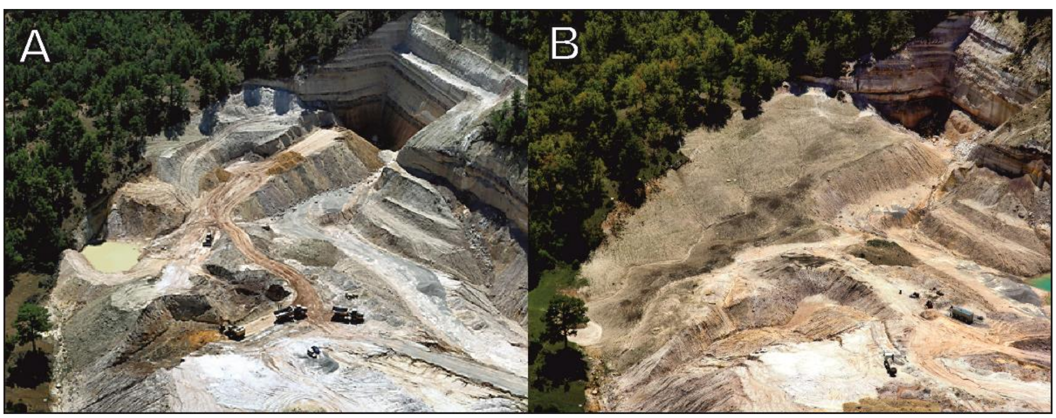


Figure 2: *Oblique aerial photographs showing the geomorphological restoration of El Machorro: A) at the beginning of the works, September 2012; B) once the first phase of the recontouring was completed (May 2014). Photos by Paisajes Españoles.*

Figure 3: *Sequence of the Geomorphology-based restoration at El Machorro. Left, before rehabilitation (August 2012). Centre, after the geomorphological re-grading and top-soil spreading. Right, initial vegetation growing. Earthworks by Excavaciones Félix Moya, subcontracted by CAOBAR.*

6. Bibliographic references

BALAGUER, L., ESCUDERO, A., MARTÍN DUQUE, J.F., MOLA, I., ARONSON, J. (2014): The historical reference in restoration ecology: Redefining a cornerstone concept.- Biological Conservation, **176**: 12–20.

MARTÍN-MORENO, C., MARTÍN DUQUE, J.F., NICOLAU IBARRA, J.M., HERNANDO RODRÍGUEZ, N., SANZ SANTOS, M.A., SÁNCHEZ CASTILLO, L. (2016): Effects of topography and surface soil cover on erosion for mining reclamation: The experimental spoil heap at El Machorro Mine (Central Spain).- Land Degrad. Dev., **27**: 145–159.

MARTÍN-MORENO, C., MARTÍN DUQUE, J.F., NICOLAU, J.M., MUÑOZ, A., ZAPICO, I. (2018): Waste dump erosional landform stability – a critical issue for mountain mining.- Earth Surface Processes and Landforms (accepted)

ZAPICO, I., MARTÍN DUQUE, J.F., BUGOSH, N., LARONNE, J.B., ORTEGA, A., MOLINA, A., MARTÍN-MORENO, C., NICOLAU, N., SÁNCHEZ, L. (2017): Geomorphic Reclamation for reestablishment of landform stability at a watershed scale in mined sites: the Alto Tajo Natural Park, Spain.- Ecological Engineering, **111**: 110-116.

4.9.3 Best Practice Example C: Stabilisation of reactive wastes

1. Description

Dolomite quarry and plant that produces various Ca-Mg-oxides, lime and dolomites for a wide range of applications. The dolomite is subject to thermal treatment to obtain the oxide and residues are returned to the quarry.

- The processing of the dolomite into lime results in dusts of CaO, which are not inert, they react with water to give quicklime.
- Similarly, the settling basins from rainwater and surface run-off collection systems can contain quicklime and flue-gas dusts and are also not to be considered inert.
- The mixing of the various types of EWs and processing wastes leads to an stabilisation of the quicklime and the mixtures can be used for backfilling into the mined-out part of the quarry and other remediation purposes.
- The conversion process of quicklime to calcium-carbonate will cement the EWs and increases their stability.
- Top-soils and overburden are set aside for later use in remediation. EWs include also clays that occur in karst pockets.

2. Rationale for selecting as Best Practice

Stabilisation of reactive processing residues by mixing them with EWs.

3. Achieved environmental benefits

Long-term stabilisation of backfilled and heaped EW due to cementation by conversion of quicklime into calcium-carbonate.

4. Economical aspects

No information available.

5. Example of application

Lhoist, Usine de Neau (53) and Usine Châteauneuf -Les-Martigues (13)

6. Bibliographic references

LHOIST - CHAUX ET DOLOMIE FRANCAISES (2011): Plan de gestion des dechets inertes et des terres non poluées. Usine Neau (53) – Fiche PGD 20.

LHOIST - CHAUX DE PROVENCE SACAM (2011): Plan de gestion des dechets inertes et des terres non poluées. Usine Châteauneuf-Les-Martigues (13) – Fiche PGD 27.

4.9.4 Best Practice Example D: Waste segregation for targeted deposition to reduce chemical potentials

1. Description

Careful mapping of the 3D-distribution of acid generating materials in overburden allows the targeted extraction and segregated disposal of such materials. Materials are preferentially emplaced so that they are below the water table once the mine has been flooded.

Less pervious materials are used to cover potentially acid-generating materials during the operational phase in order to reduce the ingress of meteoric waters and atmospheric oxygen. Quick re-vegetation supports this process.

Where available, calcareous material are mixed into potentially acid-generating materials before emplacement in order to add buffering capacity.

Segregation and storage for later use is also routinely applied to top-soils. The storage has to be in a form that does not compromise the fertility of the material, e.g. the maximum height of layers should not exceed 3 m.

2. Rationale for selecting as Best Practice

The material-management measures address the acid-generation problem at the root and try to suppress it.

3. Achieved environmental benefits

Reduced groundwater contamination issues from acid rock drainage.

4. Economical aspects

n/a

5. Example of application

MIBRAG lignite mines in Saxony and Saxony-Anhalt

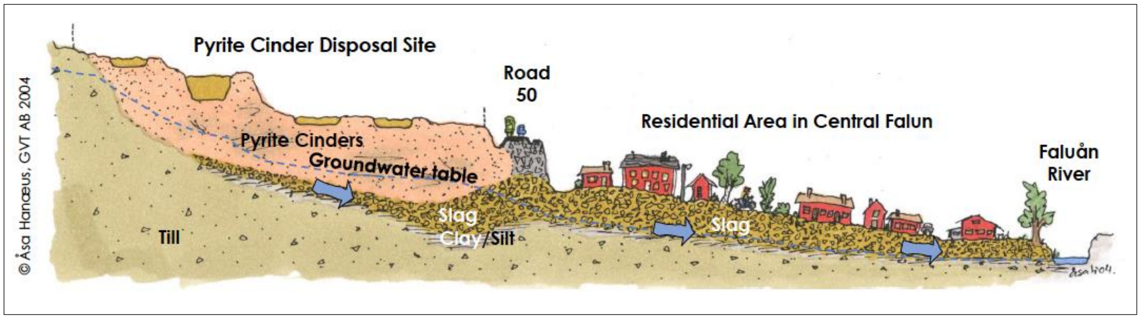
6. Bibliographic references

JOLAS, P. (2012): Abbaustrategien und Ablagerungstechnologien im laufenden Tagebaubetrieb.- Presentation at Fachveranstaltung VODAMIN/TPG/Pillnitz, 17. Oktober 2012, https://www.umwelt.sachsen.de/umwelt/download/MIBRAG_Verkippungsmanagement.pdf

4.9.5 Best Practice Example F: *In situ* rehabilitation of EW to remove the source for metal contamination

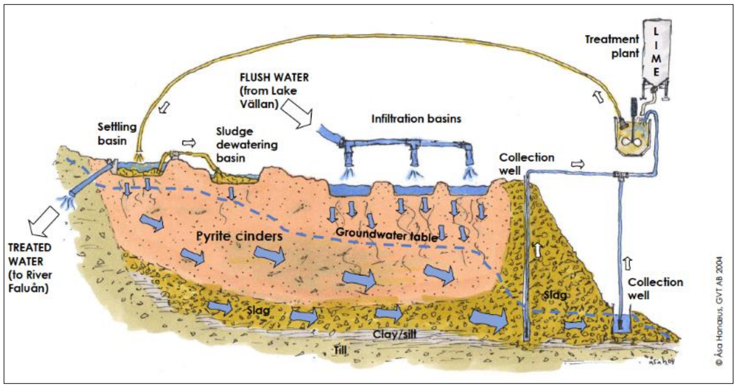
1. Description

The Dalälven river basin was a major source for metal contamination entering the Baltic sea. As the major source mine wastes in the Falun area were identified. The pyrite cinder disposal heap, resulting from the sulfuric acid production plant in operation from 1850 to 1993, was identified as the main source of Zn contamination in the Faluàn River. While large quantities of the cinder were sold as byproduct to the steel industry or used to fill mined-out voids, around 6 Mt were deposited on the surface.



Cinders had been deposited over a deposition of slags, which provided a good drainage layer. The underlying geological strata of glacial till had a low hydraulic conductivity, so that a leachate capturing system could be installed in the downstream slags. The cinders were irrigated and the leachate pumped to a treatment plant at the surface. Excess clean waters could be released into the river. The treatment sludges with the metals precipitated in a low-solubility form were deposited back onto the cinder heap. Approximately 1500 t zinc, 26 t copper and 2 t cadmium were washed out of the pyrite cinder disposal site and captured between 1995 and 2006. The flushing resulted in a reduction of metal discharges by 94 % for Zn, 96 % for Cd, and 97 % for Cu.

The cinder disposal site then was covered with a low-permeability multi-layer engineered capping to prevent further water ingress and remobilisation of contaminants in the precipitated sludges. The glacial till cover reflects the natural soils in the area.



2. Rationale for selecting as Best Practice

Long-term source term and vector/pathway supression.

3. Achieved environmental benefits

Reduction of contaminant discharges to the Faluàn river and the Baltic Sea.

4. Economical aspects

The in situ flushing and capping construction costed 6.2 M€ and 1.1 M€ respectively over the period from 1993 to 2008. This is equivalent to a rehabilitation cost of 6.4 €/t or 11 €/m^3.

5. Example of application

Falun historic mine site and World Heritage Site.

6. Bibliographic references

HANÆUS, Å., LEDIN, B. (2010): In situ tvättning av kisbränderdeponin i Falun. Åtgärder vid f.d. svavelsyrafabriken.- Rapport 6400 Naturvårdsverket, Stockholm, http://www.utslappshandel.se/Documents/publikationer6400/978-91-620-6400-6.pdf (accessed 16.05.19).

HANÆUS, Å., MATTSSON, E. (2009): Remedial Measures Taken at the Falun Mine Site, Sweden.- Proc. 8th International Conference on Acid Rock Drainage (ICARD) and Securing the Future: Mining, Metals & the Environment in a Sustainable Society 2009, Skelleftea, Sweden, 22-26 June 2009: 1617-1628.

WESTERSTRAND, M. (2009): Remedial Measures Taken at the Falun Mine Site. A Summary of “the Falun Project” 1992-2008.- https://tinyurl.com/y4hdyo7f (accessed 16.05.19).

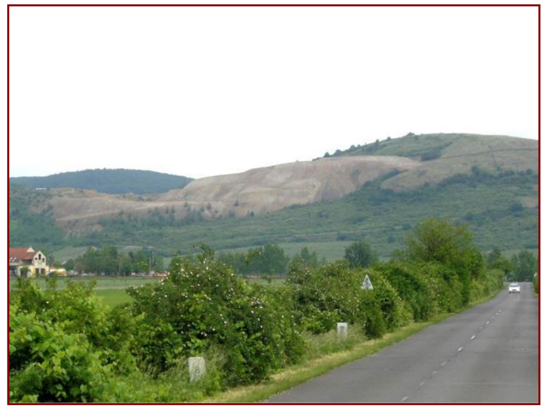
4.9.6 Best Practice Example G: Integration into Natura 2000 and World Heritage regions

1. Description

The proposed Best Practice concerns to the Tállya Andesite Quarry, which is located within a Natura 2000 area and the UNESCO Tokaj Wine Region Historic Cultural Landscape World Heritage protection area. The estimated reserves are around 50 Mm^3 andesite (of which about 450,000 m^3 will become EW) in a mining concesssion of ca. 100 hectares.

Since 2014, the quarrying company undertook a large scale landscaping project. More than 170,000 m^3 of EW waste were moved and more than 4,000 trees and 6,800 bushes were planted to landscaped two big waste dumps next to the quarry and near a village. A specialist firm was consulted due to the Cultural World Heritage protection status of the region. The EWFs were contoured to match the surrounding landscape (hills, valleys, slopes, etc.) in order to match the World Heritage expectations, because the landscape is one of the most interesting attribute of the region. Selection of tree species and bushes was carried out in consultation with the national park and the nature conservation and heritage conservation authorities.

Under the current authorisation processes, the quarrying company undertook a complex, life-cycle assessment, taking into consideration the available raw material reserves, the mode of production and the handling of the EW. The planning horizon went beyond 15 years though the maximum permit period in Hungary is 15 years.



With a significant investment into exploration (about 1,250 meters of drilling and a large-scale geophysical study) the company was able to delineate the marketable material and to determine which part would become EW. This exploration allowed to estimate total the life-time quantities of operational EW. An extension licensing Process is under way that also encompasses procedure to achieve consensus with the relevant stakeholders, such as the municipality, the national park, environmental authorities, the nature conversation authority and certainly the World Heritage Centre. As for the two other EWFs a compatible landscape will be created including specific lean meadows on silicic rocks (silicate swards). A specialised consultant was commissioned to prepare these plans to be compatible with the World Heritage Centre requirements.

2. Rationale for selecting as Best Practice

This practice is considered a Candidate Best Practice, because it specifically addresses the following points from the EWD:

- Article 5 2.(a)(i): During the design phase an EWM strategy with a life-cycle management perspective was developed;
- Article 5 2.(a): With the help of geological exploration the total life-time quantities of EW could be estimated;
- Article 5 2.(a)(iii): The landscaping activity implemented and planned can be seen as a special form of back-filling;
- Article 11 2.(b): The waste facility will be constructed such as to ensure its physical stability and to minimise damage to landscape. The implemented and also the planned landscape construction activites are supervised by geotechnical experts and will meet with the requirement of World Heritage Centre. This is also in line with the provisions of Article 1. However, after the integration into the landscape and the completion of the re-vegetation, the site will not be considered an EWF anymore;
- The sum of the above activities ensures the long-term minimisation of negative environmental and landscape effects.

3. Achieved environmental benefits

The benefits achieved include:

- The landscaping project is expected to increase the acceptance of the continuation of quarrying by local stakeholders;
- The amount of EW produced could be reduced and, hence, the volume of the EWF;
- The landscaping will include the creation of look-outs and view-points in support of the regional tourism industry;
- Revegation with indigenous tree and bush species will help to maintain the ecosystem value of the surrounding area;
- By going beyond what is the minimum regulatory requirement it is hoped that the quarrying project will find a more positive reception by regulators and the public alike.

4. Economical aspects

Since 2014 more than 400,000 EUR have been spent on the landscaping project (works and design fees). The savings are not directly measurable in monetary terms, but due to the higher acceptance by the public, the regulators and the Word Heritage Centre will help to extend the life-time of the quarry.

5. Bibliographic references

n/a

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